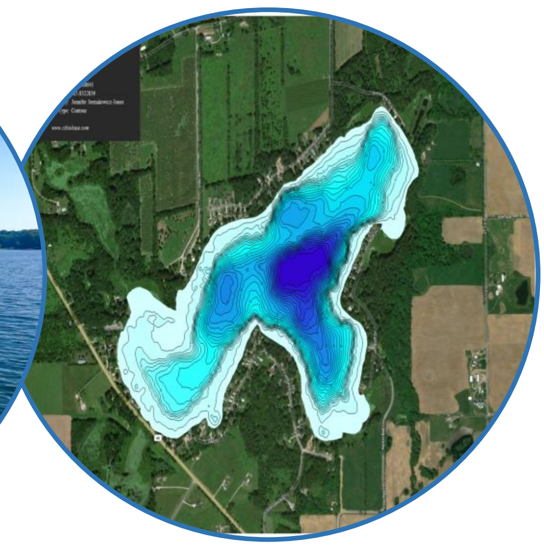
Cedar Lake Improvement Study and Management Plan
Van Buren County, Michigan



Provided for: Cedar Lake Recreation Association (CLRA) Board

Prepared by: Restorative Lake Sciences
Jennifer L. Jermalowicz-Jones, PhD
Water Resources Director
18406 West Spring Lake Road
Spring Lake, Michigan 49456
www.restorativelakesciences.com

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1.0 EXECUTIVE SUMMARY

Cedar Lake is a 270-acre natural, glacial lake located in Sections 27, 28,29,32,33, and 34 of Porter Township in Van Buren County, Michigan (T.4S, R.13W). The lake lacks in inlet and outlet and thus is dependent upon springs and surface water for the water sources. The shoreline perimeter of the lake is approximately 4.85 miles. Cedar Lake has a mean (average) depth of approximately 24.0 feet and a maximum depth of 84.8 feet (Restorative Lake Sciences, 2017). In addition, the lake has a volume of approximately 7,514.2 acre-feet (Restorative Lake Sciences, 2017).

A whole-lake aquatic plant survey and scan of aquatic vegetation biovolume was conducted on September 20, 2017. The lake scan consisted of 11,801 GPS points and the aquatic vegetation sampling survey utilized 391 points in the lake. Cedar Lake contained three invasive aquatic plant species which include the submersed Hybrid Eurasian Watermilfoil (*Myriophyllum spicatum* var. *sibiricum*), and the emergent Purple Loosestrife (*Lythrum salicaria*) and Giant Common Reed (*Phragmites australis*). These particular invasive plants threaten the biodiversity of the submersed native aquatic plant (macrophyte) communities, and may eventually threaten navigation and recreational activities as well as may reduce waterfront property values and damage the biological diversity in nearby wetlands (by the invasive emergents).

The overall water quality of Cedar Lake was measured as good with moderate nutrients such as phosphorus and nitrogen and good water clarity. The phosphorus concentrations did however increase near the lake bottom with the highest concentration recorded in deep basin #1. The pH and alkalinity of the lake indicate that it has a neutral to above-neutral pH and moderate conductivity. The immediate watershed draining to Cedar Lake is moderately small in size and approximately 3.5 times the size of Cedar Lake. This helps protect the water quality of Cedar Lake.

Restorative Lake Sciences recommends two annual whole-lake GPS surveys and a whole-lake benthic scan to determine the relative abundance of all native and invasive aquatic plant species, their relative abundance, and the percent cover of the lake surface area. Additional surveys are recommended following any needed treatment or other management methods. This data will be used each year to make management decisions about where to treat and what method(s) to use.

Where aquatic herbicide treatment is not desired, the use of a DASH boat may be practical for small treatment areas of dense exotic vegetation such as milfoil.

Restorative Lake Sciences recommends installation of aeration systems with bioaugmentation in the deep basins of Cedar Lake which would reduce the nutrients over time and likely reduce the growth of nuisance submersed aquatic vegetation such as milfoil.

RLS also recommends continued education of lake riparians on nutrient reduction to the lake and lake protection Best Management Practices (BMP's) that are emphasized in this report. The CLRA should develop a "mission statement" that assists the board with improvement direction based on the recommendations of these scientific findings in this report. Finally, RLS recommends an annual review of the 5-year plan objectives to assist the CLRA in prioritization of goals and allow for any adaptive modifications if needed.

2.0 LAKE ECOLOGY BACKGROUND INFORMATION

2.1 Introductory Concepts

Limnology is a multi-disciplinary field which involves the study of the biological, chemical, and physical properties of freshwater ecosystems. A basic knowledge of these processes is necessary to understand the complexities involved and how management techniques are applicable to current lake issues. The following terms will provide the reader with a more thorough understanding of the forthcoming lake management recommendations for Cedar Lake. The purpose of this study and report is to evaluate the current aquatic vegetation communities in the lake as they relate to water quality and to provide scientifically-sound and affordable management options to the Cedar Lake community.

2.1.1 Lake Hydrology

Aquatic ecosystems include rivers, streams, ponds, lakes, and the Laurentian Great Lakes. There are thousands of lakes in the state of Michigan and each possesses unique ecological functions and socio-economic contributions (O'Neil and Soulliere 2006). In general, lakes are divided into four categories:

- Seepage Lakes,
- Drainage Lakes,
- Spring-Fed Lakes, and
- Drained Lakes.

Some lakes (seepage lakes) contain closed basins and lack inlets and outlets, relying solely on precipitation or groundwater for a water source. Seepage lakes generally have small watersheds with long hydraulic retention times which render them sensitive to pollutants. Drainage lakes receive significant water quantities from tributaries and rivers. Drainage lakes contain at least one inlet and an outlet and generally are confined within larger watersheds with shorter hydraulic retention times. As a result, they are less susceptible to pollution. Spring-fed lakes rarely contain an inlet but always have an outlet with considerable flow. The majority of water in this lake type originates from groundwater and is associated with a short hydraulic retention time. Drained lakes are similar to seepage lakes, yet rarely contain an inlet and have a low-flow outlet. The groundwater and seepage from surrounding wetlands supply the majority of water to this lake type and the hydraulic retention times are rather high, making these lakes relatively more vulnerable to pollutants. The water quality of a lake may thus be influenced by the quality of both groundwater and precipitation, along with other internal and external physical, chemical, and biological processes. Cedar Lake may be categorized as a seepage lake and does not receive external water supplies from tributaries (inlets) and lacks an outlet.

2.1.2 Lake Eutrophication

All inland lakes experience some degree of lake aging. This process occurs when nutrients such as phosphorus and nitrogen are introduced to a lake and cause accelerated aquatic vegetation and algae growth. Over time, the lake basin becomes shallower and organic material accumulates on the lake bottom. This organic material serves as a nutrient-rich substrate for further primary production in the form of vegetation and algae growth. Shallow, small lakes and canals are most vulnerable to this natural process due to less depth and probability of accumulation. Shallow waters also have warmer water temperatures and this creates an ideal environment for aquatic vegetation and algae growth. The largest threat to inland lakes is the accelerated lake ageing “eutrophication” from land use activities such as agriculture, urban runoff, and failing septic systems. Millions of dollars are spent annually in Michigan alone to counteract the effects of lake eutrophication in order to gain full property value benefits and improve recreation and lake fisheries. Figure 1 shows this gradual process of eutrophication.

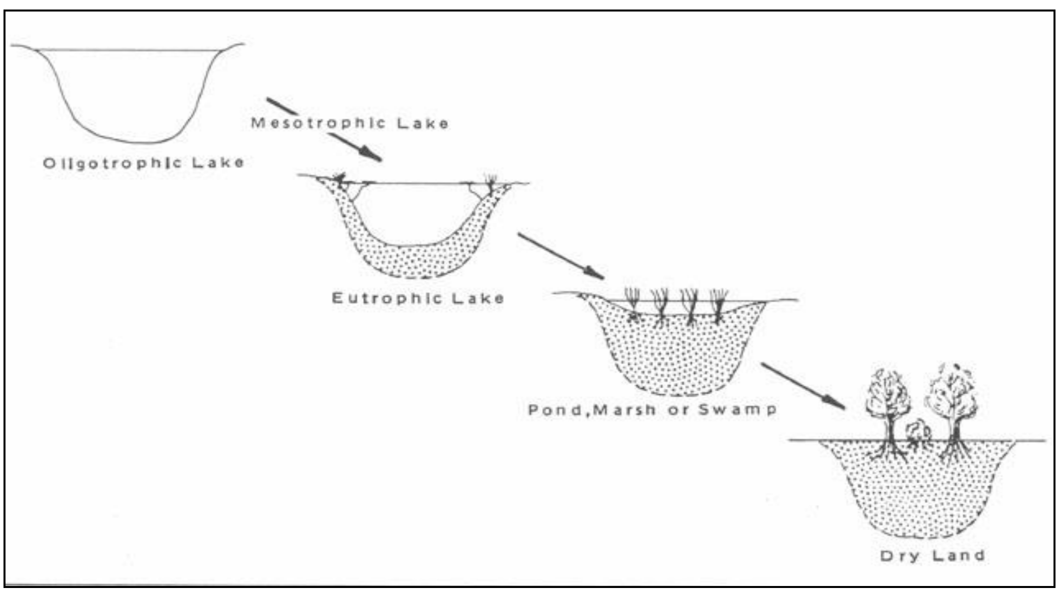


Figure 1. A diagram showing the lake aging (eutrophication) process.

2.1.3 Biodiversity and Habitat

A healthy aquatic ecosystem possesses a variety and abundance of niches (environmental habitats) available for all of its inhabitants. The distribution and abundance of preferable habitat depends on limiting influence from man and development, while preserving sensitive or rare habitats. As a result of this, undisturbed or protected areas generally contain a greater number of biological species and are considered more diverse. A highly diverse aquatic ecosystem is preferred over one with less diversity because it allows a particular ecosystem to possess a greater number of functions and contribute to both the intrinsic and socio-economic values of the lake. Healthy lakes have a greater biodiversity of aquatic macroinvertebrates, aquatic macrophytes (plants), fishes, zooplankton, phytoplankton, and may possess a plentiful yet beneficial benthic microbial community (Wetzel, 2001).

2.1.4 Watersheds and Land Use

A watershed is defined as an area of land that drains to a common point. It is influenced by both surface water and groundwater resources that are often impacted by land use activities. In general, larger watersheds possess more opportunities for pollutants to enter the ecosystem, altering the water quality and ecological communities. In addition, watersheds that contain abundant development and industrial sites are more vulnerable to water quality degradation since from pollution which may negatively affect both surface and ground water. Since many inland lakes in Michigan are relatively small in size (i.e. less than 300 acres), they are inherently vulnerable to nutrient and pollutant inputs, due to the reduced water volumes and small surface areas. As a result, the living (biotic) components of the smaller lakes (i.e. fishery, aquatic plants, macro-invertebrates, benthic organisms, etc.) are highly sensitive to changes in water quality from watershed influences. Land use activities have a dramatic impact on the quality of surface waters and groundwater.

In addition, the topography of the land surrounding a lake may make it vulnerable to nutrient inputs and consequential loading over time. Topography and the morphometry of a lake dictate the ultimate fate and transport of pollutants and nutrients entering the lake. Surface runoff from the steep slopes surrounding a lake will enter a lake more readily than runoff from land surfaces at or near the same grade as the lake. In addition, lakes with steep drop-offs may act as collection basins for the substances that are transported to the lake from the land.

All land uses contribute to the water quality of the lake through the influx of pollutants from non-point and point sources. Non-point sources are often diffuse and arise when climatic events carry pollutants from the land into the lake. Point-source pollutants are discharged from a pipe or input device and empty directly into a lake or watercourse. Activities, such as residential land use, industrial land use, agricultural land use, water supply land use, wastewater treatment land use, and storm water management, influence the watershed of a particular lake. Residential land use activities involve the use of lawn fertilizers on lakefront lawns, the utilization of septic tank systems for treatment of residential sewage, the construction of impervious (impermeable, hard-surfaced) surfaces on lands within the watershed, the burning of leaves near the lakeshore, the dumping of leaves or other pollutants into storm drains, and removal of vegetation from the land and near the water. In addition to residential land use activities, agricultural practices by vegetable crop and cattle farmers may contribute nutrient loads to lakes and streams. Industrial land use activities may include possible contamination of groundwater through discharges of chemical pollutants.

3.0 CEDAR LAKE PHYSICAL AND WATERSHED CHARACTERISTICS

3.1 The Cedar Lake Basin

Cedar Lake is a 270-acre natural, glacial lake located in Sections 27, 28,29,32,33, and 34 of Porter Township in Van Buren County, Michigan (T.4S, R.13W). The lake lacks in inlet and outlet and thus is dependent upon springs and surface water for its water sources. The shoreline perimeter of the lake is approximately 4.85 miles. Cedar Lake has a mean (average) depth of approximately 24.0 feet and a maximum depth of 84.8 feet (Restorative Lake Sciences, 2017). In addition, the lake has a volume of approximately 7,514.2 acre-feet (Restorative Lake Sciences, 2017).

The whole lake was scanned on September 20, 2017 and this produced a modernized depth contour map (Figure 2) which show the various depths of the lake based on location. The fetch of the lake (longest distance across the lake) was calculated to be approximately 1.1 miles (Restorative Lake Sciences, 2017). The lake is classified as a meso-eutrophic (moderately nutrient-enriched) aquatic ecosystem with a small to moderate-sized littoral (shallow) zone that is capable of supporting rigorous submersed rooted, aquatic plant growth. A whole-lake sediment bottom hardness scan (Figure 3) was also conducted and shows the various relative bottom hardness types such as firmer bottom (consolidated) and softer bottom (more flocculent) and their distribution along the lake bottom.

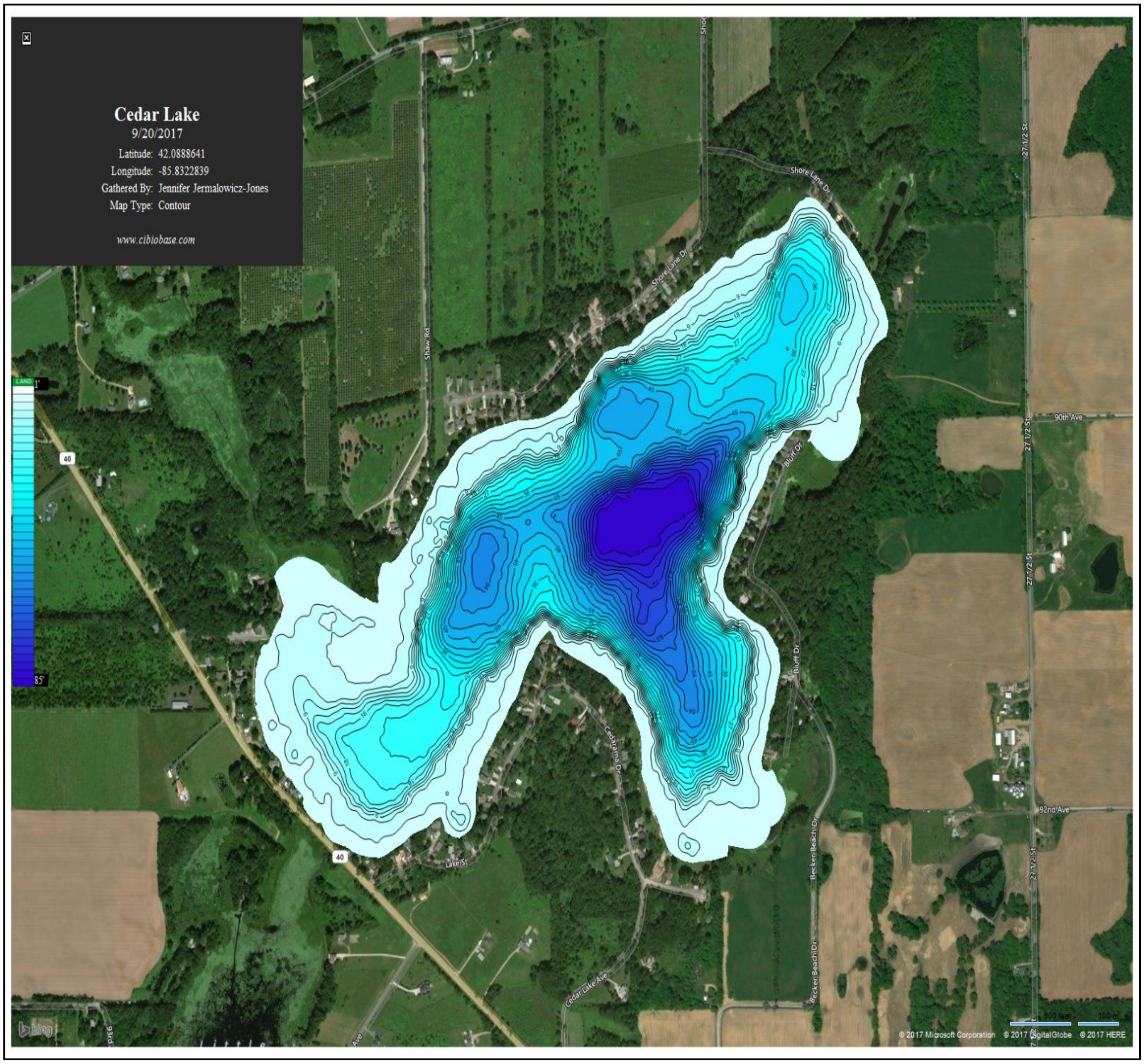


Figure 2. Cedar Lake, Van Buren County, Michigan (RLS, 2017).

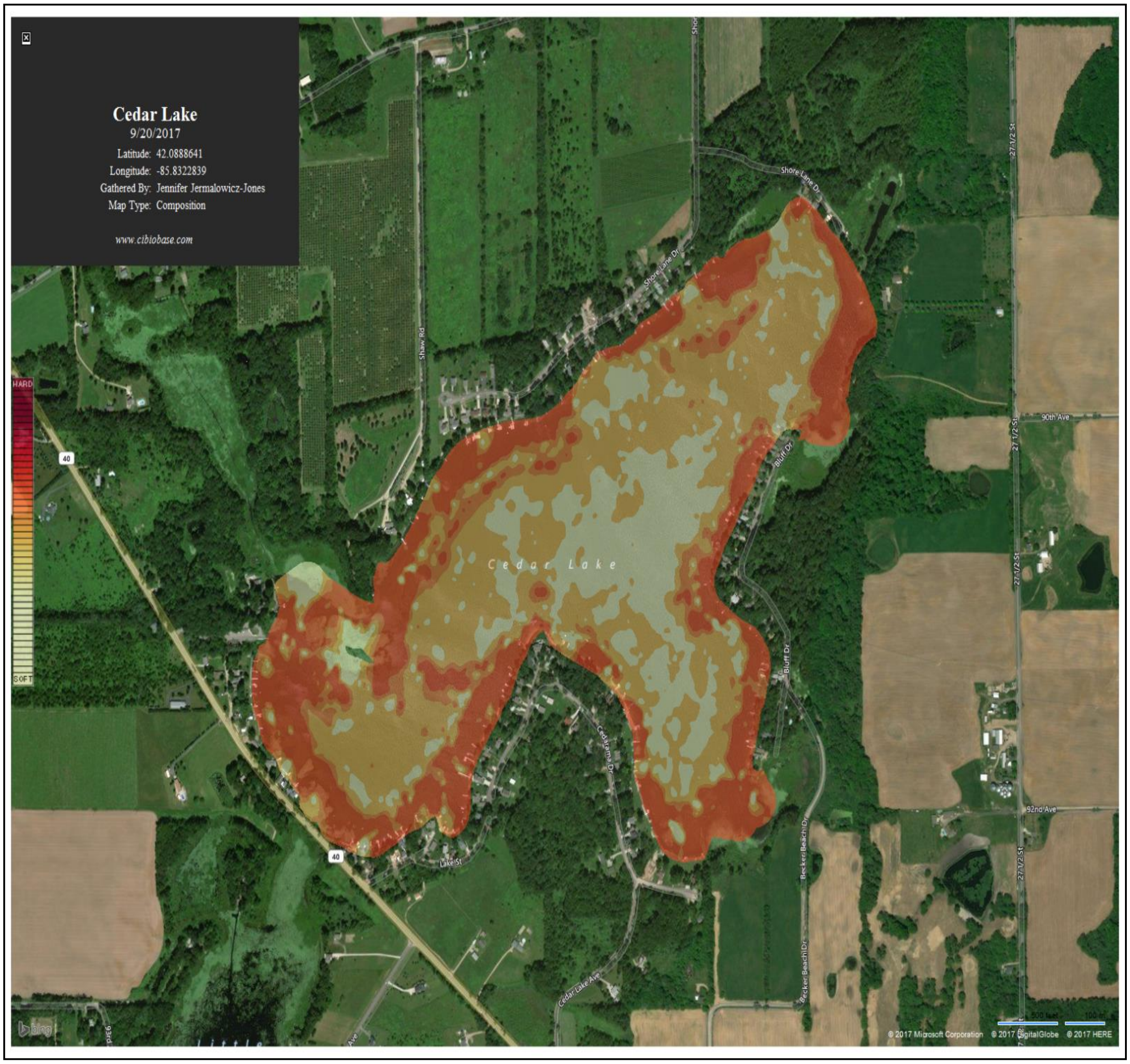


Figure 3. Cedar Lake Van Buren County, Michigan, sediment bottom hardness scan map (RLS, 2017). Note: On this map of relative bottom hardness, areas with firmer more consolidated sediments appear as dark orange whereas areas with soft bottom appear as light beige in color.

3.2 Cedar Lake Extended and Immediate Watershed and Land Use Summary

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 with high 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. The Cedar Lake extended watershed (St. Joseph River; Figure 4) is approximately 2,998,400 acres (approximately 4,685 mi^2) in area and includes portions of 15 counties, including Berrien, Branch, Calhoun, Cass, Hillsdale, Kalamazoo, St. Joseph and Van Buren County in Michigan, and De Kalb, Elkhart, Kosciusko, Lagrange, Noble, St. Joseph, and Steuben Counties in Indiana (http://www.stjoeriver.net). This extended watershed consists of agricultural lands, with more than 50% of the riparian habitat being agricultural or urban, and 25-50% as forested area.

The immediate watershed area is approximately 944 acres in area (Restorative Lake Sciences, 2017; Figures 5a and 5b). If desired, specific locations within this watershed can be determined through the use of a smaller sub-watershed scale in the future to investigate nutrient inputs on a local scale, while assessing critical source areas (CSA's) at the previous larger scale. It is worth noting that extensive areas of wetlands exist in the immediate watershed and thus anthropogenic (man-made) inputs of phosphorus and nitrogen are likely to occur more locally such as from the use of fertilizers and leaking septic tanks and drain fields. The immediate watershed is approximately 3.5 times larger than the size of Cedar Lake, which indicates the presence of small-sized immediate watershed.

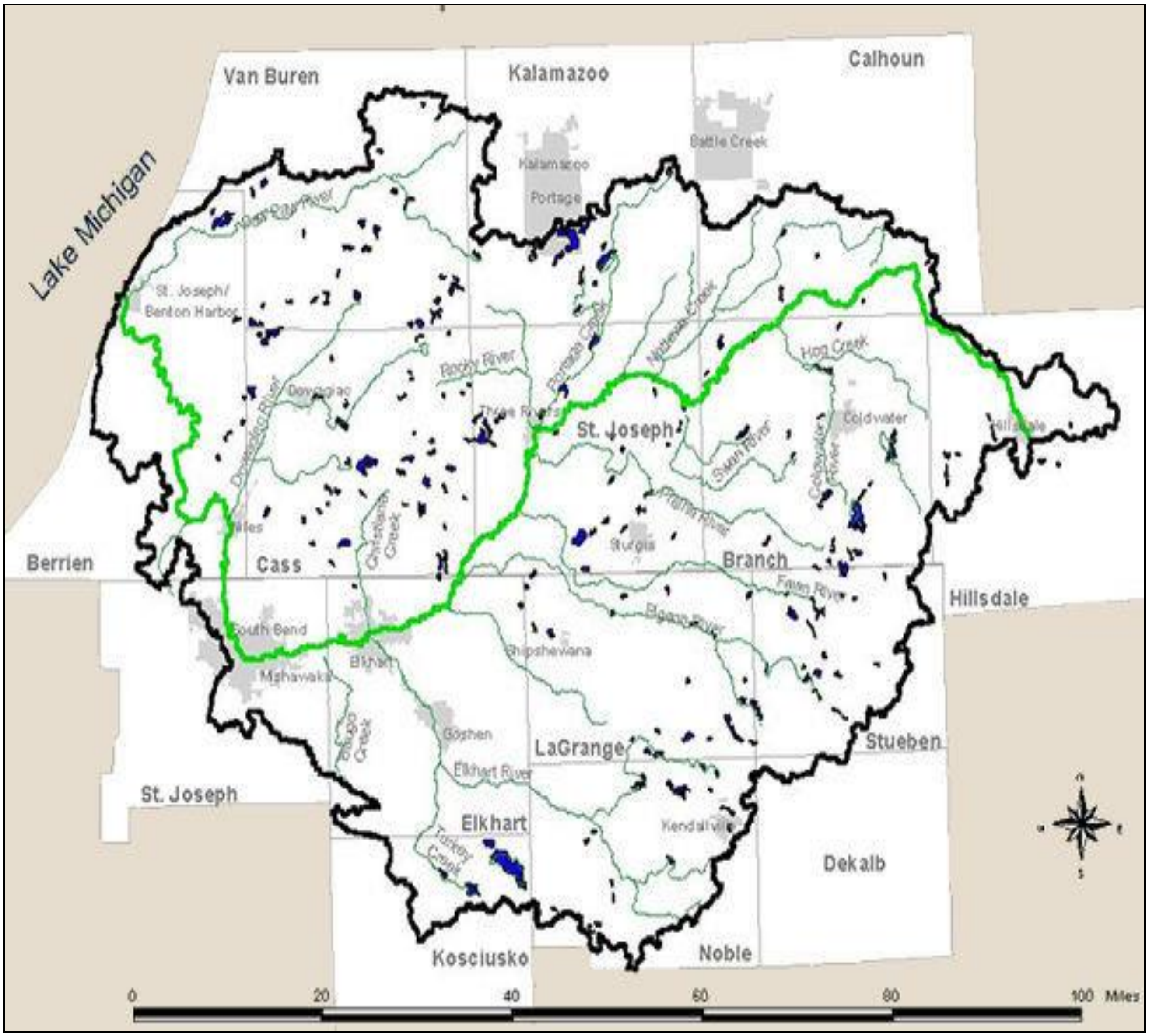


Figure 4. Extended St. Joseph River Watershed (www.stjoeriver.net, online resource).

Figure 5a. Immediate Watershed draining into Cedar Lake, Van Buren County, Michigan (Restorative Lake Sciences, 2017).

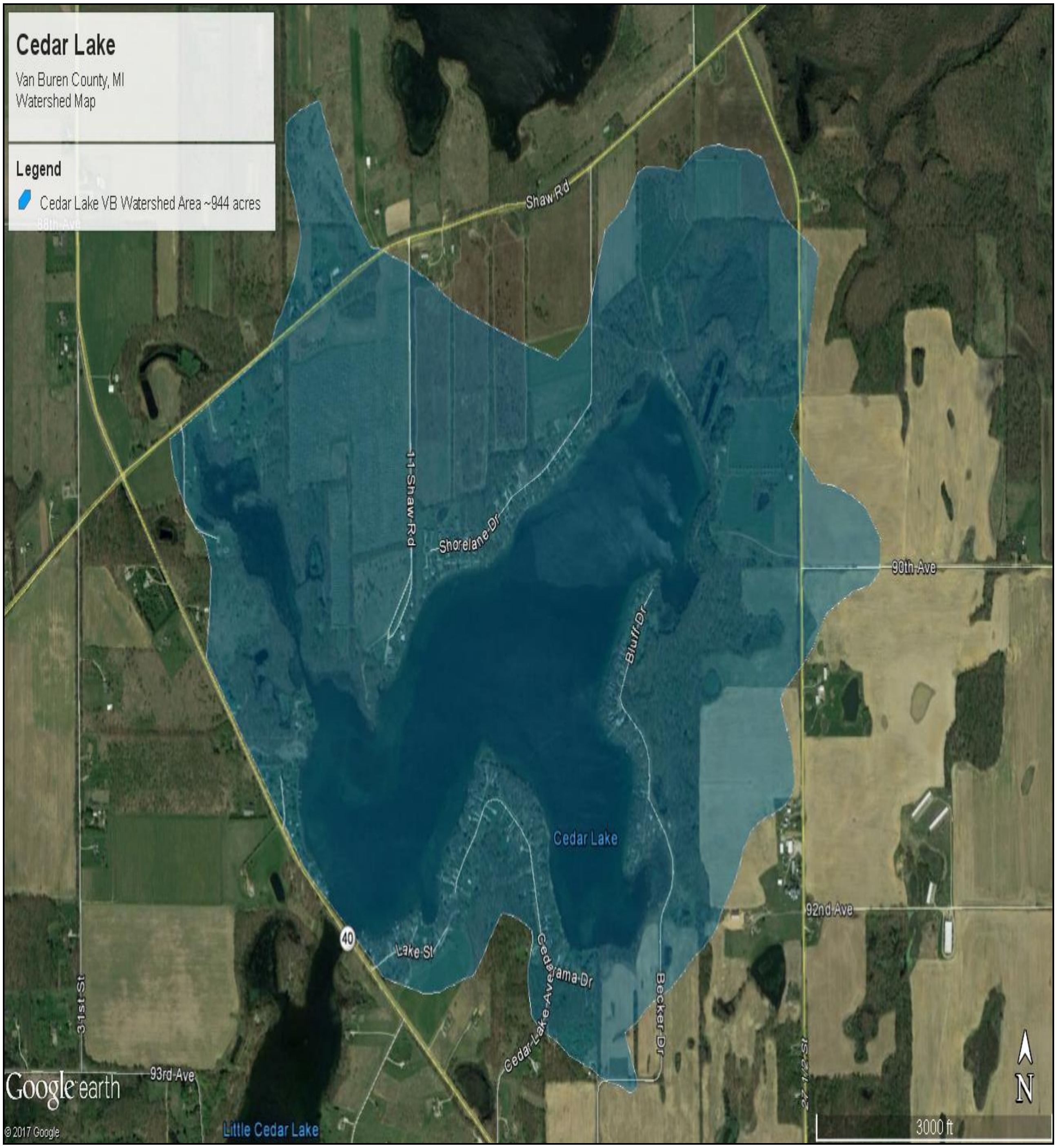


Figure 5b. Immediate Watershed draining into Cedar Lake, Van Buren County, Michigan (Restorative Lake Sciences, 2017).

3.3 Cedar Lake Shoreline Soils

There are 9 major soil types immediately surrounding Cedar Lake which may impact the water quality of the lake and may dictate the particular land use activities within the area. Figure 6 (created with data from the United States Department of Agriculture and Natural Resources Conservation Service, 1999) demonstrates the precise soil types and locations around Cedar Lake. Major characteristics of the dominant soil types directly surrounding the Cedar Lake shoreline are discussed below. The major characteristics of each soil type are listed in Table 1 below.

Table 1. Cedar Lake Shoreline Soil Types (USDA-NRCS, 1999).

USDA-NRCS Soil Series	***General Characteristics***
Oshtemo sandy loam 0-6% slopes	Very deep, well-drained, low-moderate runoff potential
Oshtemo sandy loam 6-12% slopes	Very deep, well-drained, moderate runoff potential
Oshtemo-Coloma loamy sands 18-25% slopes	Very deep, excessively drained, high runoff potential
Histosols and Aquents, ponded	Organic (peat), poorly drained, high runoff potential
Spinks loamy sand 0-6% slopes	Very deep, well-drained, low runoff potential
Kalamazoo loam 0-2% slopes	Very deep, well-drained, low runoff potential
Kalamazoo loam 2-6% slopes	Very deep, well-drained, low runoff potential
Kalamazoo loam 6-12% slopes	Very deep, well-drained, moderate runoff potential
Bronson sandy loam 0-1% slopes	Very deep, moderately well-drained, low runoff potential

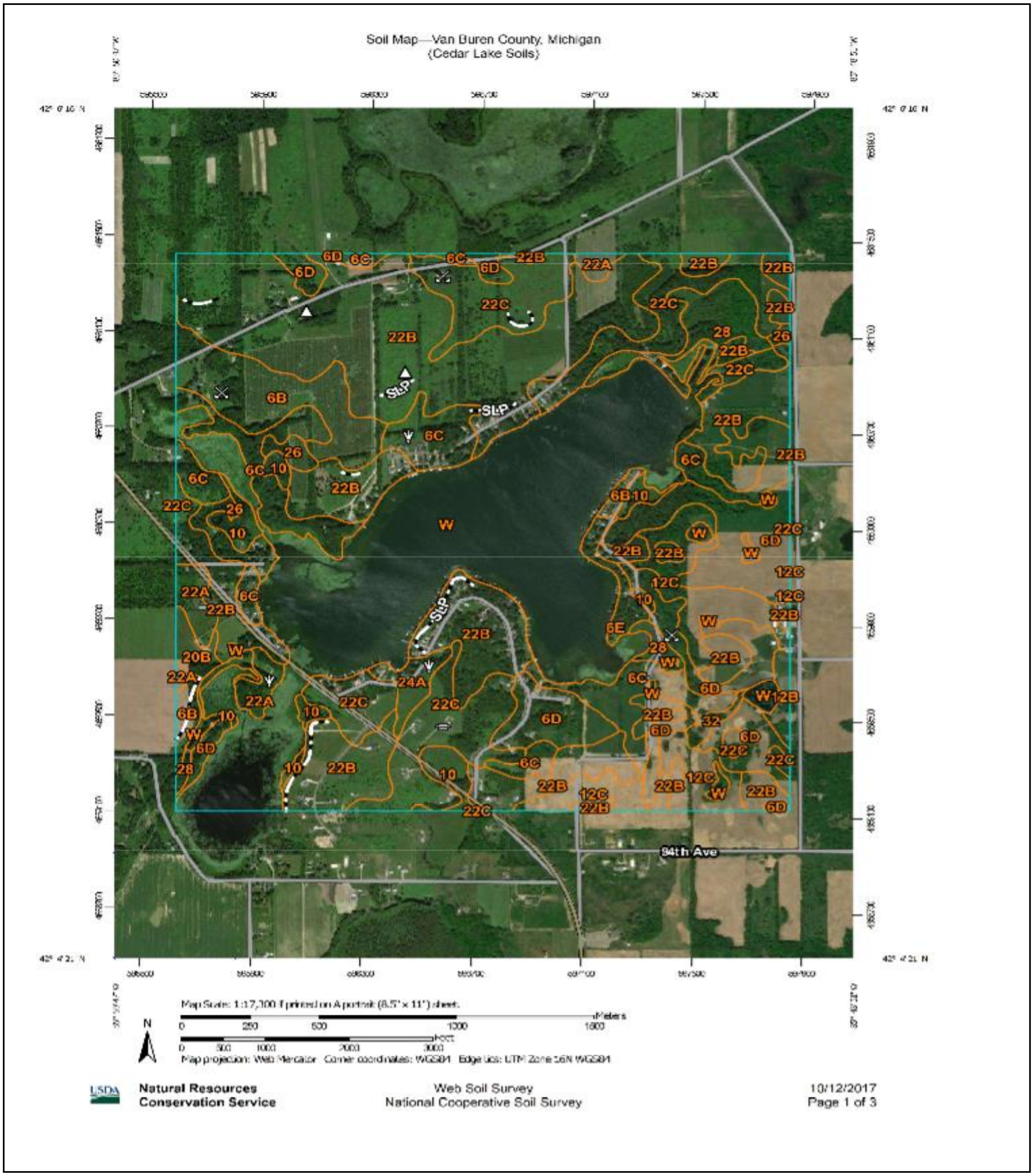


Figure 6. Shoreline soils map for Cedar Lake, Van Buren County, Michigan (USDA-NRCS data).

The majority of the soils around Cedar Lake are well drained soils with a low probability of ponding but an increased probability for runoff due to high slopes (>6%). Ponding occurs when water cannot permeate the soil and accumulates on the ground surface which then may runoff into nearby waterways and carry nutrients and sediments into the water. Excessive ponding of such soils may lead to flooding of some low-lying shoreline areas, resulting in nutrients entering the lake via surface runoff since these soils do not promote adequate drainage or filtration of nutrients. Some Best Management Practices (BMP's) are offered later in this study report for those that may reside on properties that have mucky soils or soils that are prone to erosion.

Many of the soils around the lake are on land with high slopes (>6%) which means that rainfall, especially heavy rainfall, can enter the lake downslope and carry soils and nutrients into the lake from the surrounding land. This is especially the case for land that is not vegetated and has exposed soils such as sand or loam that can easily be transported into the lake. These particles and nutrients not only fill in the lake at a faster rate (than would naturally occur) but also contribute nutrients such as nitrogen and phosphorus that lead to increased algal and aquatic plant growth.

4.0 CEDAR LAKE WATER QUALITY

Water quality is highly variable among Michigan's inland lakes, although some characteristics are common among particular lake classification types. The water quality of each lake is affected by geology, land use practices, and climatic events. Climatic factors (i.e. spring runoff, heavy rainfall) may alter water quality in the short term; whereas, anthropogenic (man-induced) factors (i.e. shoreline development, lawn fertilizer use) alter water quality over longer time periods. Since many lakes have a fairly long hydraulic residence time, the water may remain in the lake for years and is therefore sensitive to nutrient loading and pollutants. Furthermore, lake water quality helps to determine the classification of particular lakes (Table 2). Lakes that are high in nutrients (such as phosphorus and nitrogen) and chlorophyll-*a*, and low in transparency are classified as eutrophic; whereas those that are low in nutrients and chlorophyll-*a*, and high in transparency are classified as oligotrophic. Lakes that fall in between these two categories are classified as mesotrophic. Cedar Lake is classified as mesotrophic.

Cedar Lake harbors a healthy fishery with species such as pan fish, largemouth bass, northern pike, rainbow trout, walleye, and yellow perch and thus protection of its water quality is paramount. Cedar Lake has historically been stocked with rainbow trout (1979-1996) and walleye (1984-2017) according to the Michigan Department of Natural Resources Fish Stocking Database.

The database can be found at: (www.michigandnr.com/FISHSTOCK). The information below displays the water quality data collected from Cedar Lake including recent and historical data.

Table 2. Lake Trophic Status Classification Table (MDNR).

Lake Trophic Status	*Total Phosphorus (mg/l)*	*Chlorophyll-a (µg/l[1])*	*Secchi Transparency (feet)*
Oligotrophic	< 0.010	< 2.2	> 15.0
Mesotrophic	0.010-0.020	2.2 – 6.0	7.5 – 15.0
Eutrophic	> 0.020	> 6.0	< 7.5

4.1 Water Quality Parameters

Parameters such as, but not limited to, dissolved oxygen (DO), water temperature (Temp), conductivity (Cond), total dissolved solids (TDS) and total suspended solids (TSS), turbidity (Turb), pH, total alkalinity (Talk), total phosphorus (TP) and ortho-phosphorus (Ortho-P), total Kjeldahl nitrogen (TKN), chlorophyll-*a* (chl-a), algal composition, and Secchi transparency, are critical indicators of water quality. In addition, sediment parameters such as percentage of organic matter (%OM) and sediment total phosphorus (Sed TP) are indicators of lake sediment muck and fertility which both influence the growth and distribution of all forms of aquatic vegetation in and around Cedar Lake.

On September 20, 2017, RLS collected water samples from within 3 deep basins in Cedar Lake (Figure 7) with the use of a Van Dorn horizontal water sampler and also measured water quality parameters with a calibrated Eureka Manta II® sonde and probe system (Tables 4-6). In addition, RLS collected 20 sediment samples from around the lake bottom (Figure 8) with the use of an Ekman hand dredge. The results are discussed below and are presented in Table 7. Whenever possible, historical trend data (from previous data collected by both PLM and through the CLMP program) are displayed to show the changes in a particular water quality parameter with time.

Chlorophyll-a was measured *in situ* with a calibrated chlorophyll-a meter from Turner Designs®. Total alkalinity was titrated in the RLS wet laboratory using method EPA 310.1. All other water samples were analyzed at Trace Analytical Laboratories in Muskegon, Michigan. Water column TP was analyzed in the laboratory with method EPA 200.7 Rev 4.4. Water column TKN was analyzed in the laboratory with Method EPA 351.2 Rev 2.0. Water column Ortho-P was analyzed in the laboratory with method SM 4500-P E-11. Water column TSS was analyzed in the laboratory with method SM 2540 D-11. Sediment % organic matter was analyzed in the laboratory with method ASTM D2974 (Plumb) and sediment TP was analyzed in the laboratory with method EPA 6010B.

Algal community composition analysis was conducted using a phase-contrast light compound microscope with Sedgewick Rafter counting cells to determine relative abundance.

Figure 7. Locations for water quality sampling of the 3 basins in Cedar Lake, Van Buren County, Michigan (September 20, 2017).

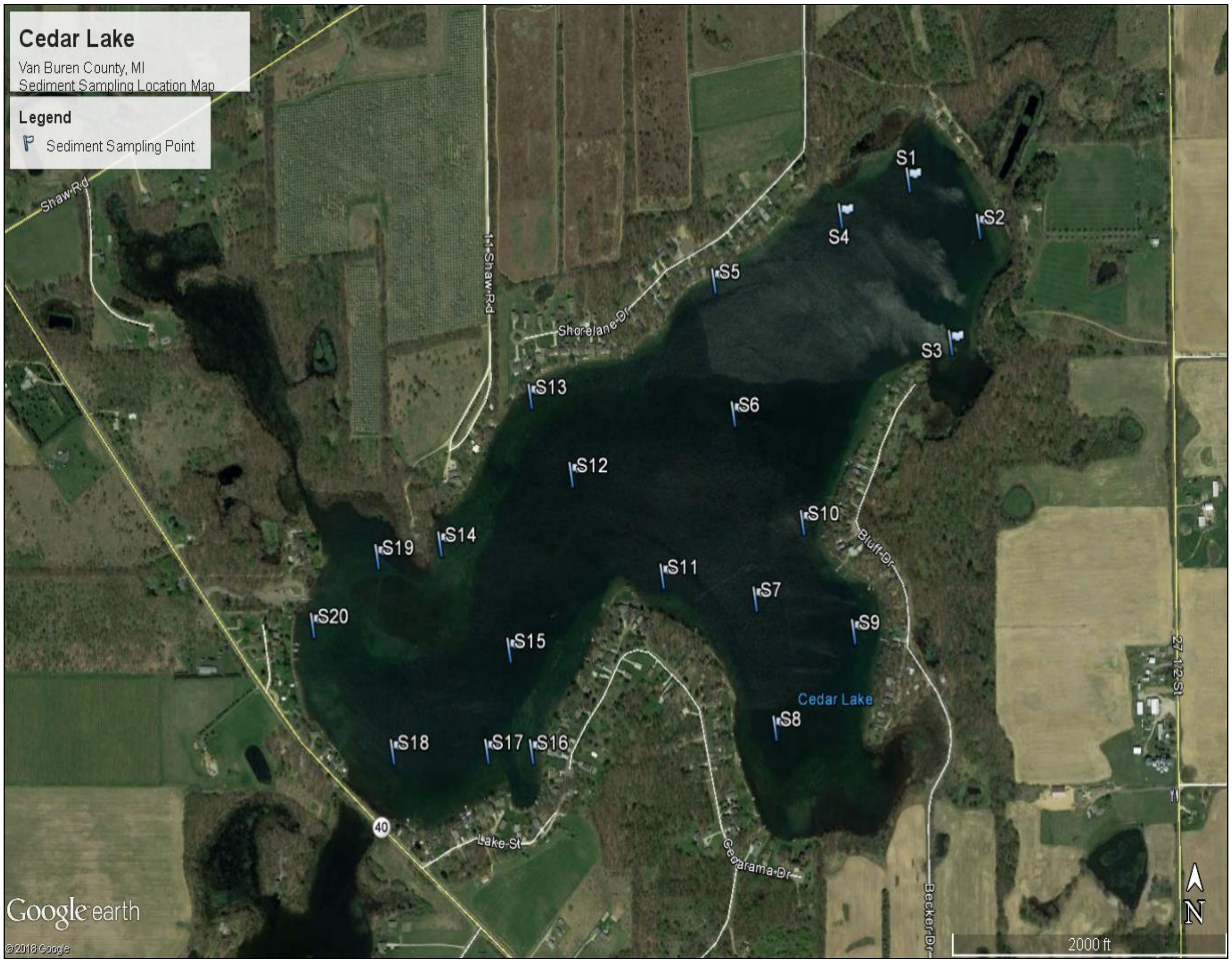
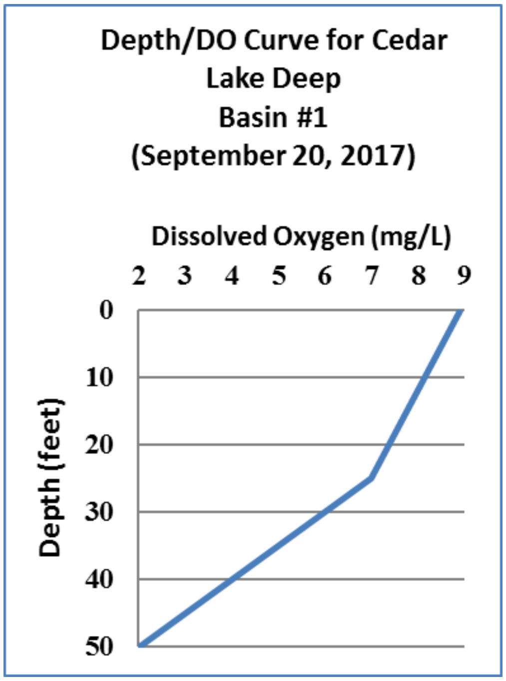
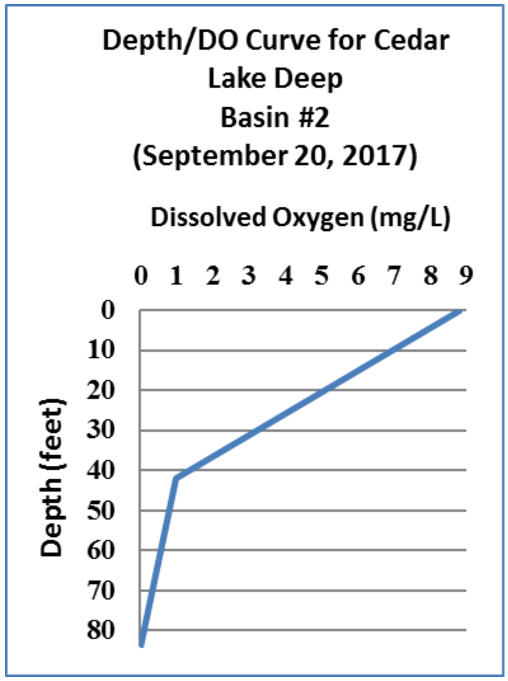


Figure 8. Locations for water quality sampling of the 20 sediment sites in Cedar Lake, Van Buren County, Michigan (September 20, 2017).

4.1.1 Dissolved Oxygen

Dissolved oxygen is a measure of the amount of oxygen that exists in the water column. In general, dissolved oxygen levels should be greater than 5 mg/l to sustain a healthy warm-water fishery. Dissolved oxygen concentrations may decline if there is a high biochemical oxygen demand (BOD) where organismal consumption of oxygen is high due to respiration. Dissolved oxygen is generally higher in colder waters. Dissolved oxygen was measured in milligrams per liter (mg/l) with the use of a calibrated Eureka Manta II® dissolved oxygen meter. During the summer months, dissolved oxygen at the surface is generally higher due to the exchange of oxygen from the atmosphere with the lake surface, whereas dissolved oxygen is lower at the lake bottom due to decreased contact with the atmosphere and increased biochemical oxygen demand (BOD) from microbial activity. Dissolved oxygen concentrations during the September 20, 2017 sampling event ranged from 0.0-8.6 mg/l, with concentrations of dissolved oxygen higher at the surface and much lower at the bottom. Figure 9 below shows the changes in dissolved oxygen with depth in the 3 deep basins of Cedar Lake. The dissolved oxygen concentration declines with depth in all basins but most prominently in deep basin #2 which is the deepest of the 3 basins.





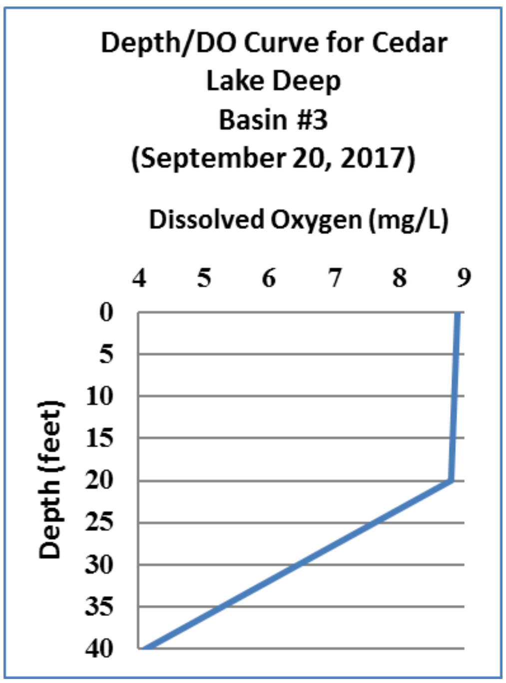


Figure 9. Dissolved oxygen/depth profiles for the 3 deep basins in Cedar Lake, Van Buren County, Michigan (RLS, 2017).

4.1.2 Water Temperature

A lake's water temperature varies within and among seasons, and is nearly uniform with depth under the winter ice cover because lake mixing is reduced when waters are not exposed to the wind. When the upper layers of water begin to warm in the spring after ice-off, the colder, dense layers remain at the bottom (Figure 10). This process results in a "thermocline" that acts as a transition layer between warmer and colder water layers. During the fall season, the upper layers begin to cool and become denser than the warmer layers, causing an inversion known as "fall turnover". In general, shallow lakes will not stratify and deeper lakes may experience single or multiple turnover cycles. Cedar Lake has 3 deep basins with considerable depth and thus will strongly stratify each year. Water temperature was measured in degrees Fahrenheit (ºF) with the use of a calibrated submersible thermometer. The September 20, 2017 water temperatures of Cedar Lake demonstrated strong thermoclines in all 3 basins and ranged from a low of 45.4°F at the bottom to a high of 74.9°F at the surface.

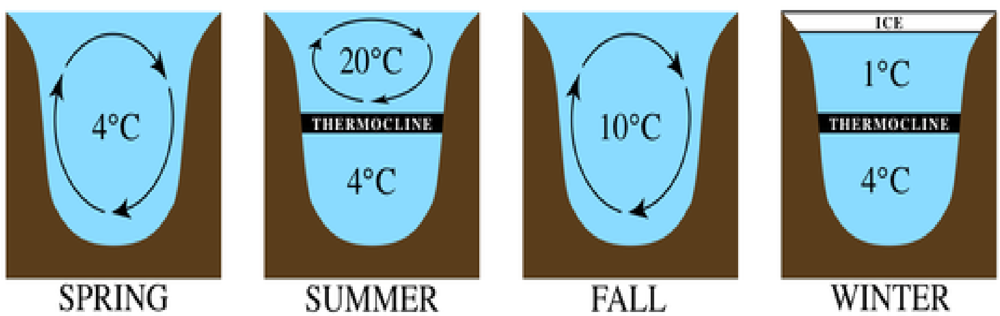


Figure 10. Diagram showing the process of stratification and turnover in lakes.

4.1.3 Specific Conductivity

Specific conductivity is a measure of the amount of mineral ions present in the water, especially those of salts and other dissolved inorganic substances. It increases under anoxic (low dissolved oxygen) conditions. Specific conductivity generally increases with the amount of dissolved minerals and salts in a lake. Specific conductivity was measured in micro Siemens per centimeter (µS/cm) with the use of a calibrated conductivity probe meter. The mean specific conductivity for the Cedar Lake deep basins was 291 mS/cm during the September 20, 2017 sampling event. This value is moderate for an inland lake and means that the lake water contains some dissolved metals. Baseline parameter data such as conductivity are important to measure the possible influences of land use activities (i.e. road salt influences) on Cedar Lake over a long period of time, or to trace the origin of a substance to the lake in an effort to reduce pollutant loading.

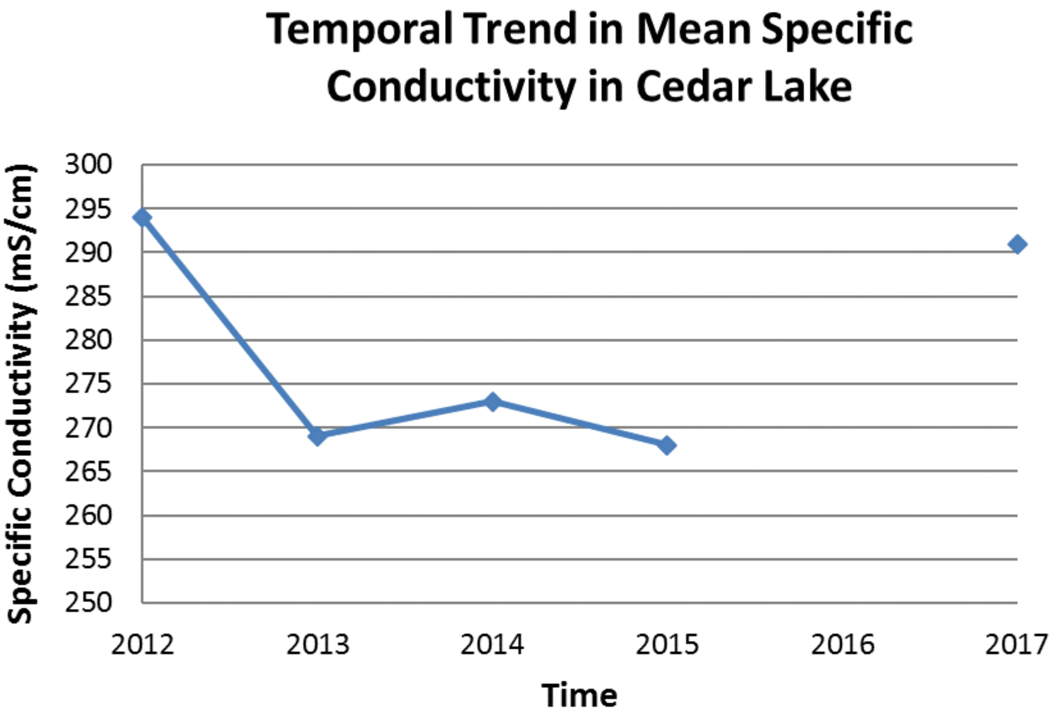


Figure 11. Graph of the changes in mean specific conductivity with time in Cedar Lake, Van Buren County, Michigan (data sources include PLM and RLS data).

4.1.4 Total Dissolved Solids, Total Suspended Solids, and Turbidity

Total dissolved solids (TDS) is a measure of the amount of dissolved organic and inorganic particles in the water column. Particles dissolved in the water column absorb heat from the sun and raise the water temperature and increase conductivity. TDS was measured with the use of a calibrated TDS probe in mg/l. Spring values are usually higher due to increased watershed inputs from spring runoff and/or increased planktonic algal communities. The mean TDS in Cedar Lake was 187 mg/l for the deep basins on September 20, 2017, which is moderate but favorable for an inland lake. The preferred range for TDS in surface waters is between 0-1,000 mg L^{-1} with the lower values most favorable.

Total Suspended Solids

Total suspended solids (TSS) refers to the quantity of solid particles detected in the water column that reduce light penetration and create turbidity in the water column. The ideal concentration for TSS in inland lakes is ≤ 20 mg/l. The TSS values in deep basin #2 and deep basin #3 were all <10 mg/l. The TSS values in deep basin #1 were much higher and ranged from <10-90 mg/l with the highest value recorded at the lake bottom. This could indicate that bottom sediments are re-suspended into the water column near the lake bottom which could be due to aquatic life activity and or water currents.

Turbidity is a measure of the loss of water transparency due to the presence of suspended particles. The turbidity of water increases as the number of total suspended particles increases. Turbidity may be caused by erosion inputs, phytoplankton blooms, storm water discharge, urban runoff, re-suspension of bottom sediments, and by large bottom-feeding fish such as carp. Particles suspended in the water column absorb heat from the sun and raise water temperatures. Since higher water temperatures generally hold less oxygen, shallow turbid waters are usually lower in dissolved oxygen. Turbidity was measured in Nephelometric Turbidity Units (NTU's) with the use of a calibrated Lutron® turbidimeter.

The World Health Organization (WHO) requires that drinking water be less than 5 NTU's; however, recreational waters may be significantly higher than that. The turbidity of Cedar Lake was quite low and ranged from 0.4-2.1 NTU's during the September 20, 2017 sampling event. The lake bottom is predominately mineral which is moderate in bulk density and may remain suspended in the water column for only short periods, which reduces turbidity and enhances water clarity. Spring values would likely be higher due to increased watershed inputs from spring runoff and/or from increased algal blooms in the water column from resultant runoff contributions. Figure 12 below shows the changes in TDS with time in Cedar Lake.

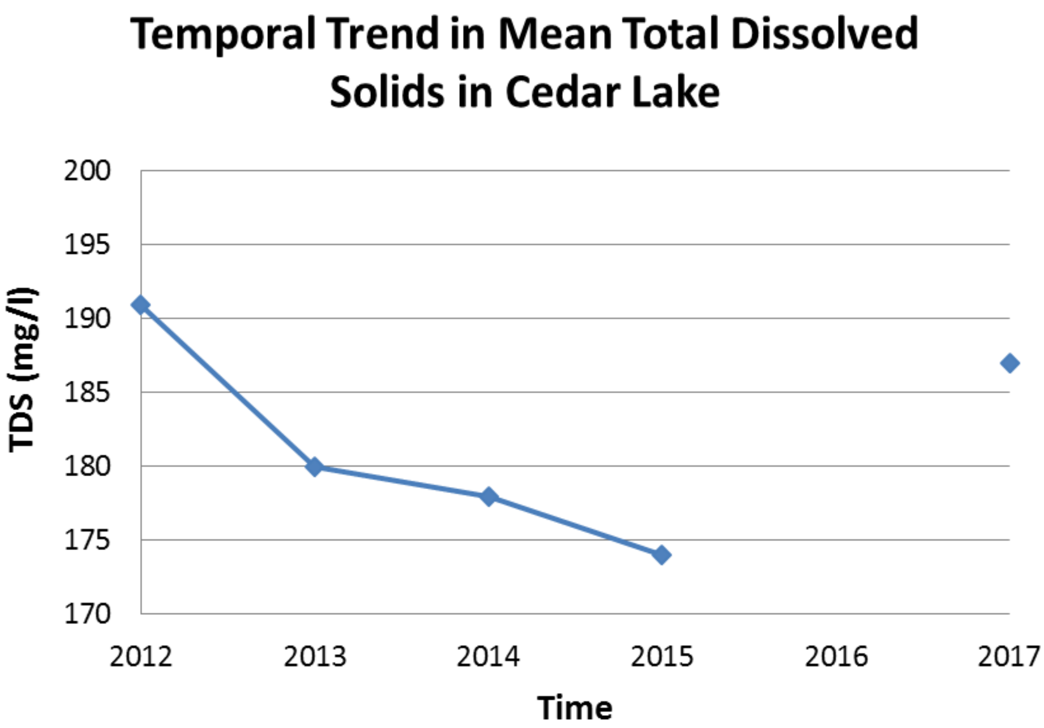


Figure 12. Graph of changes in mean TDS with time in Cedar Lake, Van Buren County, Michigan (data sources include PLM and RLS data).

4.1.5 pH

pH is the measure of acidity or alkalinity of water. pH was measured with a calibrated pH electrode and pH-meter in Standard Units (S.U). The standard pH scale ranges from 0 (acidic) to 14 (alkaline), with neutral values around 7. Most Michigan lakes have pH values that range from 6.5 to 9.5. Acidic lakes (pH < 7) are rare in Michigan and are most sensitive to inputs of acidic substances due to a low acid neutralizing capacity (ANC). pH changes on a daily basis due to changes in aquatic plant photosynthesis which actively grow during the daytime and respire at night. Generally speaking, the pH is usually lower in the hypolimnion (bottom depths) of a lake. The pH of Cedar Lake water has been relatively stable over time and averaged 8.0 S.U. during the September 21, 2017 sampling event. Figure 13 below shows the changes in mean pH with time in Cedar Lake.

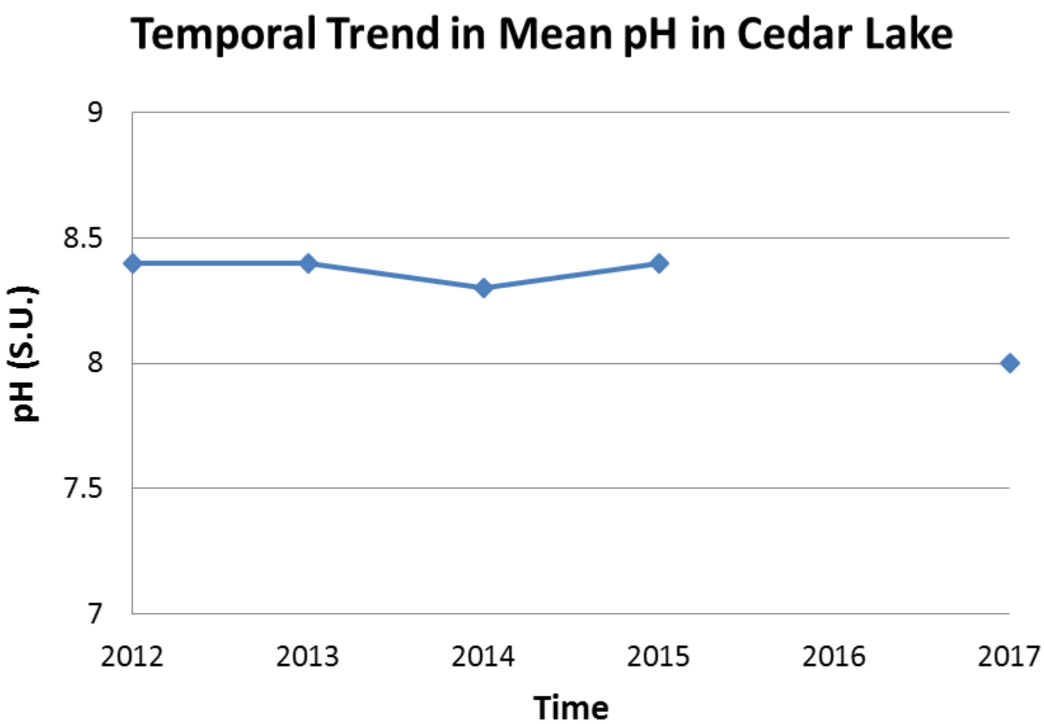


Figure 13. Graph of changes in mean pH with time in Cedar Lake, Van Buren County, Michigan (data sources include PLM and RLS data).

4.1.6 Total Alkalinity

Total alkalinity is the measure of the pH-buffering capacity of lake water. Lakes with high alkalinity (> 150 mg/l of $CaCO_3$) are able to tolerate larger acid inputs with less change in water column pH. Many Michigan lakes contain high concentrations of $CaCO_3$ and are categorized as having "hard" water. Total alkalinity was measured in milligrams per liter of $CaCO_3$ through an acid titration method (method EPA 310.1).

The total alkalinity of Cedar Lake is considered "moderate" (< 150 mg/l of $CaCO_3$), and indicates that the water is neither hard nor soft. Total alkalinity in the deep basins averaged 113 mg/l of $CaCO_3$ during the September 20, 2017 sampling event and have historically ranged from 96-128 mg/l of $CaCO_3$. Total alkalinity may change on a daily basis due to the re-suspension of sedimentary deposits in the water and respond to seasonal changes due to the cyclic turnover of the lake water. Figure 14 below shows the changes in mean total alkalinity with time in Cedar Lake.

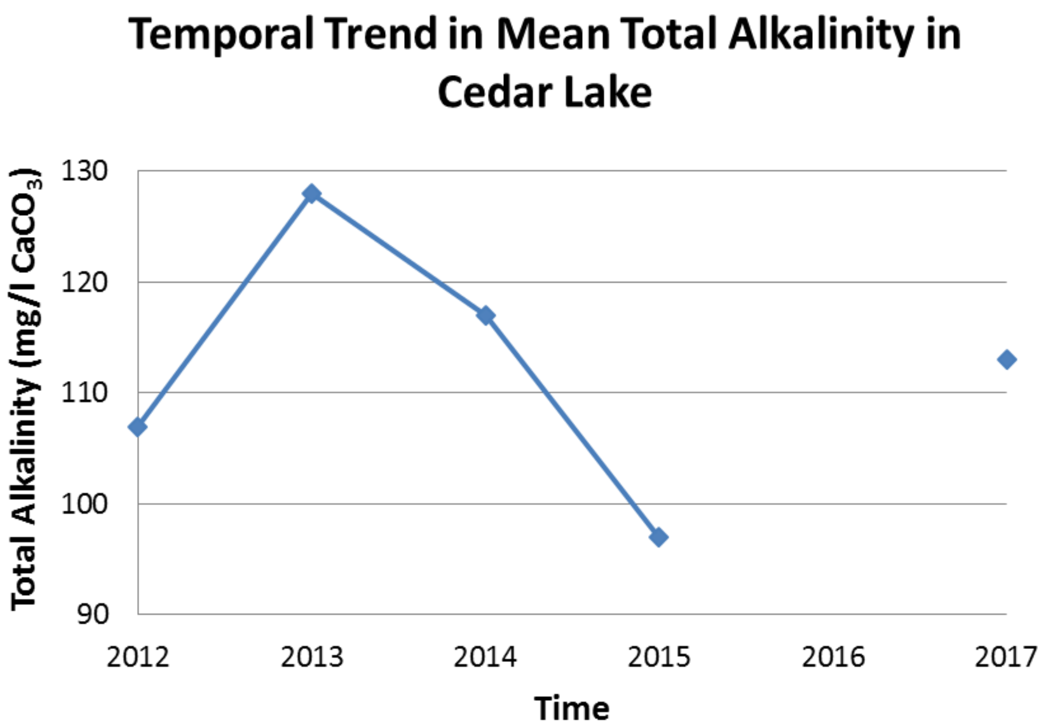


Figure 14. Graph of changes in mean total alkalinity with time in Cedar Lake, Van Buren County, Michigan (data sources from PLM and RLS data).

4.1.7 Total Nitrogen

Total Kjeldahl Nitrogen (TKN) is the sum of nitrate (NO_3^-), nitrite (NO_2^-), ammonia (NH_4^+), and organic nitrogen forms in freshwater systems. Much nitrogen (amino acids and proteins) also comprises the bulk of living organisms in an aquatic ecosystem. Nitrogen originates from atmospheric inputs (i.e. burning of fossil fuels), wastewater sources from developed areas (i.e. runoff from fertilized lawns), agricultural lands, septic systems, and from waterfowl droppings. It also enters lakes through ground or surface drainage, drainage from marshes and wetlands, or from precipitation (Wetzel, 2001). In lakes with an abundance of nitrogen (N: P > 15), phosphorus may be the limiting nutrient for phytoplankton and aquatic macrophyte growth. Alternatively, in lakes with low nitrogen concentrations (and relatively high phosphorus), the blue-green algae populations may increase due to the ability to fix nitrogen gas from atmospheric inputs. Lakes with a mean TKN value of 0.66 mg/l may be classified as oligotrophic, those with a mean TKN value of 0.75 mg/l may be classified as mesotrophic, and those with a mean TKN value greater than 1.88 mg/l may be classified as eutrophic. The mean TKN concentration in Cedar Lake during the September 20, 2017 sampling event averaged 1.1 mg/l, which is moderately low for an inland lake. Historical data on nitrates has been collected by PLM but TKN consists of all forms of nitrogen. Typically in most aquatic systems, nitrate and nitrite are much lower than ammonia.

4.1.8 Total Phosphorus and Ortho-Phosphorus

Total phosphorus (TP) is a measure of the amount of phosphorus (P) present in the water column. Phosphorus is the primary nutrient necessary for abundant algae and aquatic plant growth. Lakes which contain greater than 20 µg/l (0.020 mg/l) of TP are defined as eutrophic or nutrient-enriched. TP concentrations are usually higher at increased depths due to the higher release rates of P from lake sediments under low oxygen (anoxic) conditions. Phosphorus may also be released from sediments as pH increases. Total phosphorus was measured in milligrams per liter (mg/l) with the use of a chemical auto analyzer. The mean TP concentration in the deep basins of Cedar Lake was 0.030 mg/l on September 20, 2017. Historical mean concentrations in the spring have been much lower but spiked in 2015. In addition, summer values have historically been lower than observed in 2017. This may be due to the fact that RLS collected water column profiles which demonstrated that the phosphorus at the bottom of each deep basin ranged from 0.031-0.100 mg/l. This is one reason why it is so important to sample TP at the lake bottom, especially during stratification (summer) since it demonstrates how much TP can potentially be released into the water column under low oxygen conditions. Figure 15 below shows the changes in mean spring TP with time in Cedar Lake and Figure 16 shows the changes in mean summer TP with time in Cedar Lake.

Ortho-phosphorus (Ortho-P) refers to the concentration of phosphorus that is soluble and thus bioavailable to aquatic life. TP can be very high in some lakes and if the Ortho-P is low, then much of that phosphorus is not available to be used by aquatic life. Alternatively, the TP can be low and the Ortho-P equal to the TP which indicates that all of the TP would be available for use by aquatic life. The ideal concentration of ortho-phosphorus is < 0.010 mg/l. All but one of the ortho-phosphorus concentrations in Cedar Lake were < 0.010 mg/l. The bottom sample from deep basin #2 had nearly equal concentrations of TP and Ortho-P at 0.057 mg/l and 0.053 mg/l, respectively.

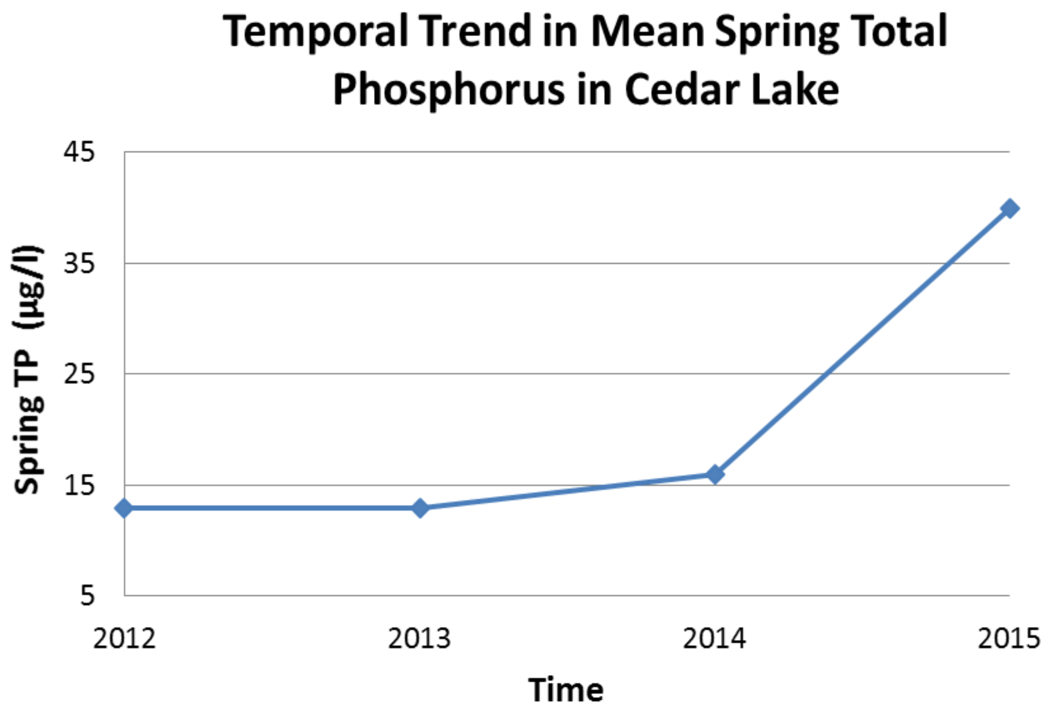


Figure 15. Graph of changes in mean spring TP with time in Cedar Lake, Van Buren County, Michigan (data sources from PLM and CLMP). Note: Data went to 2015 as RLS did not begin current study until late summer of 2017.

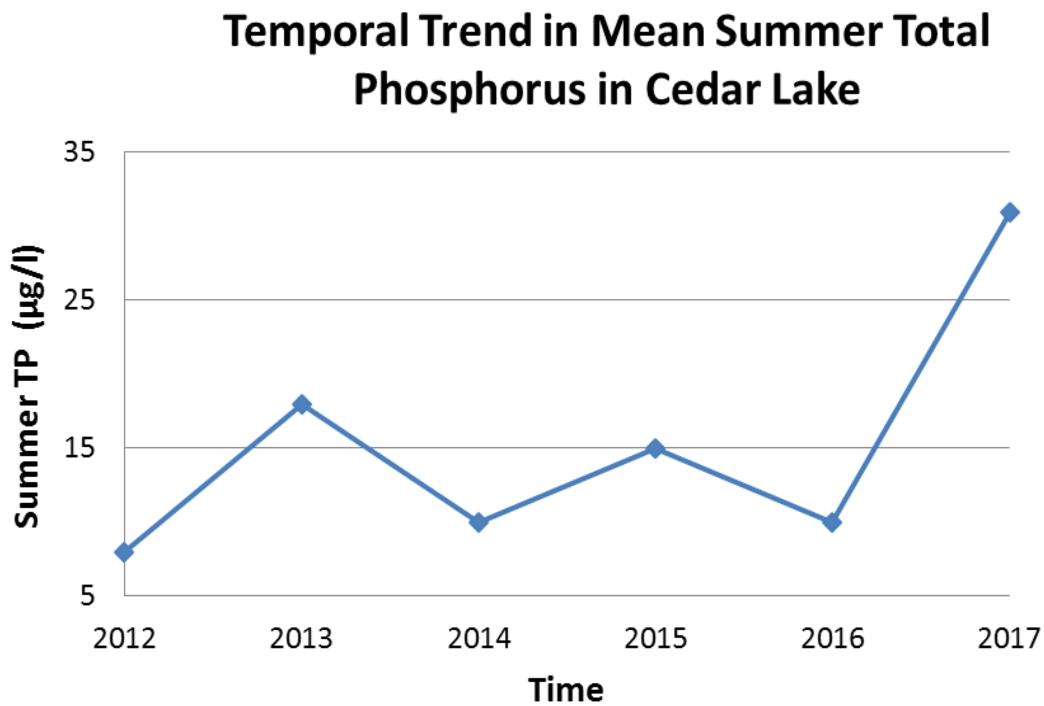


Figure 16. Graph of change in mean summer TP with time in Cedar Lake, Van Buren County, Michigan (data sources include PLM, RLS, and CLMP data).

4.1.9 Chlorophyll-a and Algae

Chlorophyll-*a* is a measure of the amount of green plant pigment present in the water, typically in the form of planktonic algae. High chlorophyll-*a* concentrations are indicative of nutrient-enriched lakes. 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 measured in micrograms per liter (µg/l) with the use of a calibrated in situ fluorimeter by Turner Designs®.

The chlorophyll-*a* concentrations in Cedar Lake were determined by collecting composite samples of the algae throughout the water column at each of the 3 deep basin sites from just above the lake bottom to the lake surface. The mean chlorophyll-*a* concentration in the deep basins was 1.0 µg/l on September 20, 2017 which is low and favorable. It is likely that these values are higher in the spring after spring runoff or in late summer when water temperatures increase and lead to the growth of algae in the water column (planktonic form) or on the surface (filamentous form). These concentrations have been variable over time, likely due to the presence of Zebra Mussels that filter algae from the water and lower the amount of algal pigment in the water. These invasive mussels have a unique population cycle that results in their prevalence in certain years and scarcity during subsequent years.

These population changes can explain the fluctuations in algae and chlorophyll-*a*. Note: Zebra Mussels are an invasive species and further introduction into Cedar Lake should be reduced. Figure 17 below shows the trend in mean chlorophyll-*a* with time in Cedar Lake.

Algal genera from a composite water sample collected over the deep basins of Cedar Lake were analyzed under a compound brightfield microscope. Genera are listed here in the order of most abundant to least abundant. The genera and relative abundance of key taxa in the deep basins are listed in Table 3. The dominant algal genera found in the deep basins consisted of single-celled, multi-celled, and filamentous algae as well as diatoms. The most dominant algae, *Chlorella* consists of a small single cell that is bright green due to its classification as a green algae. Blue-green algae such as *Oscillatoria* sp. were found in the samples but in moderation. It is always preferred to have a higher abundance of green algae and diatoms than of blue-green algae which tend to secrete toxins that can be harmful to human and animal health.

The aforementioned species indicate a diverse algal flora and represent a relatively balanced freshwater ecosystem, capable of supporting a strong zooplankton community in favorable water quality conditions. The waters of Cedar Lake are rich in the Chlorophyta (green algae) and diatoms, which are indicators of productive but healthy waters that would support a robust zooplankton population for a healthy fishery. Table 3 below shows the most dominant algal taxa found in each of the lake deep basins.

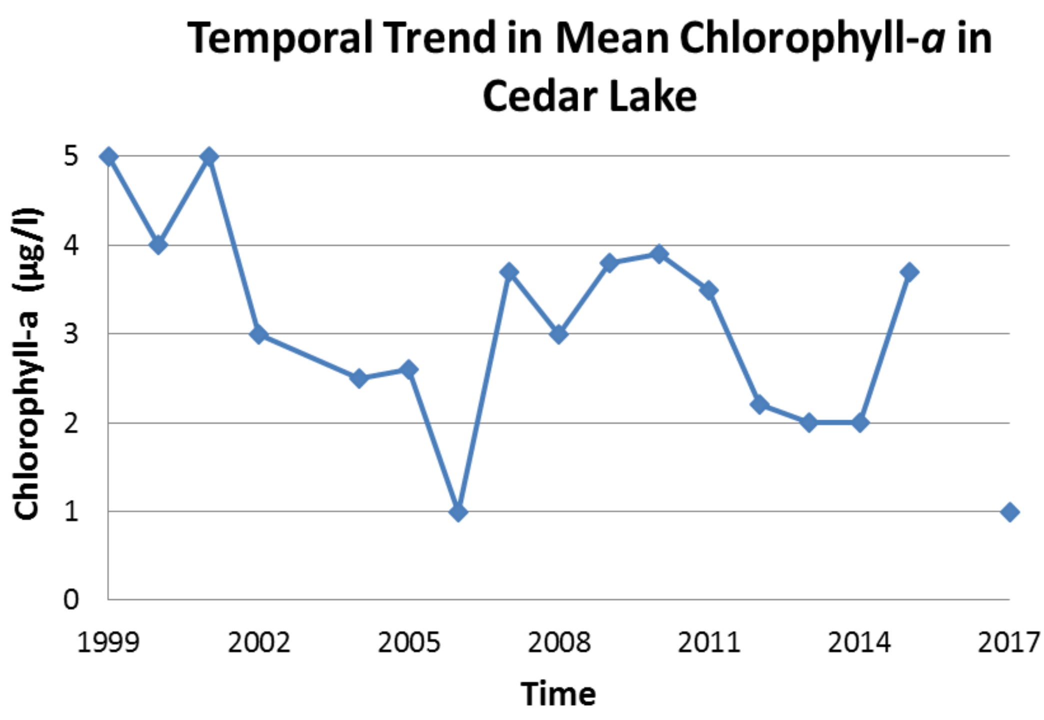


Figure 17. Graph of changes in mean chl-*a* with time in Cedar Lake, Van Buren County, Michigan (data sources include CLMP and RLS data).

Table 3. Dominant algal taxa found in the Cedar Lake deep basins (September 20, 2017).

Algae Sample Location	Dominant Algal Genera
DB #1	*Chlorella* sp., *Scenedesmus* sp., *Pediastrum* sp., *Mougeotia* sp., *Oscillatoria* sp., *Closterium* sp., *Akinistrodesmus* sp., *Spirogyra* sp., and *Cladophora* sp., *Navicula* sp., and *Synedra* sp.
DB #2	*Chlorella* sp., *Scenedesmus* sp., *Closterium* sp., *Cladophora* sp., *Merismopedia* sp., *Mougeotia* sp., *Synedra* sp, and *Cymbella* sp.
DB #3	*Chlorella* sp., *Scenedesmus* sp., *Pediastrum* sp., *Spirogyra* sp., *Mougeotia* sp., and *Synedra* sp.

4.1.10 Secchi Transparency

Secchi transparency is a measure of the clarity or transparency of lake water, and is measured with the use of an 8-inch diameter standardized Secchi disk (Figure 18). Secchi disk transparency was measured by lowering the disk over the shaded side of a boat around noon and taking the mean of the measurements of disappearance and reappearance of the disk. Elevated Secchi transparency readings are usually correlated with increased aquatic plant and algae growth. Eutrophic systems generally have Secchi disk transparency measurements less than 7.5 feet due to turbidity caused by excessive planktonic algae growth. Further, elevated phytoplankton and turbidity also are associated with decreased Secchi transparency. The Secchi transparency of Cedar Lake averaged 13.8 feet over the deep basins of Cedar Lake during the September 20, 2017 sampling event. This transparency is adequate to allow abundant growth of algae and aquatic plants in the majority of the littoral (shallow) zone of the lake. Secchi transparency is variable and depends on the amount of suspended particles in the water (often due to windy conditions of lake water mixing) and the amount of sunlight present at the time of measurement. The Secchi transparency has increased steadily over the past few years which has also allowed more light to penetrate to the lake bottom and increase potential for submersed aquatic plant growth. The water clarity of Cedar Lake may be increasing with time due to the activity of Zebra Mussels which are prevalent in the lake (discovered in the lake in 1998) and filter phytoplankton out of the water column which increases water clarity. Figure 19 below shows the mean Secchi transparency with time in Cedar Lake.

Figure 18. A Secchi disk

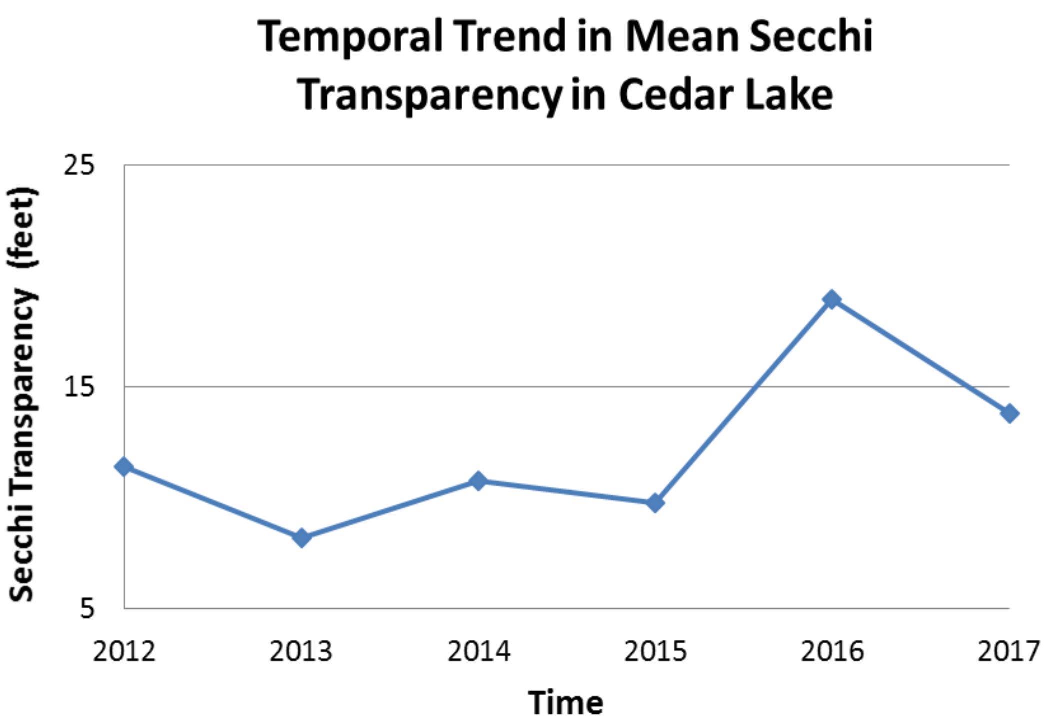


Figure 19. Graph of mean Secchi transparency with time in Cedar Lake, Van Buren County, Michigan (data sources include PLM, RLS, and CLMP data).

4.1.11 Sediment Organic Matter and Phosphorus

Organic matter (OM) contains a high amount of carbon which is derived from biota such as decayed plant and animal matter. Detritus is the term for all dead organic matter which is different than living organic and inorganic matter. OM may be autochthonous or allochthonous in nature where it originates from within the system or external to the system, respectively. Sediment OM is measured with the ASTM D2974 Method and is usually expressed in a percentage (%) of total bulk volume. Many factors affect the degradation of organic matter including basin size, water temperature, thermal stratification, dissolved oxygen concentrations, particle size, and quantity and type of organic matter present.

The organic content ranged from 1.3-45% organic matter which is quite variable and indicates that the lake sediments are comprised of a mix of sand, organic muck, and inorganic minerals. Sediment phosphorus ranged from 74-7,400 mg/kg, which is highly variable but contains a high amount of nutrient for rooted aquatic plants.

4.1.12 Oxidative Reduction Potential

The oxidation-reduction potential (ORP or E_h) of lake water describes the effectiveness of certain atoms to serve as potential oxidizers and indicates the degree of reductants present within the water. In general, the E_h level (measured in millivolts) decreases in anoxic (low oxygen) waters. Low E_h values are therefore indicative of reducing environments where sulfates (if present in the lake water) may be reduced to hydrogen sulfide (H_2S). Decomposition by microorganisms in the hypolimnion may also cause the E_h value to decline with depth during periods of thermal stratification. The E_h values for the Cedar Lake ranged from -11.5-194.6 mV from the bottom to the surface. The high variability could be due to numerous factors such as degree of microbial activity near the sediment-water interface, quantity of phytoplankton in the water, or mixing of the lake water. Thus, the lowest values are usually recorded near the lake bottom where dissolved oxygen is often absent or low.

Cedar Lake Deep Basin Water Quality Data:

Table 4. Cedar Lake water quality parameter data collected over Deep Basin 1 on September 20, 2017.

Depth ft.	*Water Temp ºF*	*DO mg/l*	*pH S.U.*	*Cond. µS/cm*	*TDS mg/l*	*TP mg/l*	*Ortho-P mg/l*	*TKN mg/l*	*Chl-a µg/l*	*TSS mg/l*	*Talk mg/l*
0	74.7	8.9	8.6	280	179	<0.010	<0.010	0.6	2.0	<10	109
25	66.4	7.0	7.9	287	185	0.011	<0.010	0.8	--	22	111
50	46.6	2.0	7.5	306	196	0.100	<0.010	2.9	--	90	117

Table 5. Cedar Lake water quality parameter data collected over Deep Basin 2 on September 20, 2017.

Depth ft.	*Water Temp ºF*	*DO mg/l*	*pH S.U.*	*Cond. µS/cm*	*TDS mg/l*	*TP mg/l*	*Ortho-P mg/l*	*TKN mg/l*	*Chl-a µg/l*	*TSS mg/l*	*Talk mg/l*
0	74.9	8.8	8.6	279	179	<0.010	<0.010	0.6	0	<10	118
42	50.0	1.0	7.5	300	192	<0.010	<0.010	0.7	--	<10	109
84	45.4	0.0	7.5	304	195	0.057	0.053	1.3	--	<10	126

Table 6. Cedar Lake water quality parameter data collected over Deep Basin 3 on September 20, 2017.

Depth ft.	*Water Temp ºF*	*DO mg/l*	*pH S.U.*	*Cond. µS/cm*	*TDS mg/l*	*TP mg/l*	*Ortho-P mg/l*	*TKN mg/l*	*Chl-a µg/l*	*TSS mg/l*	*Talk mg/l*
0	74.5	8.9	8.6	279	179	<0.010	<0.010	0.8	1.0	<10	109
20	68.0	8.8	8.2	281	180	0.029	<0.010	0.5	--	<10	113
40	48.8	4.0	7.6	305	195	0.031	<0.010	1.5	--	<10	107

Table 7. Cedar Lake sediment data collected in 20 sampling sites on September 20, 2017.

Sediment Site	*Total Phosphorus mg/kg*	*% Organic Matter*
1	860	34.0
2	74	1.3
3	280	15.0
4	7,400	25.0
5	410	17.0
6	530	22.0
7	710	29.0
8	530	31.0
9	330	13.0
10	460	14.0
11	650	20.0
12	770	34.0
13	210	13.0
14	140	14.0
15	860	45.0
16	160	8.5
17	390	14.0
18	790	24.0
19	190	21.0
20	360	30.0

5.0 CEDAR LAKE ZOOPLANKTON & MACROINVERTEBRATES

Freshwater macroinvertebrates are ubiquitous, as even the most impacted lake contains some representatives of this diverse and ecologically important group of organisms. Benthic macroinvertebrates are key components of lake food webs both in terms of total biomass and in the important ecological role that they play in the processing of energy. Others are important predators, graze alga on rocks and logs, and are important food sources (biomass) for fish. The removal of macroinvertebrates has been shown to impact fish populations and total species richness of an entire lake or stream food web (Lenat and Barbour 1994). In the food webs of lakes, benthic macroinvertebrates have an intermediate position between primary producers and higher trophic levels (as fish) on the other side. Hence, they play an essential role in key ecosystem processes (food chain dynamics, productivity, nutrient cycling and decomposition). These may also include many rare species.

Several characteristics of benthic macroinvertebrates make them useful bio-indicators of lake water quality including that many are sensitive to changes in physical, chemical, and biological conditions of a lake. Also, many complete their life cycle in a single year and their life cycles and ecological requirements are generally well known. They are sessile organisms and cannot readily escape pollution or other negative aspects and they are easily collected. Their ubiquitous nature and varied ecological role in lakes make them very useful as indicators of water quality. As benthic macroinvertebrates respond sensitively not only to pollution, but also to a number of other human impacts (hydro-logical, climatological, morphological, navigational, recreational, and others), they could potentially be used for a holistic indication system for lake ecosystem health (Solimini et *al.* 2006).

Some of the common lake macroinvertebrates include the Diptera (true flies), Coleoptera (beetles), Odonata (damselflies and dragonflies), Ephemeroptera (mayflies), Hemiptera (true bugs), Megaloptera (hellgrammites), Trichoptera (caddisflies), Plecoptera (stoneflies), Crustacea (freshwater shrimp, crayfish, isopods), Gastropoda (snails), Bivalvia (clams and mussels), Oligochaeta (earthworms), Hirudinea (leeches), Turbellaria (planarians). While the majority of these are native species, numerous invasive species have been impacting lakes in the Great Lakes Region.

Restorative Lake Sciences, LLC, collected sediment macroinvertebrates from 5 separate locations (north, south, east, west, and central regions) within Cedar Lake on September 20, 2017 (Table 8) using an Ekman hand dredge (Figure 20). The sampling found mayflies (*Hexagenia limbata*, Ephemeridae), midges (Chironomindae), wheel snails (Planorbidae), fingernail clams (Sphaeriidae), freshwater shrimp (Gammaridae), segmented worms (Oligochaeata), pond snails (Physidae), and caddisfly larvae (Limnephilidae), among a few other taxa. While the species were native, some are located universally in low quality and high quality water. The midge larvae family Chironomidae can be found in both high and low quality water (Lenat and Barbour 1994). The mayfly, *Hexagenia limbata*, found within this lake, has been shown to be linked with good water quality.

Native lake macroinvertebrate communities can and have been impacted by exotic and invasive species. A study by Stewart and Haynes (1994) examined changes in benthic macroinvertebrate community in southwestern Lake Ontario following the invasion of zebra and quagga mussels (*Dreissena spp*.). They found that *Dreissena* had replaced a species of freshwater shrimp as the dominant species. However, they also found that additional macroinvertebrates actually increased in the 10-year study, although some species were considered more pollution-tolerant than others. This increase was thought to have been due to an increase in *Dreissena* colonies increasing additional habitat for other macroinvertebrates.

In addition to exotic and invasive macroinvertebrate species, macroinvertebrate assemblages can be affected by land-use. Stewart et *al.* (2000) showed that macroinvertebrates were negatively affected by surrounding land-use. They also indicated that noted these land-use practices are important to restoration and management and of lakes. Schreiber et *al.*, (2003) stated that disturbance and anthropogenic land use changes are usually considered to be key factors facilitating biological invasions.

A vertical zooplankton tow was conducted on Cedar Lake on September 20, 2017 using a vertical plankton tow (Figure 21) net and samples were analyzed under a microscope. Five major taxa of zooplankton were present and included *Daphnia* sp., *Bosmina* sp., *Mysis* sp (freshwater shrimp) and the rotifer *Keratella* sp. and the cladoceran *Chydorus* sp. The most dominant were the *Daphnia* sp. and *Mysis* sp. These taxa indicate a healthy zooplankton community that is available to higher life forms to support a robust lake food chain which is ultimately important for the lake fishery.

Figure 20. An Ekman hand dredge used to sample sediment macroinvertebrates in Cedar Lake, Van Buren County, Michigan.

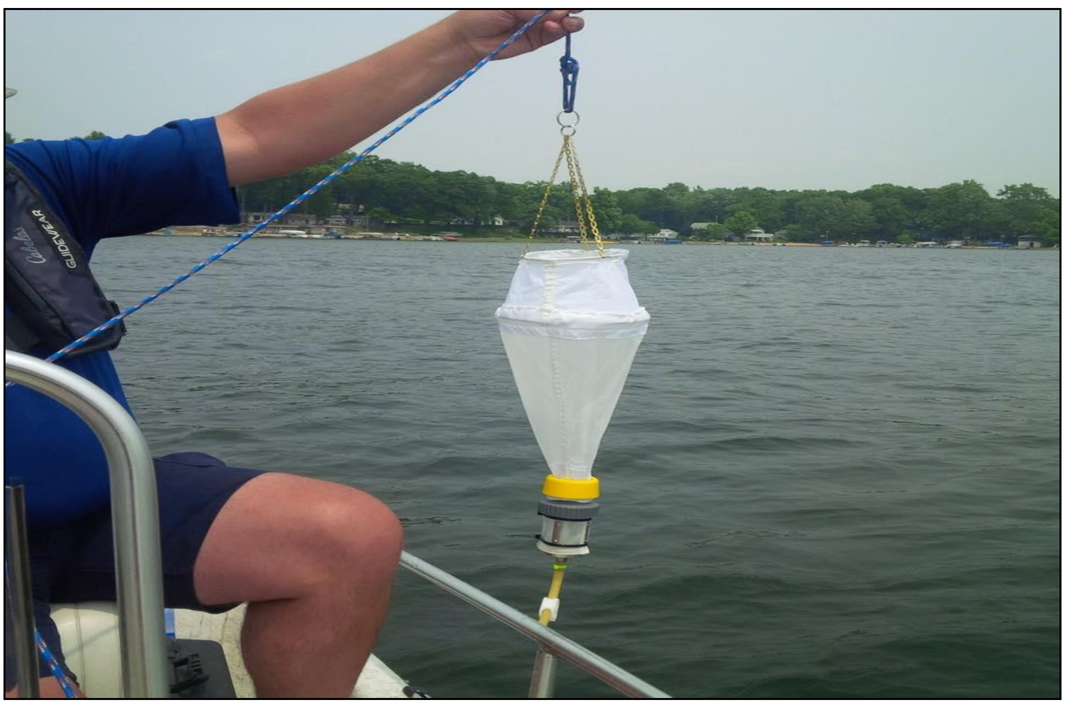


Figure 21. A vertical zooplankton tow net used to sample sediment macroinvertebrates in Cedar Lake, Van Buren County, Michigan.

Table 8. Sediment macroinvertebrates collected at the N (north), S (south), W (west), E (east), and C (central) regions of Cedar Lake Van Buren County, Michigan.

Sample 1-N	**Sample type – Sediment Grab**				
		Amphipoda	Gammaridae	4	Freshwater shrimp
		Annelida	Oligochaeata	1	Segmented worms
		Bivalvia	Sphaeridae	3	Fingernail clams
		Ephemeroptera	Ephemerillidae	4	Mayfly larvae
		Gastropoda	Physidae	8	Pond snails
		Trichoptera	Limnephilidae	4	Caddis larvae
		Diptera	Chironomidae	12	Midge larvae
		Gastropoda	Physidae	12	Wheel snails
			Total	**48**	
Sample 2-S	**Sample type – Sediment Grab**				
		Gastropoda	Physidae	5	Pond snails
		Bivalvia	Sphaeridae	1	Fingernail clams
		Amphipoda	Gammaridae	3	Freshwater shrimp
		Diptera	Chironomidae	10	Midge larvae
		Ephemeroptera	Ephemerillidae	2	Mayfly larvae
		Annelida	Oligochaeata	1	Segmented worms
		Gastropoda	Physidae	9	Wheel snails
			Total	**31**	

Sample 3-W	**Sample type – Sediment Grab**				
		Amphipoda	Gammaridae	1	Freshwater shrimp
		Annelida	Oligochaeata	5	Segmented worms
		Ephemeroptera	Ephemerillidae	2	Mayfly larvae
		Bivalvia	Spaeridae	3	Fingernail clams
		Gastropoda	Physidae	15	Pond snails
		Trichoptera	Limnephilidae	3	Caddis larvae
		Diptera	Chironomidae	18	Midge larvae
		Gastropoda	Planorbidae	10	Wheel snails
			Total	**57**	
Sample 4-E	**Sample type – Sediment Grab**				
		Gastropoda	Physidae	12	Pond snails
		Bivalvia	Sphaeridae	1	Fingernail clams
		Amphipoda	Gammaridae	5	Freshwater shrimp
		Diptera	Chironomidae	14	Midge larvae
			Total	**33**	

Sample 5-C	**Sample type – Sediment Grab**				
		Gastropoda	Physidae	2	Pond snails
		Amphipoda	Gammaridae	2	Freshwater shrimp
		Gastropoda	Planorbidae	9	Wheel snails
		Diptera	Chironomidae	2	Midge larvae
		Arthropoda	Chaoboridae	4	Glass worms
		Annelida	Oligochaeata	6	Segmented worms
			Total	**25**	

6.0 CEDAR LAKE AQUATIC VEGETATION COMMUNITIES

6.1 Overview of Aquatic Vegetation and the Role for Lake Health

The overall health of Cedar Lake is strongly connected to the type and density of aquatic vegetation present in the lake. Aquatic plants (macrophytes) are an essential component in the littoral zones of most lakes in that they serve as habitat and food for macroinvertebrates, contribute oxygen to the surrounding waters through photosynthesis, stabilize bottom sediments (if in the rooted growth form), and contribute to the cycling of nutrients. 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, pickerelweed; Figure 22) 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. 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. Similarly, an overabundance of exotic aquatic plant species can also negatively impact native aquatic plant communities and create an unbalanced aquatic ecosystem.

Figure 22. Cedar Lake emergent aquatic vegetation (September 20, 2017).

6.2 Aquatic Vegetation Sampling Methods

The aquatic plant sampling methods used for lake surveys of aquatic plant communities commonly consist of shoreline surveys, visual abundance surveys, transect surveys, AVAS surveys, and Point-Intercept Grid surveys. An Aquatic Vegetation Assessment Site (AVAS) Survey, or a GPS Point-Intercept survey (or both) is conducted on most inland lakes following large-scale aquatic herbicide treatments or prior to these treatments to assess the changes in aquatic vegetation structure and to record the relative abundance and locations of native aquatic plant species. A whole-lake GPS sampling site survey (Figure 23) was conducted on September 20, 2017 to assess all aquatic plants, including submersed, floating-leaved, and emergent species.

The use of a side-scan sonar GPS device to scan the aquatic plant biovolume, bathymetric contours, and sediment bottom hardness of the lake was conducted using a Lowrance® HDS 8 unit with BioBase® software. The lake scan consisted of 11,801 GPS points and the aquatic vegetation sampling survey utilized 391 points throughout the lake. Figure 24 below shows the aquatic vegetation biovolume in Cedar Lake. The biovolume represents the actual height of the aquatic plants off of the lake bottom. Thus, aquatic plants that canopy on the surface (such as lily pads, milfoil, Curly-leaf Pondweed, etc.) will have a higher biovolume than low-growing aquatic plants such as Chara or naiads. On these maps, a blue color represents a lack of aquatic vegetation in an area (such as deep basins); a green color represents low-growing aquatic vegetation (such as Chara) and a red or orange color represents high-growing aquatic vegetation. These maps are useful in the prioritization of treatment areas.

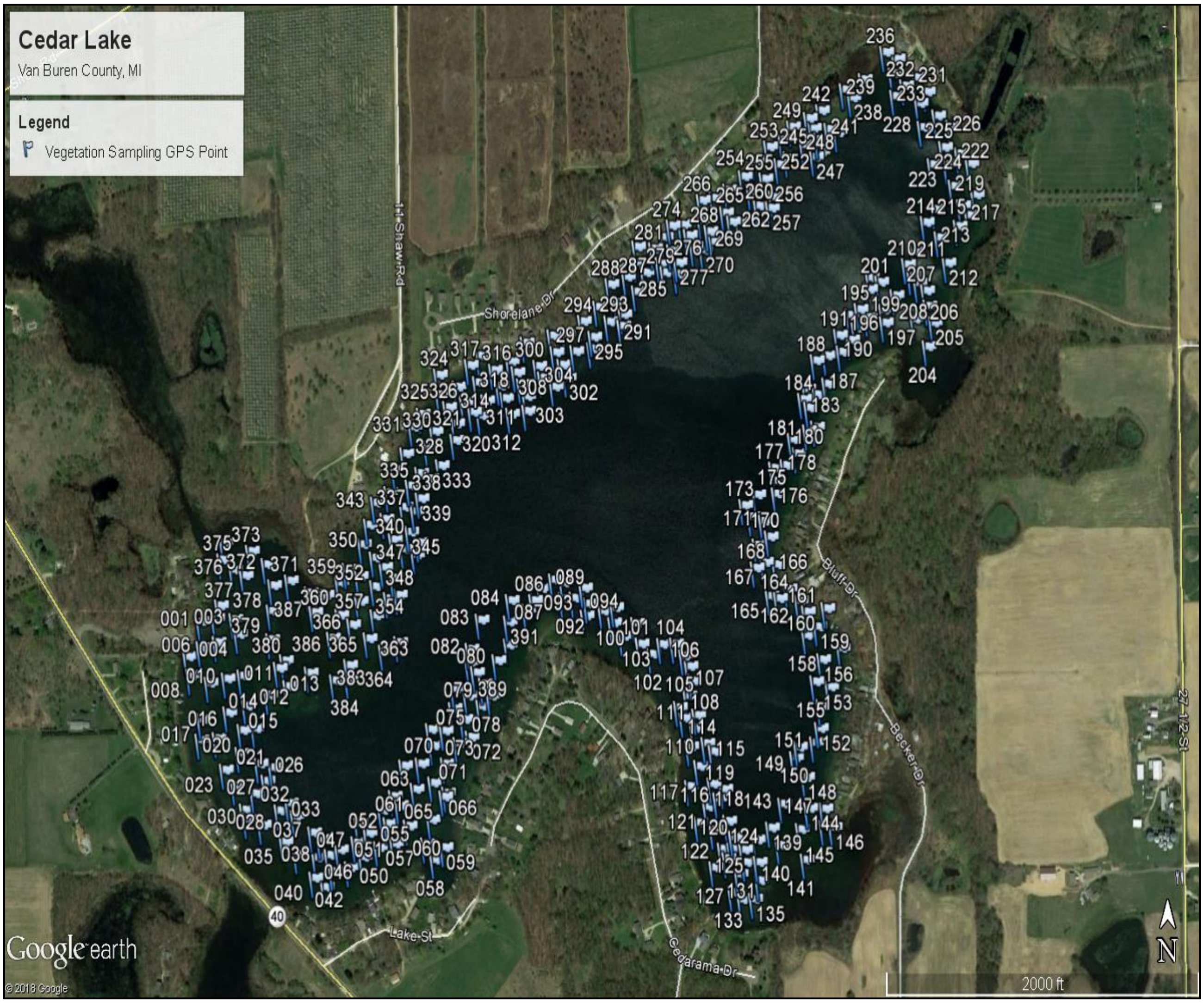


Figure 23. Aquatic vegetation sampling point locations in Cedar Lake, Van Buren County, Michigan (September 20, 2017).

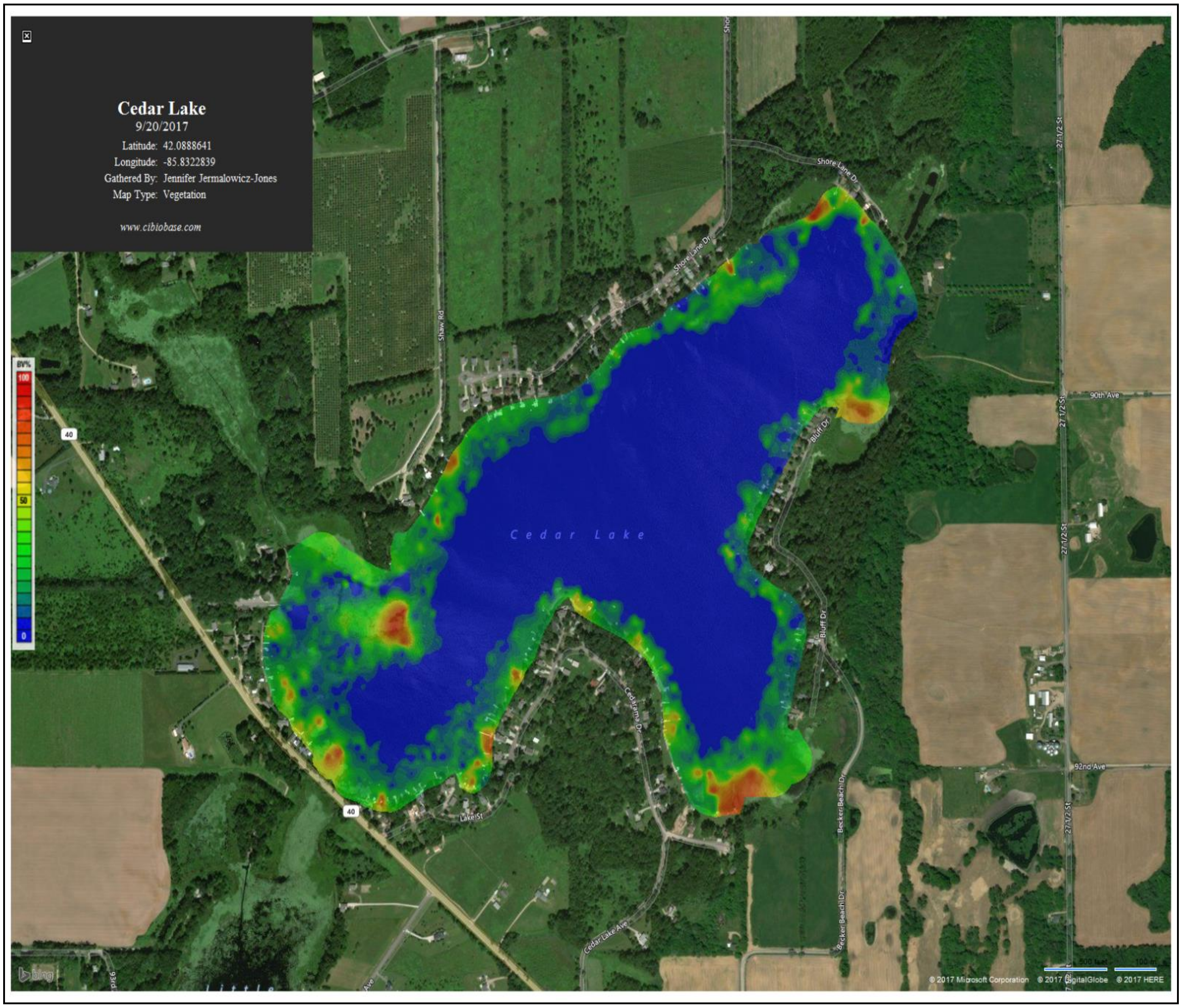


Figure 24. Aquatic vegetation biovolume scan map of Cedar Lake, Van Buren County, Michigan (September 20, 2017). Note: The blue color represents areas that are not covered with aquatic vegetation. The green color represents low-growing aquatic vegetation and the red colors represent high-growing aquatic vegetation. This scan does not differentiate between invasive and native aquatic vegetation biovolume which is why the GPS-point intercept survey is also executed in concert with the whole-lake scan.

6.3 Cedar Lake Exotic Aquatic Macrophytes

Exotic aquatic plants (macrophytes) are not native to a particular site, but are introduced by some biotic (living) or abiotic (non-living) vector. Such vectors include the transfer of aquatic plant seeds and fragments by boats and trailers (especially if the lake has public access sites), waterfowl, or by wind dispersal. In addition, exotic species may be introduced into aquatic systems through the release of aquarium or water garden plants into a water body. An aquatic exotic species may have profound impacts on the aquatic ecosystem.

Hybrid Watermilfoil (*Myriophyllum spicatum var. sibiricum*; Figure 25) is an exotic aquatic macrophyte that is a serious problem in Michigan inland lakes and has been previously genetically determined in Cedar 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 regards 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). Approximately 5.8 acres of hybrid milfoil were found in Cedar Lake during the September 20, 2017 survey. It is possible that more may have existed prior to the lake study and was reduced due to recent treatments.

Furthermore, the required dose of aquatic herbicide for successful control of the hybrid watermilfoil is 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. 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 and even within sites.

Purple Loosestrife (*Lythrum salicaria*; Figure 26) is an invasive (exotic) emergent aquatic plant that inhabits wetlands and shoreline areas. It has showy magenta-colored flowers that usually bloom in mid-July and terminate in late September. The seeds are highly resistant to tough environmental conditions and may reside in the ground for extended periods of time. It exhibits rigorous growth and may out-compete other favorable native emergents such as cattails (*Typha latifolia*) or native swamp loosestrife (*Decodon verticillatus*) and thus reduce the biological diversity of Cedar Lake. The plant is spreading rapidly across the United States and is converting diverse wetland habitats to monocultures with substantially lower biological diversity. This plant was found in 9 locations around the lake shoreline.

The Giant Common Reed (*Phragmites australis*; Figure 27) was found in four locations along the shoreline of Cedar Lake and should be promptly removed before mitigation efforts become too costly due to rapid spread of the plant. *Phragmites* is an imminent threat to the surface area and shallows of the lake since it may grow submersed in water depths of ≥ 2 meters (Herrick and Wolf, 2005), thereby drying up wetland habitat and reducing lake surface area. In addition, large, dense stands of *Phragmites* accumulate sediments, reduce habitat variability, and impede natural water flow (Wang et *al*., 2006).

A list of all invasive species found in and around Cedar Lake on September 20, 2017 is shown below in Table 9. The distribution and relative abundance of hybrid watermilfoil in 2017 is shown in Figure 28. The distribution and relative abundance of the emergent invasives Phragmites and Purple Loosestrife is shown in Figure 29.

Table 9. Exotic invasive aquatic plant species found in Cedar Lake in 2017.

Exotic Aquatic Plant Species Name	***Exotic Aquatic Plant Common Name***	***Exotic Aquatic Plant Growth Habit***	***Abundance in or around Cedar Lake (acres or # locations)***
Myriophyllum spicatum var. *sibiricum*	Hybrid Eurasian Watermilfoil	Submersed; Rooted	5.08
Lythrum salicaria	Purple Loosestrife	Emergent	9 locations
Phragmites australis	Giant Common Reed	Emergent	4 locations

Figure 25. Eurasian Watermilfoil ©RLS

Figure 26. Purple Loosestrife ©RLS

Figure 27. Phragmites ©RLS

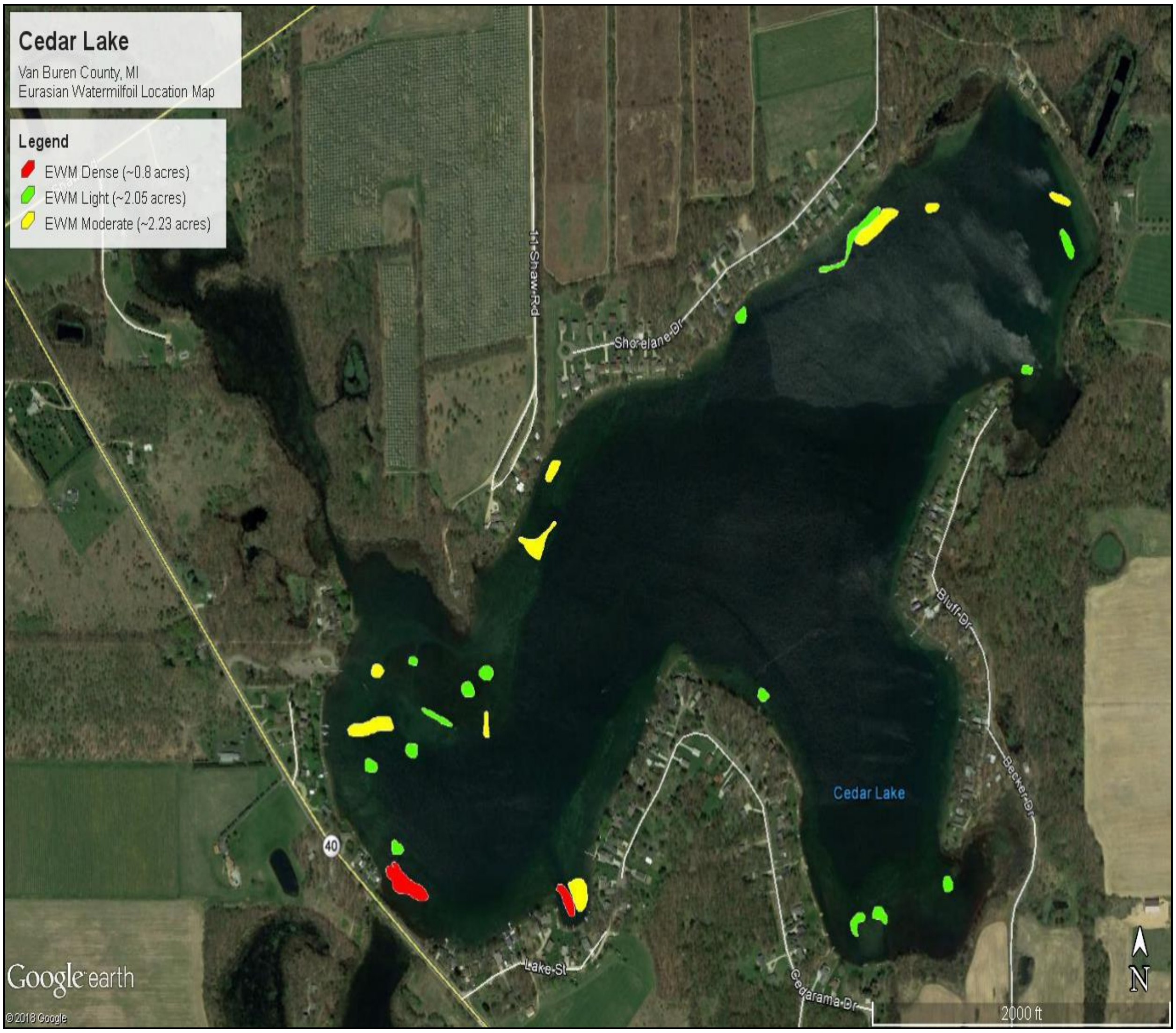


Figure 28. Hybrid Eurasian Watermilfoil locations in Cedar Lake, Van Buren County, Michigan based on relative abundance (September 20, 2017).

Figure 29. Invasive emergent Phragmites and Purple Loosestrife locations in Cedar Lake, Van Buren County, Michigan (September 20, 2017). Note: Polygons appear larger than actual size to demonstrate precise locations of invasives.

6.4 Cedar Lake Native Aquatic Macrophytes

There are hundreds of native aquatic plant species in the waters of the United States. The most diverse native genera include the Potamogetonaceae (Pondweeds) and the Haloragaceae (Watermilfoils). Native aquatic plants may grow to nuisance levels in lakes with abundant nutrients (both water column and sediment) such as phosphorus, and in sites with high water transparency. The diversity of native aquatic plants is essential for the balance of aquatic ecosystems, because each plant harbors different macroinvertebrate communities and varies in fish habitat structure.

Cedar Lake contained 15 native submersed, 2 floating-leaved, and 6 emergent aquatic plant species, for a total of 23 native aquatic macrophyte (plant) species (Table 10). Photos of all native aquatic plants are shown below in Figures 30-52. The majority of the emergent macrophytes may be found along the shoreline of the lake and in wetland areas. Additionally, the majority of the floating-leaved macrophyte species can be found near the shoreline of the lake. This is likely due to enriched sediments and shallower water depth with reduced wave energy that facilitates the growth of aquatic plants with floating-leaf morphological forms.

The first most common aquatic plant species was the submersed Wild Celery (*Vallisneria americana*) which has long, green, ribbon-like leaves that emerge from a basal rosette that can reach the lake surface in shallow areas. The plant reproduces via seed and also through the production of underground runners or stolons. After sexual fertilization is complete, the plant produces a spiral stalk in the center of it which is quite distinct in appearance. The plant can become a nuisance in shallow areas and was planted by the MDNR many decades ago to serve as a food source for migratory waterfowl.

The second most dominant aquatic plant in the main part of the lake included the macro alga, *Chara* which is also called “skunkweed” due to its strong odor. This algae is only anchored to the bottom sediments by tiny rhizoids and serves as excellent fish spawning habitat. It is brittle to the touch and carpets many shallow bottom areas of the lake. It is beneficial in keeping lake bottom sediments from suspension into the water column which can reduce water clarity. It is one reason why the water clarity of Cedar Lake is so favorable.

There were also two floating-leaved macrophyte species, including *Nymphaea odorata* (White Waterlily), which is critical for housing macroinvertebrates and should be protected and preserved in non-recreational areas to serve as food sources for the fishery and wildlife around the lake, and *Nuphar variegata* (Yellow Waterlily), which harbors seeds that are eaten by waterfowl. The emergent plants, such as *Typha latifolia* (Cattails), and *Scirpus acutus* (Bulrushes) are critical for shoreline stabilization as well as for wildlife and fish spawning habitat. The presence of invasive emergents such as Purple Loosestrife and Phragmites around the Cedar Lake shoreline are currently low in abundance but could become a threat to the native emergent macrophyte populations if not controlled. These plants threaten the biodiversity of emergent aquatic plant communities and can eventually displace native species that are critical to the lake ecosystem.

Table 10. Cedar Lake native aquatic plant species (September 20, 2017).

Native Aquatic Plant Species Name	***Aquatic Plant Common Name***	***% Cover***	***Aquatic Plant Growth Habit***
Chara vulgaris	Muskgrass	11.5	Submersed, Rooted
Potamogeton pectinatus	Thin-leaf Pondweed	0.1	Submersed, Rooted
Potamogeton amplifolius	Large-leaf Pondweed	5.5	Submersed, Rooted
Potamogeton zosteriformis	Flat-stem Pondweed	0.1	Submersed, Rooted
Potamogeton gramineus	Variable-leaf Pondweed	2.8	Submersed, Rooted
Potamogeton robbinsii	Fern-leaf Pondweed	0.2	Submersed, Rooted
Potamogeton natans	Floating-leaf Pondweed	0.1	Submersed, Rooted
Potamogeton illinoensis	Illinois Pondweed	4.9	Submersed, Rooted
Zosterella dubia	Water Stargrass	0.3	Submersed, Rooted
Vallisneria americana	Wild Celery	13.1	Submersed, Rooted
Elodea canadensis	Common Waterweed	0.1	Submersed, Rooted
Ceratophyllum demersum	Coontail	0.7	Submersed, Non-Rooted
Utricularia vulgaris	Bladderwort	1.0	Submersed, Non-Rooted
Najas guadalupensis	Southern Naiad	4.1	Submersed, Rooted
Scirpus subterminalis	Submersed Bulrush	0.9	Submersed, Rooted
Nymphaea odorata	White Waterlily	7.5	Floating-Leaved, Rooted
Nuphar variegata	Yellow Waterlily	0.6	Floating-Leaved, Rooted
Typha latifolia	Cattails	1.3	Emergent
Scirpus acutus	Bulrushes	6.2	Emergent
Iris sp.	Iris	0.4	Emergent
Decodon verticillatus	Swamp Loosestrife	0.7	Emergent
Sagittaria sp.	Arrowhead	0.1	Emergent
Pontedaria cordata	Pickerelweed	1.7	Emergent

Figure 30. Chara (Muskgrass) ©RLS

Figure 31. Thin-leaf Pondweed ©RLS

Figure 32. Large-leaf Pondweed ©RLS

Figure 33. Variable-leaf Pondweed ©RLS

Figure 34. Fern-leaf Pondweed ©RLS

Figure 35. Flat-stem Pondweed ©RLS

Figure 36. Floating-leaf Pondweed ©RLS

Figure 37. Water Stargrass ©RLS

Figure 38. Bladderwort ©RLS

Figure 39. Wild Celery ©RLS

Figure 40. Illinois Pondweed ©RLS

Figure 41. Elodea ©RLS

Figure 42. Coontail ©RLS

Figure 43. Southern Naiad ©RLS

Figure 44. Submersed Bulrush ©RLS

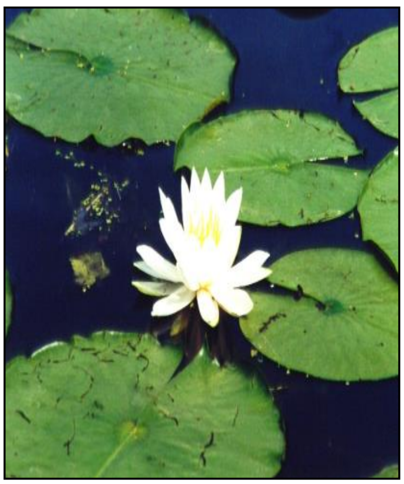


Figure 45. White Waterlily ©RLS

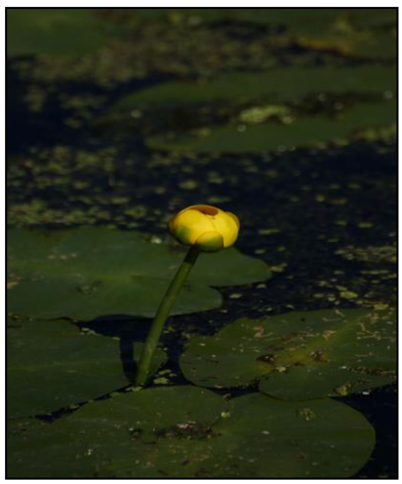


Figure 46. Yellow Waterlily ©RLS

Figure 47. Swamp Loosestrife ©RLS

Figure 48. Cattails ©RLS

Figure 49. Bulrushes ©RLS

Figure 50. Yellow Iris ©RLS

Figure 51. Pickerelweed ©RLS

Figure 52. Arrowhead ©RLS

7.0 CEDAR LAKE MANAGEMENT IMPROVEMENT METHODS

7.1 Cedar Lake Aquatic Plant Management Methods

Improvement strategies, including the management of exotic aquatic plants, control of land and shoreline erosion, and further nutrient loading from external sources, are available for the various problematic issues facing Cedar Lake. The lake management components involve both within-lake (basin) and around-lake (watershed) solutions to protect and restore complex aquatic ecosystems. The goals of a lake improvement program are to improve aquatic vegetation biodiversity, improve water quality and wildlife habitat, protect recreational use of a water resource and protect waterfront property values. Regardless of the management goals, all management decisions must be site-specific and should consider the socio-economic, philosophical, scientific, and environmental components of the lake management plan.

The management of invasive submersed and emergent invasive aquatic plants is necessary in Cedar 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 some are capable of achieving strong results when used properly. Exotic aquatic plant species should be managed with solutions that will yield long-term results. There are two major goals that the Cedar Lake Recreation Association (CLRA) should pursue relative to vegetation management: 1) reduction of invasive aquatic plant species such as hybrid watermilfoil, Phragmites, and Purple Loosestrife, 2) protection of the native aquatic plant species found throughout the lake, and 3) protection of the lake water quality in terms of nutrient management. These three objectives are critical for the health and balance of Cedar Lake and will take special management recommendations to accomplish both. It must be stated that they are not mutually exclusive since the protection of the native species must be compatible with management of the invasives. The sections below discuss the individual lake management methods (tools) and then ultimately lead to a section with specific recommendations using those methods. Since there were only a few locations with the invasive emergent Purple Loosestrife and Phragmites, removal of these invasives by hand-pulling is recommended over other methods. Care should be taken to remove all of the roots and stolons from the plants and the plants should be discarded in wrapped plastic bags and taken to a landfill.

7.1.1 Aquatic Herbicides and Applications

The use of aquatic chemical herbicides is regulated by the MDEQ under Part 33 (Aquatic Nuisance) of the Natural Resources and Environmental Protection Act, P.A. 451 of 1994, and requires a permit. 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. Aquatic herbicides are usually applied with a skiff boat or an airboat (Figure 53).

Contact herbicides such as diquat, hydrothol, and flumioxazin cause damage to leaf and stem structures; whereas systemic herbicides are assimilated by the plant roots and are lethal to the entire plant. Wherever possible, it is preferred to use a systemic herbicide on milfoil for longer-lasting aquatic plant control. There are often restrictions with usage of some systemic herbicides around shoreline areas that contain shallow drinking wells. In Cedar Lake, the use of contact herbicides is not recommended for the control of native vegetation due to the low amount in the lake relative to the size of the lake.

Systemic herbicides such as 2, 4-D and triclopyr are the two primary systemic herbicides used to treat Hybrid Watermilfoil. Fluridone (trade name, SONAR®) is a systemic whole-lake herbicide treatment that is applied to the entire lake volume in the spring and is used for extensive infestations. Fortunately, the patchy distribution of hybrid watermilfoil in Cedar Lake can be effectively spot-treated with granular triclopyr nearshore and granular 2,4-D or triclopyr in offshore areas. Triclopyr must be used in near shore areas with shallow well (< 30 feet deep) restrictions.

Figure 53. An herbicide treatment airboat and crew preparing for a lake treatment.

7.1.2 Mechanical Harvesting

Mechanical harvesting involves the physical removal of nuisance aquatic vegetation with the use of a mechanical harvesting machine (Figure 54). The mechanical harvester collects numerous loads of aquatic plants as they are cut near the lake bottom. The plants are off-loaded onto a conveyor and then into a dump truck.

Harvested plants are then taken to an offsite landfill or farm where they can be used as fertilizer. Mechanical harvesting is preferred over chemical herbicides when primarily native aquatic plants exist, or when excessive amounts of plant biomass need to be removed. Mechanical harvesting is usually not recommended for the removal of milfoil since the plant may fragment when cut and re-grow on the lake bottom. Mechanical harvesting does not require a permit from the Michigan Department of Environmental Quality (MDEQ); however, some counties require a launch site use permit from the Michigan Department of Natural Resources (MDNR) if a public access site is present. This technology would have the most efficacy on very large weed beds where milfoil is sparse or not present. It may also be useful in areas such as public boat launches to reduce nuisance native aquatic vegetation biomass. At this time, harvesting is not needed but could be used in the future if native aquatic plants grow dense in specific areas of the lake.

Figure 54. A mechanical harvester. Photo courtesy of Dave Foley.

7.1.3 Diver Assisted Suction Harvesting (DASH)/Dredging

Suction harvesting via a Diver Assisted Suction Harvesting (DASH) boat (Figure 55) 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 generally recommended for small (less than 1 acre) spot removal of vegetation since it is costly on a large scale. It may be used as an alternative to spot-treatment with aquatic herbicides if desired.

The advantage it has is that it can be selective in what species it removes since a diver is guiding the suction hose to targeted plants. This process may remove either plant material or sediments and requires a joint MDEQ/USACE bottomlands permit. Furthermore, this activity may cause re-suspension of sediments (Nayar et *al*., 2007) which may lead to temporarily increased turbidity and reduced clarity of the water.

Figure 55. A DASH boat for hand-removal of watermilfoil or other nuisance vegetation. ©Restorative Lake Sciences, LLC

7.1.4 Biological Control

In the past, the use of the aquatic weevil, *Euhrychiopsis lecontei* (Figure 56) to control Hybrid Watermilfoil was implemented to reduce milfoil infestations and had highly variable results among and within lakes.

The land beetle, *Galerucella sp.* (Figure 57) has been effective on the treatment of shoreline Purple Loosestrife in many locations throughout the Midwest and especially in Michigan. However, these beetles usually prefer a large stand of Purple Loosestrife to promote their population. Fortunately, only a small area around Cedar Lake contained this plant and hand-pulling is recommended at this time over biological control due to the overall low abundance and biomass.

Figure 56. The watermilfoil weevil (*Euhrychiopsis lecontei*). Photo from R. Newman used with permission.

Figure 57. *Galerucella* sp. The "Purple Loosestrife" beetle.

7.1.5 Laminar Flow Aeration and Bioaugmentation

Laminar flow aeration systems (Figure 58) are retrofitted to a particular site and account for variables such as water depth and volume, contours, water flow rates, and thickness and composition of lake sediment. The systems are designed to completely mix the surrounding waters and evenly distribute dissolved oxygen throughout the lake sediments for efficient microbial utilization. A laminar flow aeration system utilizes diffusers which are powered by onshore air compressors. The diffusers are connected via extensive self-sinking airlines which help to purge the lake sediment pore water of gases such as hydrogen sulfide (H_2S) which gives lake sediments a "rotten egg" odor. In addition to the placement of the diffuser units, the concomitant use of bacteria and enzymatic treatments to facilitate the microbial breakdown of organic sedimentary constituents is also used as a component of the treatment. Beutel (2006) found that lake oxygenation eliminates release of NH_3+ (ammonia) from sediments through oxygenation of the sediment-water interface. Allen (2009) demonstrated that NH_3+ oxidation in aerated sediments was significantly higher than that of control mesocosms with a relative mean of 2.6 ± 0.80 mg N g dry wt. day^{-1} for aerated mesocosms and 0.48 ± 0.20 mg N g dry wt. day^{-1} in controls.

Recent case studies have shown promise on the positive impacts of laminar flow aeration systems on aquatic ecosystem management with respect to organic matter degradation and resultant increase in water depth, and rooted aquatic plant management in eutrophic ecosystems (Jermalowicz-Jones, 2010-2017). Additionally, Toetz (1981) found evidence of a decline in *Microcystis* algae (a toxin-producing blue-green algae) in Arbuckle Lake in Oklahoma. Other studies (Weiss and Breedlove, 1973; Malueg et *al.*, 1973) have also shown declines in overall algal biomass. The philosophy and science behind the laminar flow aeration system is to reduce the organic matter layer in the sediment so that a significant amount of nutrient is removed from the sediments and excessive sediments are reduced to yield a greater water depth.

Limitations of Laminar Flow Aeration

The laminar flow aeration system has some limitations including the inability to break down mineral sediments and the requirement of a constant Phase I electrical energy source to power the units. Regular equipment maintenance is also required.

Design of the Laminar Flow Aeration System

The design of a laminar flow system would be retrofitted to a particular lake. The system has several components which consists of lake basin components such as micro-porous ceramic diffusers, onshore compressors, self-sinking airline, and bacteria and enzyme treatments. Once the system has been installed, the MDEQ has instituted a required minimum sampling protocol to monitor the efficacy of the system for the intended purposes as determined by stakeholders.

The use of aeration with bioaugmentation (addition of microbes) is recommended to increase dissolved oxygen in all 3 deep basins and reduce the release of phosphorus from nutrient-enriched bottom waters and sediments. A whole-lake system may not be needed as shallow areas in the lake have ample dissolved oxygen and many sediments are not high in organic matter. Laminar flow aeration systems require a MDEQ permit and an entire season of baseline data is needed as a condition of the permit.

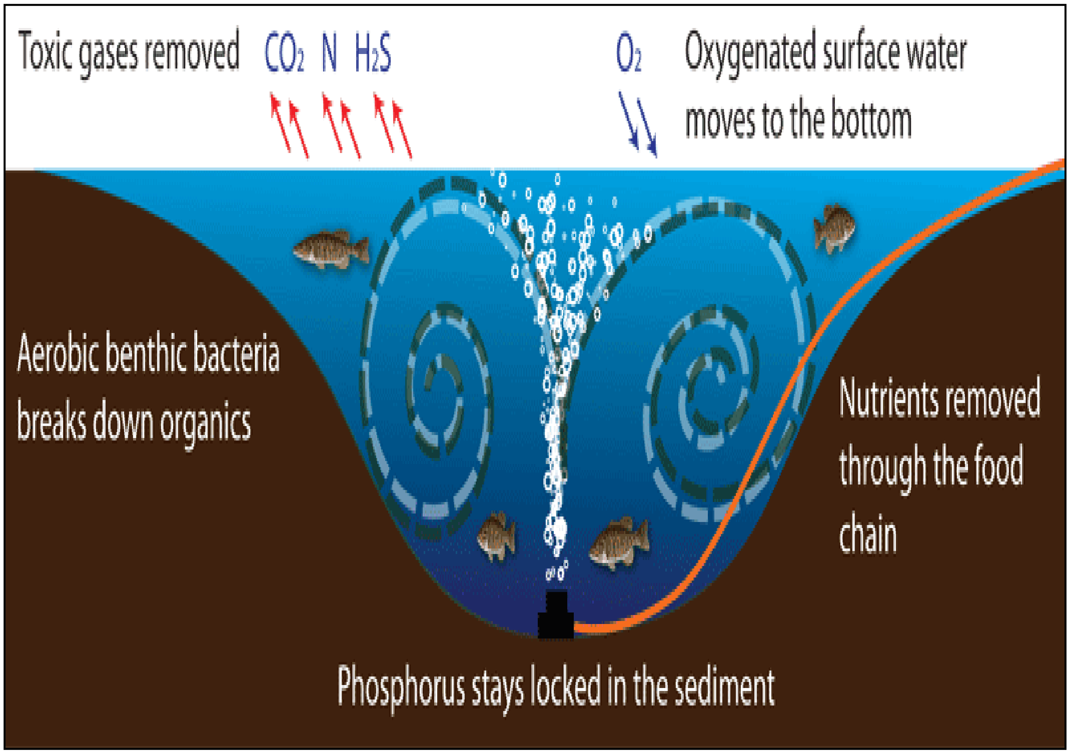


Figure 58. A diagram showing the laminar flow aeration mechanisms. ©Restorative Lake Sciences, LLC

7.1.6 Benthic Barriers and Nearshore Management Methods

The use of benthic barrier mats (Figure 59) or Weed Rollers (Figure 60) have been used to reduce weed growth in small areas such as in beach areas and around docks. The benthic mats are placed on the lake bottom in early spring prior to the germination of aquatic vegetation. They act to reduce germination of all aquatic plants and lead to a local area free of most aquatic vegetation. Benthic barriers may come in various sizes between 100-400 feet in length. They are anchored to the lake bottom to avoid becoming a navigation hazard. The implementation of a benthic barrier mat requires a minor permit from the MDEQ which can cost around $50-$100. The cost of the barriers varies among vendors but can range from $100-$1,000 per mat. Benthic barrier mats can be purchased online at: www.lakemat.com or www.lakebottomblanket.com. The efficacy of benthic barrier mats has been studied by Laitala et *al.* (2012) who report a minimum of 75% reduction in invasive milfoil in the treatment areas.

Lastly, benthic barrier mats should not be placed in areas where fishery spawning habitat is present and/or spawning activity is occurring. These may be useful in beach areas around Cedar Lake.

Weed Rollers are electrical devices that utilize a rolling arm which rolls along the lake bottom in small areas (usually not more than 50 feet) and pulverizes the lake bottom to reduce germination of any aquatic vegetation in that area. They can be purchased online at: www.crary.com/marine or at: www.lakegroomer.net. They would also be useful for controlling nuisance growth in nearshore and beach areas. They are more costly than benthic barriers.

Both methods are useful in recreational lakes such as Cedar Lake and work best in beach areas and near docks to reduce nuisance aquatic vegetation growth.

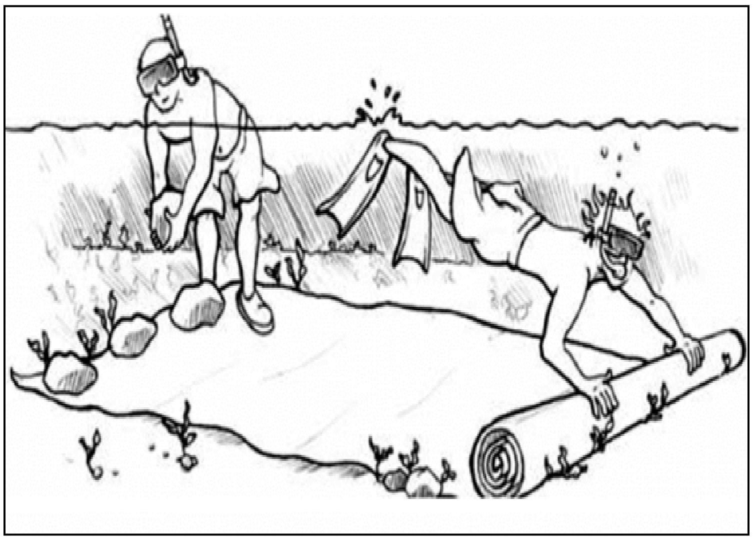


Figure 59. A Benthic Barrier. Photo courtesy of Cornell Cooperative Extension.

Figure 60. A Weed Roller.

7.1.7 Boat Launch Washing Station

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. Cedar Lake was noted to be infested with Zebra Mussels in 1998. 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. The CLRA should consider construction of a volunteer boat washing station that is voluntary for incoming and exiting boaters (Figure 61). 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 educational program 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. Once a boat washing station is in place on Cedar Lake, the CLRA should work 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 use the washing station.

Figure 61. A boat washing station on a Michigan inland lake (©RLS).

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

1) MLSA: www.mymlsa.org/aquatic-invasive-species
2) MDEQ: www.mi.gov/aquaticinvasives
3) MDNR: www.mi.gov/invasivespecies
4) MISIN: www.misin.msu.edu
5) Stop Aquatic Hitchhikers!: www.protectyourwaters.net

7.2 Cedar Lake Watershed Management Methods

In addition to the proposed treatment of Hybrid Watermilfoil and emergent invasives in and around Cedar Lake, it is recommended that Best Management Practices (BMP's) be implemented to improve the lake's water quality. The guidebook, Lakescaping for Wildlife and Water Quality (Henderson et *al*. 1998) provides the following guidelines:

1) Maintenance of brush cover on lands with steep slopes (those > 6% grade; see Cedar Lake soils map)
2) Development of a vegetation buffer zone 25-30 feet from the land-water interface with approximately 60-80% of the shoreline bordered with vegetation
3) Limiting boat traffic and boat size to reduce wave energy nearshore and thus erosion potential
4) Encouraging the growth of dense shrubs or native emergent shoreline vegetation to control erosion
5) Using only <u>native</u> genotype plants (those native to Cedar Lake or the region) around the lake since they are most likely to establish and thrive than those not acclimated to growing in the area soils

The book may be ordered online at: http://www.web2.msue.msu.edu/bulletins/mainsearch.cfm.

7.2.1 Cedar Lake Erosion and Sediment Control

The construction of impervious surfaces (i.e. paved roads and walkways, houses) should be minimized and kept at least 100 feet from the lakefront shoreline to reduce surface runoff potential. In addition, any wetland areas around Cedar Lake should be preserved to act as a filter of nutrients from the land and to provide valuable wildlife habitat. Construction practices near the lakeshore should minimize the chances for erosion and sedimentation by keeping land areas adjacent to the water stabilized with rock, vegetation, or wood retaining walls. This is especially critical in areas that contain land slopes greater than 6%. Erosion of land into the water may lead to increased turbidity and nutrient loading to the lake. Seawalls should consist of rip-rap (stone, rock), rather than metal, due to the fact that rip-rap offers a more favorable habitat for lakeshore organisms, which are critical to the ecological balance of the lake ecosystem. Rip-rap should be installed in front of areas where metal seawalls are currently in use. The rip-rap should extend into the water to create a presence of microhabitats for enhanced biodiversity of the aquatic organisms within Cedar Lake. The emergent aquatic plant, *Scirpus* sp. (Bulrushes) present around Cedar Lake offers satisfactory stabilization of shoreline sediments and assists in the minimization of sediment release into the lake.

7.2.2 Cedar Lake Nutrient Source Control

Based on the high ratio of nitrogen to phosphorus (i.e. N: P > 15), any additional inputs of phosphorus to the lake are likely to create additional algal and aquatic plant growth. Accordingly, RLS recommends the following procedures to protect the water quality of Cedar Lake:

1) Avoid the use of lawn fertilizers that contain phosphorus (P). P is the main nutrient required for aquatic plant and algae growth, and plants grow in excess when P is abundant. When possible, water lawns with lake water that usually contains adequate P for successful lawn growth. If you must fertilize your lawn, assure that the middle number on the bag of fertilizer reads "0" to denote the absence of P. If possible, also use low N in the fertilizer or use lake water. Fortunately, there exists a county ordinance where P fertilizers are not allowed. Individual riparians should never use P in fertilizers since it will create more algae and weed growth in the lake over time. Nitrogen is actually the most mobile nutrient in the groundwater that eventually enters the lake and causes enhanced aquatic vegetation growth.
2) Preserve riparian vegetation buffers around lake (such as those that consist of Cattails, Bulrushes, and native Swamp Loosestrife), since they act as a filter to catch nutrients and pollutants that occur on land and may run off into the lake. As an additional bonus, Canada geese (*Branta canadensis*) usually do not prefer lakefront lawns with dense riparian vegetation because they are concerned about the potential of hidden predators within the vegetation.
3) Do not burn leaves near the lake shoreline since the ash is a high source of P. The ash is lightweight and may become airborne and land in the water eventually becoming dissolved and utilized by aquatic vegetation and algae.
4) Assure that all areas which drain into the lake from the surrounding land are vegetated and that no fertilizers are used in areas with saturated soils.
5) If septic tank systems are in use, then annual pumping and cleaning is recommended since drainfield water eventually enters the groundwater and enters the lake. This can also lead to accelerated aquatic weed growth.

8.0 CEDAR LAKE IMPROVEMENT CONCLUSIONS & RECOMMENDATIONS

The information given above for the long-term management of Cedar Lake should be considered for effective management and ultimate protection of the lake native aquatic plants and fisheries. The overall goal of this proposed management program is to conduct whole-lake surveys and scan the lake each year to determine changes in aquatic vegetation communities with time and use that detailed data to make annual management recommendations to effectively control invasive aquatic plant species and preserve native aquatic plant species and the lake fishery. Table 11 below describes the primary and secondary goals and locations for the proposed improvement methods. The following recommendations can be made for the proposed 5 year program:

1) The use of aquatic chemical herbicides are regulated by the MDEQ under Part 33 (Aquatic Nuisance) of the Natural Resources and Environmental Protection Act, P.A. 451 of 1994, and requires a permit. 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. Wherever possible, it is preferred to use a granular systemic aquatic herbicide for longer-lasting, localized aquatic plant control.

The use of Sculpin G® or Renovate OTF LZR® is recommended for the spot-treatment of invasive hybrid watermilfoil throughout Cedar Lake. In areas where herbicides are not desired, the use of a DASH boat could be executed. This is costly though and generally ranges from $1,000-$3,000 per acre.

2) If the boat washing station is implemented, then an educational program executed by the CLRA is recommended. This program would include the elements described above that support the Clean Waters Clean Boats program.
3) Water quality parameters as noted above should be monitored in the lake during the program to continue to measure trends in the water quality and determine if any water quality corrective measures are needed in the future (i.e. Nutrient reduction).
4) Whole-lake surveys and an annual scan will be executed each year to accurately compare the changes in weed bed size and invasive species polygons in the lake over time. Surveys will result in lake scans of aquatic vegetation biovolume, sediment hardness, and maps showing the locations of all invasive species and their relative abundance. In addition, relative abundance of aquatic plants will assessed to assure the macrophyte biodiversity remains favorable for the ecological balance of the lake.
5) Utilization of benthic barriers and/or Weed Rollers are recommended in nearshore and beach areas of Cedar Lake to reduce nuisance native growth in those areas. These methods are employed in early spring before weed germination can occur. They are a cost-effective way of reducing the vegetation without the need for herbicide treatments in beach areas.
6) Implementation of a laminar flow aeration system in the deepest basins of the lake is recommended to increase dissolved oxygen with depth, reduce nutrients in the water column and nutrient release from the bottom, and ultimately reduce excessive aquatic vegetation growth through reduction of nutrients.
7) Hand-pulling and removal of the emergent invasives such as Phragmites and Purple Loosestrife is recommended over herbicide treatment but will require a volunteer program. This will remove the plants at the roots and prevent further spread.

Table 11. Proposed lake improvement methods for Cedar Lake's improvement plan.

Lake Management Activity	Primary Goal	Secondary Goal	Best Locations to Use
Aquatic herbicide treatment of hybrid milfoil	To reduce areas where the milfoil is present	To prevent these areas from spreading in the lake	Throughout entire lake
Suction Harvesting	To remove selective areas of dense invasive milfoil in growth areas without herbicides	To reduce dependency on chemical herbicides	Where milfoil polygons are dense or prevalent
Benthic Barriers/Weed Rollers	To prevent germination of nuisance weeds in beach/nearshore areas	To reduce dependency on chemicals in nearshore areas	Lakefront beach areas
Laminar Flow Aeration/Bioaugmentation	To increase dissolved oxygen in the deep basins and reduce nutrients	To facilitate a better environment for the lake fishery after stratification	3 deep basins in lake
Lake Vegetation Surveys/Scans	To determine % cover by invasives and all biodiversity and use as data tool	To compare year to year reductions in nuisance vegetation areas	Throughout entire lake in spring/summer and as needed after treatments
Hand-Removal of Emergent Invasives (Phragmites and Purple Loosestrife)	To remove invasive emergents without the use of herbicides	To reduce potential of further spread of the emergent invasives	In locations identified in this study/plan
Boat Washing Station	To clean boats of invasives before entering the lake	To educate boaters on the proper cleaning of boats and on invasives	At main boat launch access site
Water Quality/Sediment Monitoring	To troubleshoot areas that have poor water quality	To compare trend in water quality parameters with time	Throughout lake

8.1 Cost Estimates for Cedar Lake Improvements

The proposed lake improvement program for the improvements of Cedar Lake would begin during the 2018 season and continue through 2022. The reduction in acres of Hybrid Watermilfoil and emergent invasives would likely follow in 2018 and beyond and thus that portion of the annual budget may be spared and a surplus may continue in future years.

The line items including the contact herbicides and permit fees will likely exist annually due to the temporary nature of contact herbicides on pondweeds and some groups of aquatic plants. A breakdown of estimated costs associated with the various treatments in Cedar Lake is presented in Table 12. It should be noted that proposed costs are estimates and may change in response to changes in environmental conditions (i.e. increases in aquatic plant growth or distribution, or changes in herbicide costs). In addition, costs for benthic barriers and Weed Rollers would likely be the responsibility of each riparian land owner. If laminar flow aeration is desired, then cost estimates would need to be obtained from qualified vendors and the proposed annual budget would need to be modified to include that technology.

Table 12. Proposed lake improvement costs for a five year lake improvement program for Cedar Lake, Van Buren County, Michigan.

Proposed Cedar Lake Management Improvement Item	***Estimated 2018 Cost***	***Estimated 2019 Cost***	***Estimated 2020-2022 Cost***
Herbicides for Hybrid Watermilfoil and/or DASH Boat removal of invasives, hand-pulling of emergents, Permit Fees[1]	$10,000	$9,500	$9,000
Volunteer Boat Washing Station	$TBD	$TBD	$TBD
Professional Limnologist Services (limnologist surveys, water quality sampling, contractor oversight, education—see below)[2]	$8,500	$8,500	$8,500
Laminar flow aeration system of deep basins, permitting, electrical	$TBD	$TBD	$TBD
Contingency (10%)[3]	$TBD	$TBD	$TBD
TOTAL ANNUAL ESTIMATED COST	$TBD	$TBD	$TBD

[1] Herbicide treatment scope for the treatment of Hybrid Watermilfoil is proposed to decline annually due to aggressive treatment with the use of spot-treatment herbicides.
[2] Professional services includes annual GPS-guided, aquatic vegetation surveys, pre and post-treatment surveys for aquatic plant control methods, oversight and management of the aquatic plant control program, review of all invoices from contractors and others billing for services related to the improvement program, education of local riparians, and attendance at up to 3 regularly scheduled CLRA meetings. The annual lake consulting contract should be reviewed annually, based on performance and meeting of deliverables. There should also be a termination clause for either party if needed.
[3] Contingency is 10% of the total project cost, to assure that extra funds are available for unexpected expenses. Note: Contingency may be advised and/or needed for future treatment years.

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