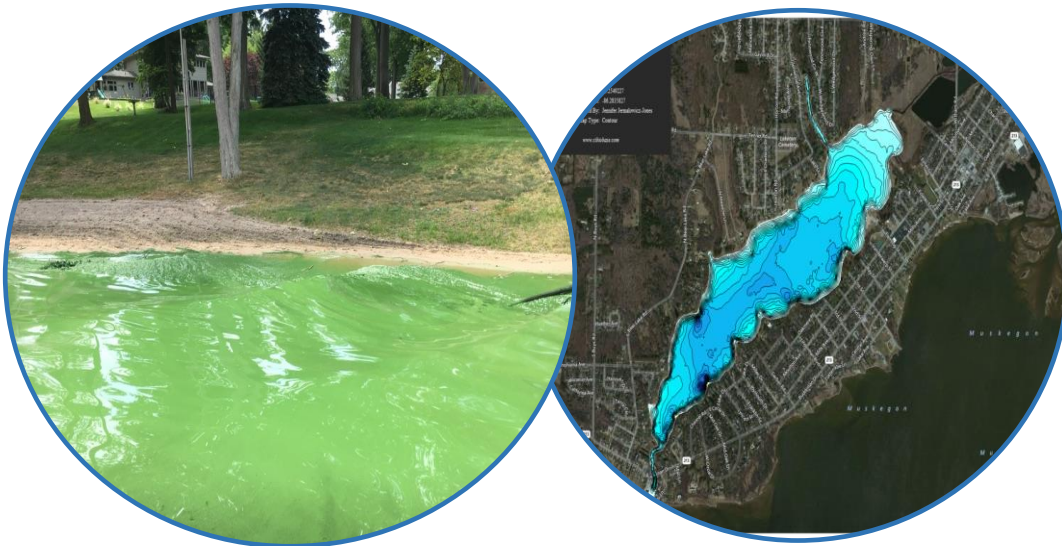




Bear Lake Improvement Feasibility Study and Lake Restoration Plan Muskegon County, Michigan



**Provided for: Bear Lake Lake Board
Pursuant to P.A. 451 of 1994, as amended**

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Bear Lake Improvement Feasibility Study and Lake Restoration Plan

July, 2017

1.0 EXECUTIVE SUMMARY

Bear Lake is a 415-acre drainage lake located in Laketon Township and the City of North Muskegon (T.12N R.16W). The lake has a mean depth of 9.9 feet and a maximum depth of 25.5 feet (RLS, 2017). The lake is polymictic which means that it continuously mixes multiple times per year. The residence time of water in the lake is short and around 78 days. The lake is classified as highly eutrophic (elevated nutrient levels) and is on the Muskegon Area of Concern (AOC) list as well as the Michigan 303(d) impaired water body list.

The lake has a Total Maximum Daily Load (TMDL) limit for phosphorus which was established by the United States Environmental Protection Agency (USEPA) through the Clean Water Act. Currently, the lake is not meeting the TMDL for phosphorus but watershed improvements are in place to try to accomplish that. This includes the recent restoration of the Celery Flats that drain into the lake at the east region. A previous study by Grand Valley State University (GVSU) estimated that the external loading of phosphorus exceeds that of internal loading and thus improvement efforts should focus more on external nutrient load reduction. Bear Creek and the nearby Celery Flats continue to contribute significant loads of nutrients to Bear Lake through an immediate watershed area of approximately 18,116 acres (RLS, 2017). In 2012, the West Michigan Shoreline Regional Development Commission (WMSRDC) received a grant to design a restoration program to rehabilitate the Flats and allow for optimum nutrient sequestration and wildlife habitat. In 2014, the Great Lakes Restoration Initiative (GLRI) and the National Oceanic Atmospheric Administration (NOAA) granted the funds needed to WMSRDC and the Great Lakes Commission (GLC) to complete the Flats restoration project. Other partners of this important project have included the Annis Water Resources Institute at Grand Valley State University (AWRI) and the Muskegon Lake Watershed Partnership (MLWP). Over the past few years, it has been reported that approximately 150,000 tons of sediment were removed and 36.4 acres of wetland have been restored. The wetland will grow in future years and allow for uptake of nutrients before they enter the lake. There may be contributions of nutrients such as phosphorus by the wetlands to the lake for some time. As a result, RLS is recommending the installation of biologically-active charcoal buffers where the Creek enters the lake and in receiving water areas near the Flats. These would be placed *in situ* and have been demonstrated to reduce phosphorus, nitrogen, and solids entering inland lakes that have flowing tributaries which empty large or agricultural watersheds.

Bear Lake has several water quality impairments including the following:

1. Reduced water clarity (Secchi measured in June/July of 2017 was 2.0-4.0 feet)
2. Excessive blue-green algal blooms (chlorophyll a concentrations from 5.0-11.0 $\mu\text{g L}^{-1}$)
3. Lack of plentiful native biodiverse aquatic plant communities (77% of the lake bottom lacked aquatic vegetation in June/July of 2017).
4. Presence of invasive aquatic plant species (including submersed hybrid Eurasian Watermilfoil and emergent *Phragmites* and Purple Loosestrife)
5. Elevated nutrient concentrations (phosphorus, ammonia nitrogen)
6. Low dissolved oxygen concentrations (depletion to 1.2 mg L^{-1} at depth)
7. Oil contamination in Fenner's Ditch and possibly other areas of the lake (detected in a sediment sample of the Ditch and also possibly at the deep basin as noted by a strong odor and sheen)
8. Low biodiversity of lake zooplankton and benthic macroinvertebrates which serve as the base of the lake food chain (limited presence of two species of zooplankton and Zebra Mussels being the dominant macroinvertebrate)

As a result of these impairments, multiple Best Management Practices (BMP's) and restoration methods are recommended for this important restoration program. A detailed description of these methods is given in Table 18 on page 93. These restoration items include:

1. Lake vegetation surveys and scans (Annually) and pre- and post-treatment surveys (may require multiple surveys per season)
2. Aquatic herbicide treatments of invasives such as hybrid Eurasian Watermilfoil and *Phragmites* (Annually) with the goal of treatment reductions over the years of the improvement program
3. Sampling of lake sediment cores for determination of petroleum, chlorides, and metals (First two years) to determine if laminar flow aeration (LFA)/bioaugmentation can be safely used in the near future
4. Sampling of lake, tributary, canal water quality (Annually) to build a working mass balance model in the near future (theoretical nutrient budget)
5. If Item #3 reveals that LFA is safe to use, implementation of a lake-wide LFA system with bioaugmentation
6. Implementation of tributary nutrient filters to reduce nutrient and sediment loads from the tributaries to the lake (Year 1 and ongoing)
7. Implementation of a simple boat washing station for boat launch users to rinse boats prior to entry and upon exit. This is to reduce the overall presence of invasives and prevent new ones from entering the lake.
8. Macroinvertebrate sampling of the lake benthic communities in Years 4-5 of the program to determine how the aforementioned BMP's have changed the benthic biota.

9. Implementation of an annual lake restoration workshop which provides riparians with hands-on learning and community engagement activities. Workshop would be held annually but riparians will be encouraged to attend regular BLLB meetings for educational information and opportunities.

RLS is confident that if the above-mentioned restoration methods are pursued, the lake water quality would be substantially improved. It is important to work from around the lake basin (watershed) as improvements are already in place, along with recommended tributary filters. Furthermore, it is also imperative to restore the lake water quality and biota through the use of lake basin restoration technologies such as the use of aeration and bioaugmentation. The total cost of the proposed restoration program is shown in Table 19 on page 95 of this report and varies each year due to changes in proposed methods each year of the program.

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 Bear Lake. The purpose of this study and report is to evaluate the current health of Bear Lake and provide scientifically-sound and affordable management options to the Bear 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. 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. Bear Lake may be categorized as a drainage lake as it receives external water supplies from the Bear Creek inlet and has an outlet which empties into Muskegon Lake at the west end of

the lake and eventually empties into Lake Michigan. The estimated hydrological retention time of water in Bear Lake is approximately 78 days.

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 aging “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.

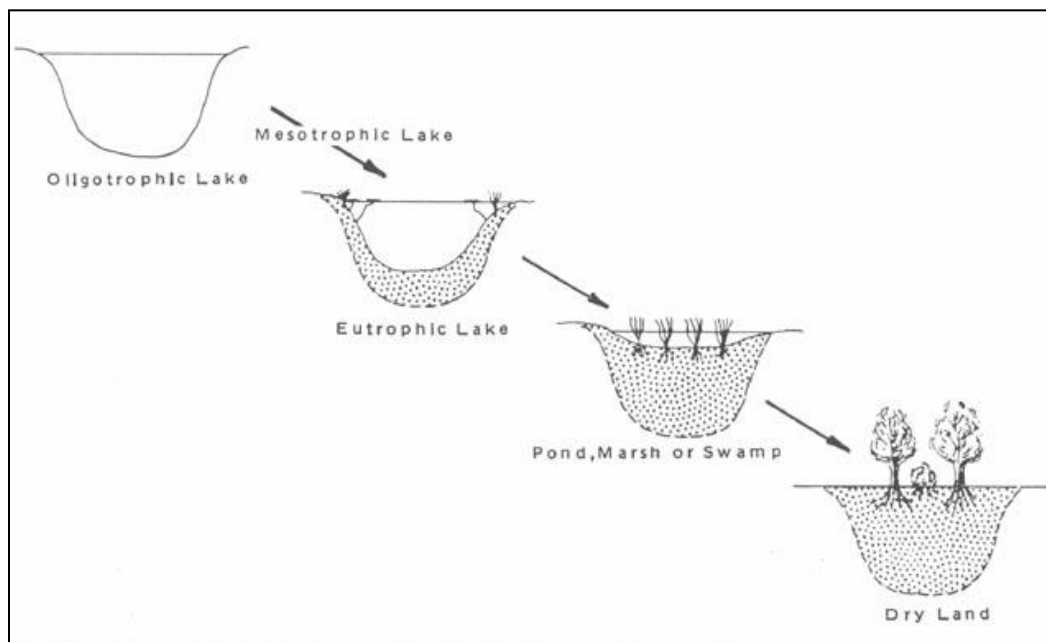


Figure 1. A diagram showing the lake aging (eutrophication) process.

2.1.3 *Biodiversity and Habitat Health*

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 man's influence from 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 BEAR LAKE PHYSICAL AND WATERSHED CHARACTERISTICS

3.1 The Bear Lake Basin

Bear Lake is located in Laketon Township and the City of North Muskegon, Michigan (T.10N, R.16W). The lake is approximately 415 acres in size and has an approximate maximum depth of 25.5 feet (RLS, 2017; based on modernized bathymetric mapping). The bathymetric scan utilized nearly 16,000 GPS sonar points to record the lake bottom (Figure 2). The mean depth of the lake is now estimated at 9.9 feet (RLS, 2017) at the current water level. The water volume was estimated at 3,878.7 acre-feet (RLS, 2017). The shoreline perimeter around Bear Lake is approximately 6.43 miles (RLS, 2017).

Bear Lake is considered eutrophic to hyper-eutrophic and is impaired by reduced water clarity, elevated harmful algal blooms, elevated nutrients, solids, and sedimentation, invasive aquatic plant species, petroleum pollution, and fish consumption advisories for polychlorinated biphenyls (PCB's) and Mercury.

The lake has a semi-consolidated lake bottom with a thick layer of black, organic flocculent material on the top layer. There is a combination of sand and organic matter as the primary sediment composition. The whole-lake bathymetric and benthic scan determined the locations of softer bottom (beige color) and firmer bottom (orange and red color) types throughout the lake bottom (Figure 3).



Figure 2. Bear Lake Depth Contour Map, Muskegon County, Michigan (RLS, 2017).



Figure 3. Bear Lake 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. The majority of the aquatic vegetation grows in areas dominated by soft bottom.

3.2 Bear 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 Bear Lake extended watershed lies just outside of the Muskegon River Watershed since the Muskegon River flows directly into Muskegon Lake but not Bear Lake. Bear Creek flows directly into Bear Lake at the northeast region of the lake. Thus, the extended watershed for Bear Lake has been called the Bear Creek and Bear Lake Watershed (Figure 4). The primary water bodies that flow into Bear Creek include Little Bear Creek, the Ribe Drain, the Furman Drain, the Brandstrom Drain, and the Pillon Staple tributary.

This extended watershed is approximately 30 mi² or 23,160 acres in area. This watershed envelopes five municipalities which includes the City of Muskegon, City of North Muskegon, Dalton Township, Cedar Creek Township, Muskegon Township, and Laketon Township. The watershed boundary begins just south of the Twin Lakes area and flows southward towards Muskegon Lake which empties into Lake Michigan at the west. Overall, the watershed has low grade slopes; however, the immediate watershed discussed below has much higher slopes, especially around the Bear Lake perimeter.

Watershed land use categorizes the many activities and land types that occur within the watershed and includes: forested land (44%), residential development or urban land (22%), agriculture (6%), wetlands (1%) and other land uses (27%; Bear Creek and Bear Lake Watershed Management Plan from the Muskegon Conservation District and the MDEQ NPS Program). The primary land uses present in the Bear Lake extended watershed include forests and wetlands, agriculture, and developed (residential and commercial) land. There are also oil fields to the north and west of Bear Lake which lie in the vicinity of the immediate watershed. There is an active Bear Creek and Bear Lake Watershed Management Plan Program that includes implementation of best management practices (BMP's) in the watershed which includes reduction of nutrients, storm water pollutants, and sediments to Bear Lake. The goals developed for the watershed management plan program will be additionally supported by the goals of the Bear Lake Lake Board (BLLB) for improving the water quality and reducing thermal pollution, reducing sedimentation to the lake, improving aquatic vegetation biodiversity, and the overall health of Bear Lake.

The immediate watershed area is approximately 18,116 acres in area (Restorative Lake Sciences, 2017; Figures 5a and 5b). This area excludes the Twin Lakes area since the immediate watershed is based on direct runoff contributions. The immediate watershed is approximately 44 times larger than the size of Bear Lake, which indicates the presence of a large-sized immediate watershed.



Figure 4. Extended Bear Creek and Bear Lake Watershed (www.activerain.com, online resource).



Figure 5a. Immediate Watershed draining into Bear Lake, Muskegon County, Michigan (Restorative Lake Sciences, 2017).

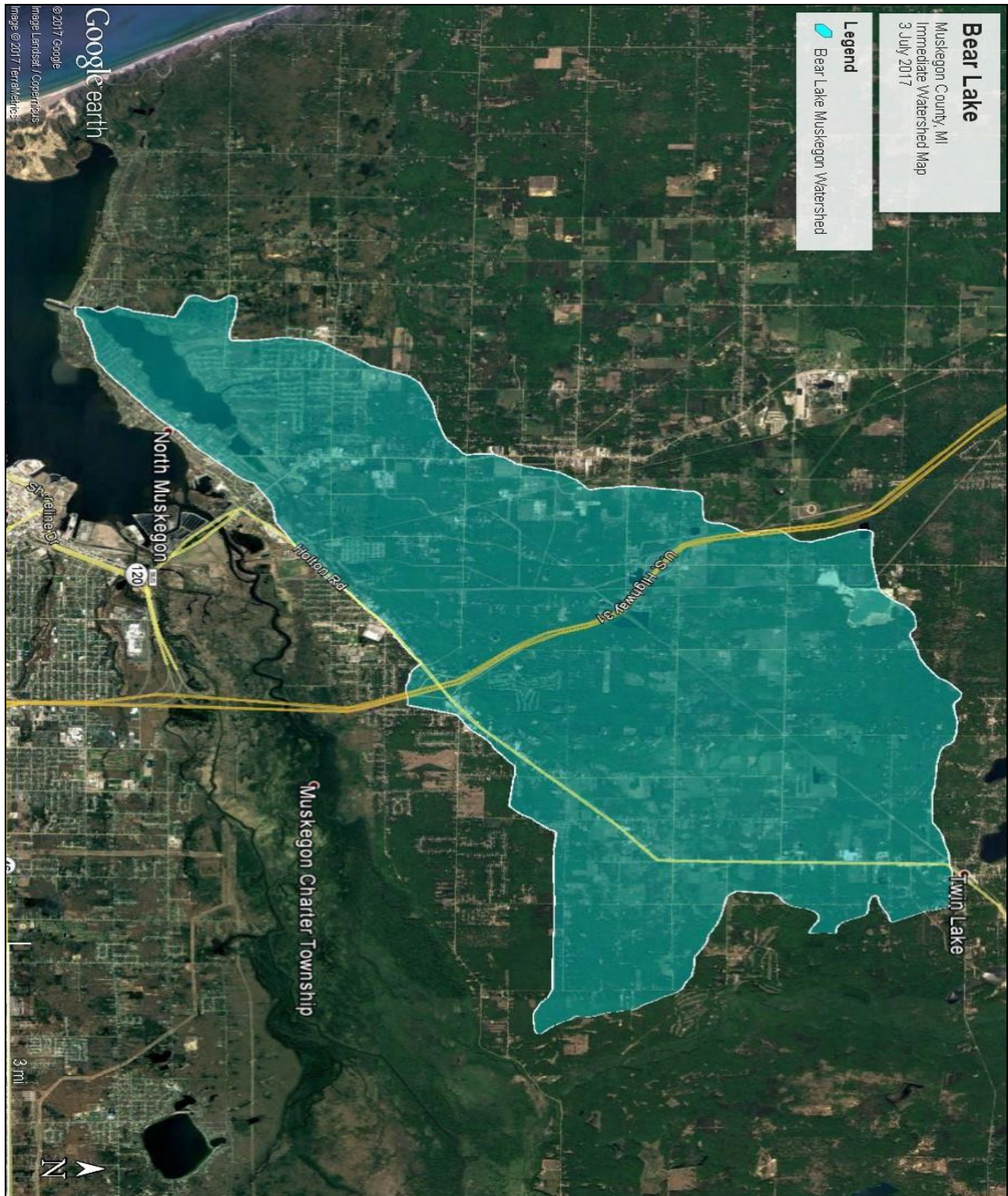


Figure 5b. Immediate Watershed draining into Bear Lake, Muskegon County, Michigan (Restorative Lake Sciences, 2017).

3.3 Bear Lake Shoreline Soils

There are 7 major soil types immediately surrounding Bear Lake that 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 Bear Lake. Major characteristics of the dominant soil types directly surrounding the Bear Lake shoreline are discussed below. The major characteristics of each soil type are listed in Table 1 below.

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

<i>USDA-NRCS Soil Series</i>	<i>General Characteristics</i>
Plainfield-Metea-Spinks Complex, 35-60% slopes	Sandy, very deep, excessively drained, erosion prone
Plainfield Sand, High Ecological Site, 30-50% slopes	Sandy, very deep, excessively drained, erosion prone
Saranac Loam	Very deep, poorly drained, loams and clays, runoff prone
Plainfield Sand, Lake Plain, 6-18% slopes	Very deep, excessively drained, erosion prone
Marsh	Organic (peat), poorly drained, high runoff
Kerston Muck	potential Organic, very deep, very poorly drained, high runoff potential
Covert-Pipestone Sands, 0-6% slopes	Sandy, Very deep, well to poorly drained, moderate to low runoff potential



The majority of the soils around Bear Lake are well drained soils such as sands but with high slopes. Areas of high slopes (>6%), can be as elevated risk factor for erosion if the area is left non-vegetated. Also, in areas with high slope, soil can enter the lake basin during intense rainfall events and create problems with turbidity and nutrient loading.

The presence of mucky soils near the wetland areas of the lake make those areas prone to failing septic tank seepage from past implementation, and also are prone to ponding during intense rainfall events. Ponding occurs when water cannot permeate the soil and accumulates on the around 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.

3.4 Bear Lake Oil Fields

In the region surrounding Bear Lake, there are an abundance of old oil wells with an estimated count of over 620 wells covering an area of 28 mi² in Laketon Township, the City of North Muskegon, and Muskegon (Muskegon County Oil Field Working Group). The majority of these wells were commissioned in the 1920's and are between 1,500-2,000 feet below ground. The presence of crude oil has been encountered while drilling a drinking well and there is concern about possible migration of the oil into groundwater. There is also concern regarding the presence of oil leaking into Fenner's Ditch from below the surface. RLS confirmed the presence of oil in a sediment sample collected in the center of the Fenner's Ditch Canal (Figure 7). The smell of oil was also detected in the deep basin sediment sample. As a result of these findings, RLS is recommended rigorous sediment core sampling be conducted throughout the Bear Lake Basin to determine the extent of any oil presence which may ultimately affect the implementation of specific lake basin improvement technologies discussed later in this study report.

Fenner's Ditch is a canal at the north shore of Bear Lake and measures approximately 0.34 miles in length. An oil boom was placed in an area of oil seepage as necessitated by the Michigan Department of Environmental Quality (MDEQ) and the USEPA through the Oil Pollution Act (Figure 8). The seepage is presumably due to an improperly abandoned oil well that was drilled and plugged in the 1930's. Unfortunately, the existing borehole cannot be located due to a lack of steel casing. The MDEQ and USEPA are currently working on a longer-term strategy to contain the oil and hopefully eliminate its discharge in the near future. This discharge may be having a negative impact on aquatic biota in the lake including aquatic plants, algae, and animals that are a vital component of the lake ecosystem (Figure 9).

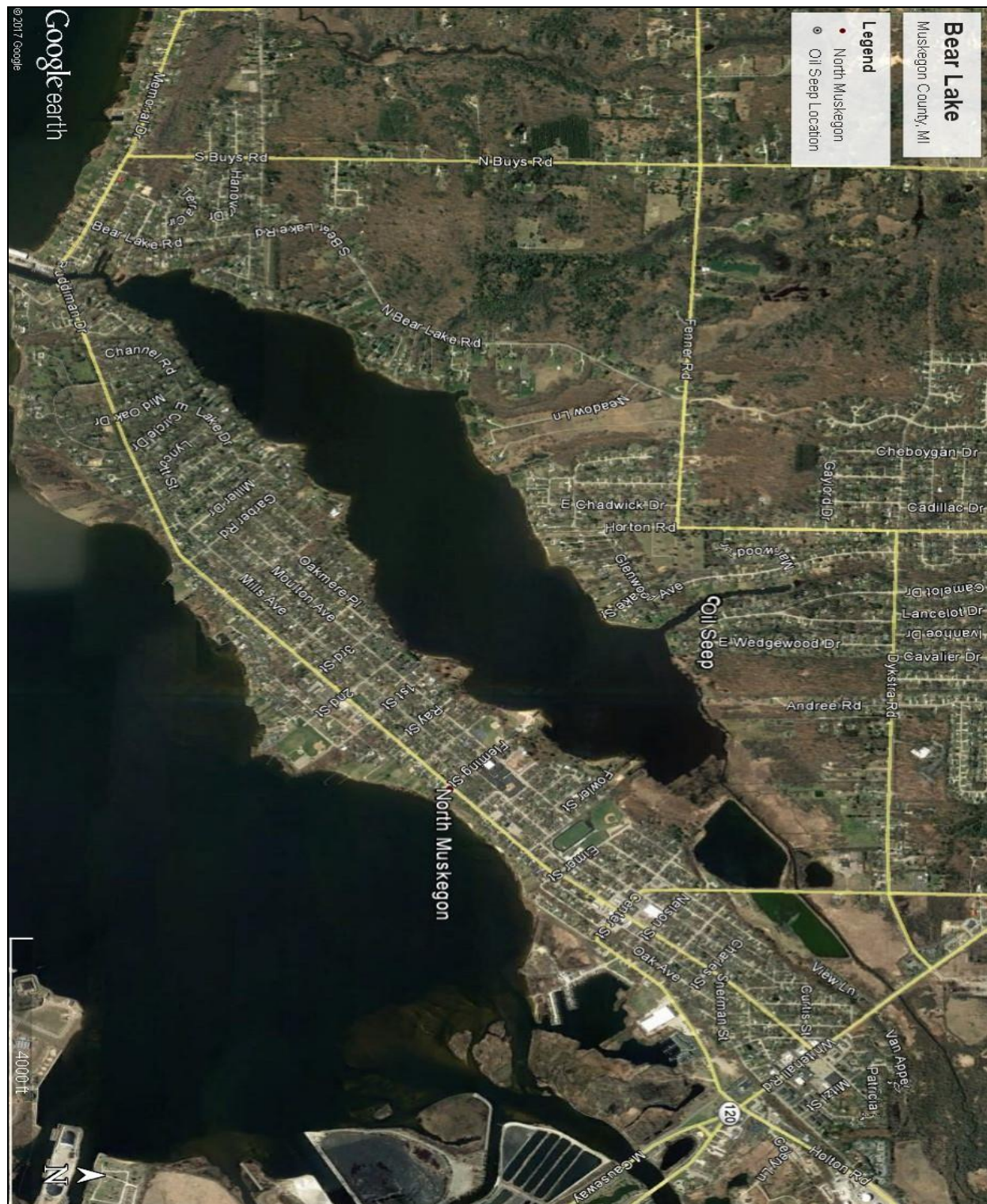


Figure 7. Aerial photo of Fenner's Ditch on Bear Lake (RLS, 2017).



Figure 8. An oil boom in place to reduce oil seepage from a property in Fenner's Ditch (RLS, 2017).



Figure 9. Oil seeping from Fenner's Ditch and collecting on algae (RLS, 2017).

4.0 BEAR LAKE WATER & SEDIMENT 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. Bear Lake is classified as eutrophic due to having elevated total phosphorus, chlorophyll-*a*, and low Secchi transparency.

Table 2. Lake Trophic Status Classification Table (MDNR)

<i>Lake Trophic Status</i>	<i>Total Phosphorus</i> <i>($\mu\text{g L}^{-1}$)</i>	<i>Chlorophyll-<i>a</i></i> <i>($\mu\text{g L}^{-1}$)</i>	<i>Secchi Transparency</i> <i>(feet)</i>
Oligotrophic	< 10.0	< 2.2	> 15.0
Mesotrophic	10.0 – 20.0	2.2 – 6.0	7.5 – 15.0
Eutrophic	> 20.0	> 6.0	< 7.5

4.1 Water Quality Parameters

Parameters such as, but not limited to, dissolved oxygen, water temperature, conductivity, total dissolved and suspended solids, pH, total alkalinity, total phosphorus, total nitrogen, chlorophyll-*a*, algal composition, and Secchi transparency, are critical indicators of water quality. On June 3, 2017 and July 3, 2017, RLS collected water samples from within the two deepest basins in Bear Lake (Figure 10). Additionally, water samples were also collected from the Bear Creek tributary and the inlet area near the terminal end of Fenner's Ditch (Figure 11). Four additional drains were located around the lake (Figure 12) but were not flowing at the time of sampling and thus samples at those sites could not be collected. Dominant algal taxa found in the deep basin samples are listed in Table 3. The results for the deep basins are discussed below and are presented in Tables 4-11. Tributary/inlet data are presented in Tables 12-13. Whenever possible, historical trend data are

discussed to show the changes in a particular water quality parameter with time. RLS recommends more modernized water quality data be collected over the next few years to generate a sound theoretical nutrient budget which would address the existing loads of phosphorus, nitrogen, and solids in the lake and entering the lake.

All water samples were collected on with the use of a Van Dorn horizontal water sampler at specific depths. All water quality physical parameters were measured with a calibrated Eureka Manta 20® multi-meter probe with parameter electrodes, respectively. All sediment samples were collected with an Ekman hand dredge. Chlorophyll-a was measured *in situ* with a calibrated chlorophyll-a meter from Turner Designs®. Algal community composition analysis was conducted using a phase-contrast light compound microscope with Sedgewick Rafter counting cells to determine relative abundance. All other water quality samples were analyzed at NELAC-certified Trace Analytical Laboratories, Inc. in Muskegon, Michigan.

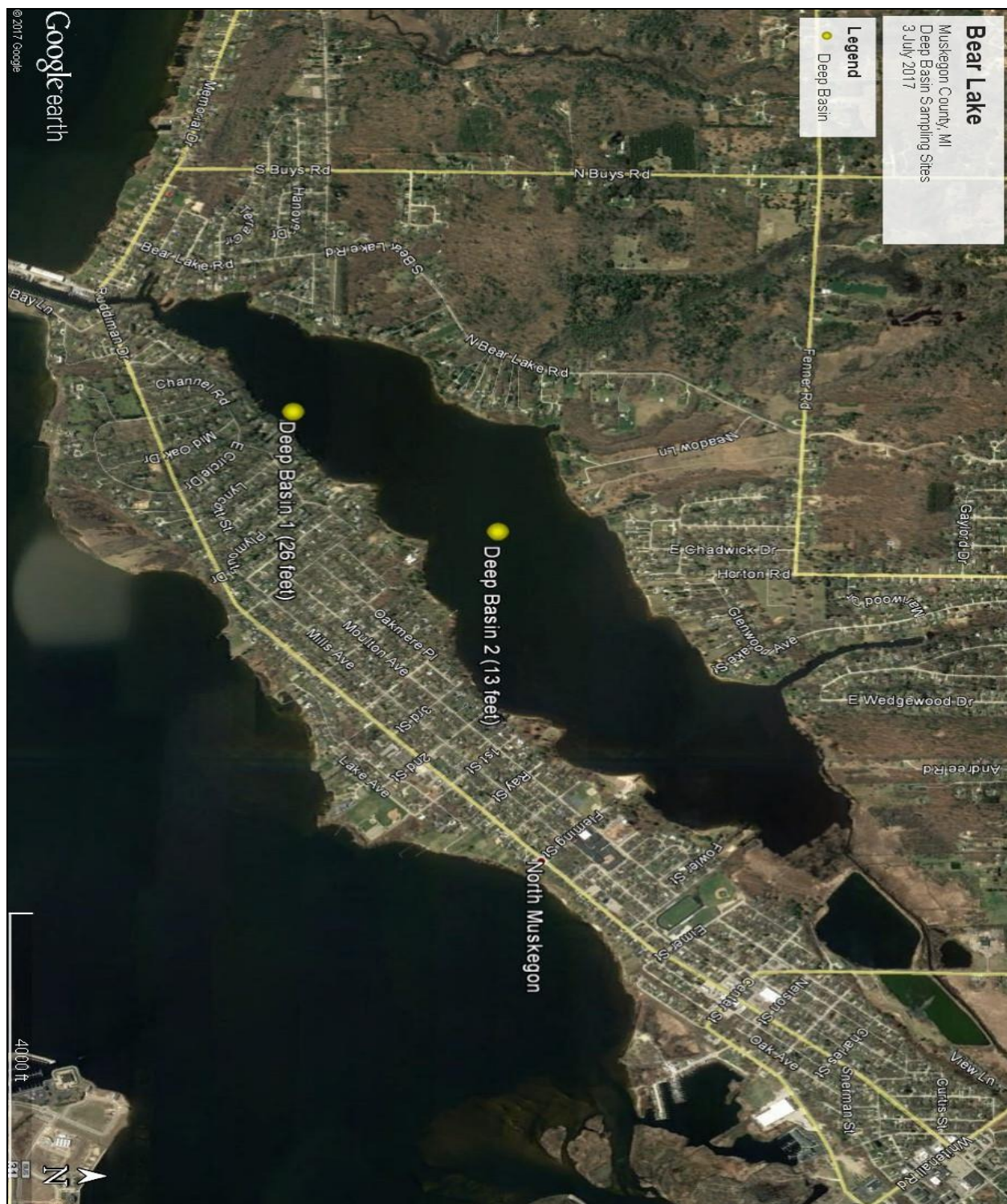


Figure 10. Water quality sampling locations for the Bear Lake deep basins (RLS, 2017).

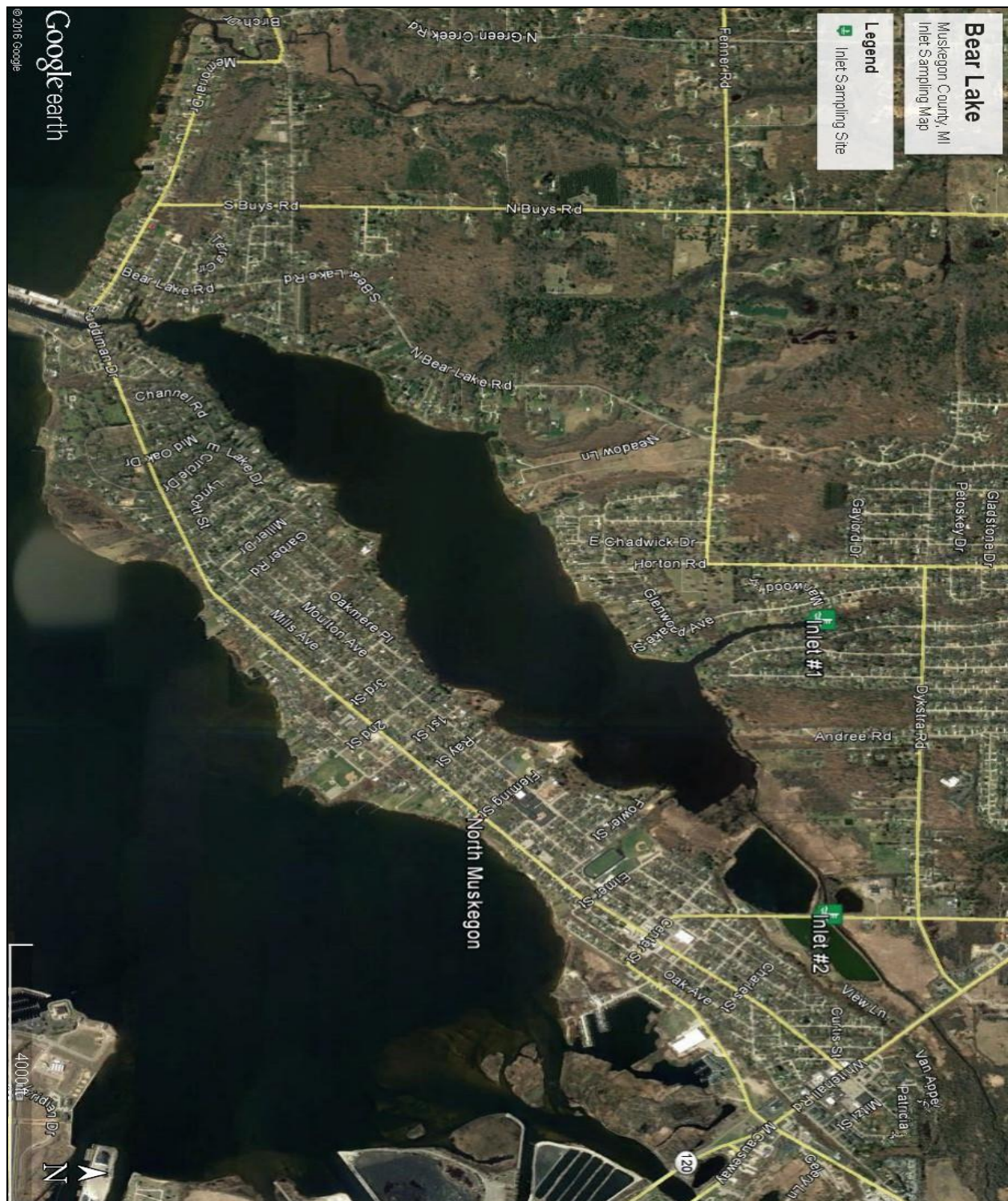


Figure 11. Inlet/tributary sampling locations on Bear Lake (RLS, 2017).

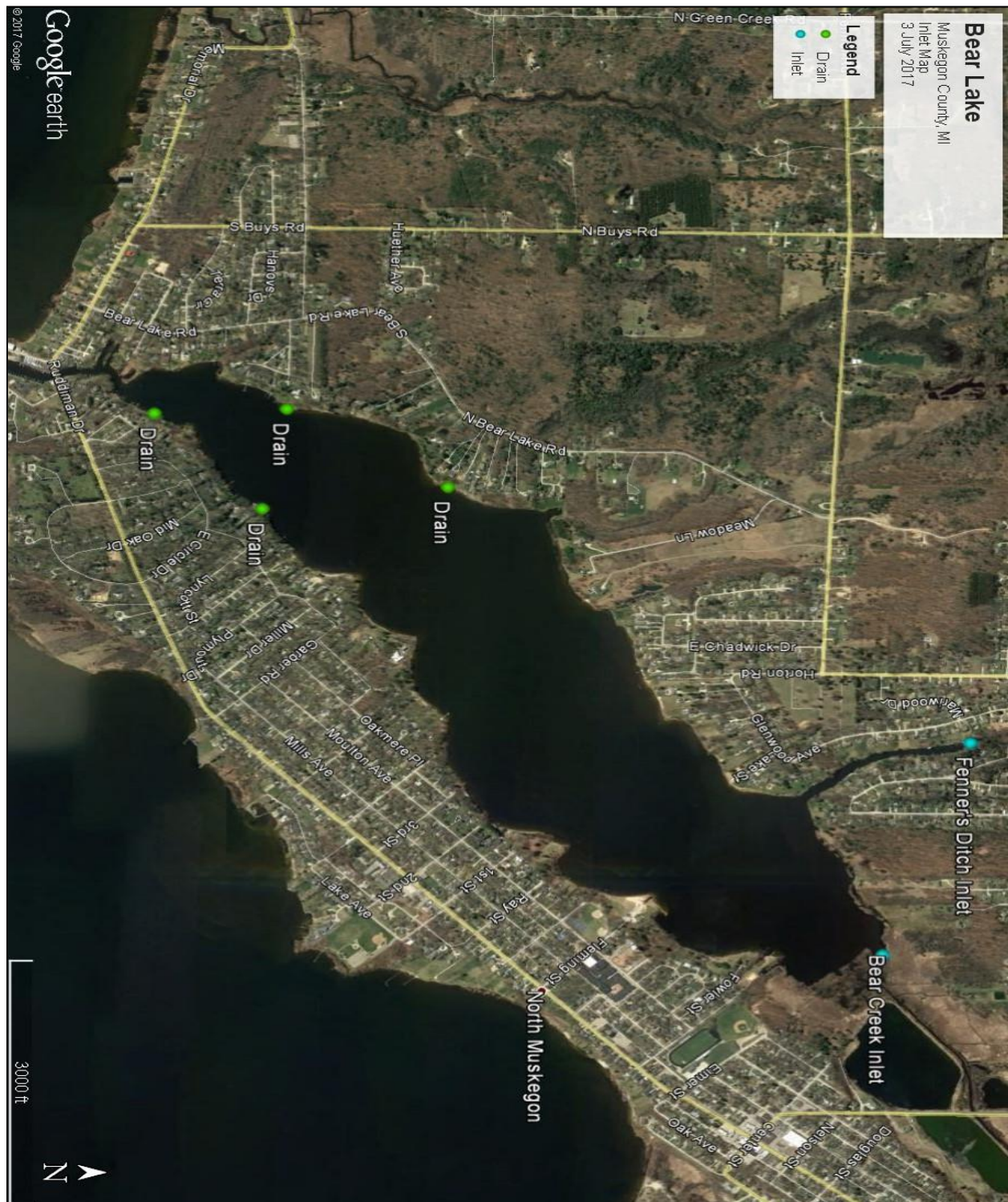


Figure 12. Water quality sampling locations for the inlet and drains (RLS, 2017).

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⁻¹ 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⁻¹) with the use of a calibrated Eureka Manta 20® 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 June, 2017 sampling event ranged from 9.0-1.2 mg L⁻¹, with concentrations of dissolved oxygen higher at the surface and lower at the bottom. The dissolved oxygen concentrations during the July, 2017 sampling event ranged from 10.0-3.0 mg L⁻¹ with the lower concentrations near the bottom of the deepest basin. The dissolved oxygen of the tributaries ranged from 9.8-8.6 mg L⁻¹ which is notably higher than the lake concentrations. All of these concentrations are likely higher (based on historical data) in the spring due to cooler water temperatures which hold more oxygen. Anoxic conditions have been reported by GVSU and the MDEQ in previous years near the lake bottom. Since the lake is polymictic, however, the dissolved oxygen may rise from dusk to dawn on a daily basis.

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 13). 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. Water temperature was measured in degrees Fahrenheit (°F) with the use of a calibrated submersible thermometer electrode. The June 3, 2017 water temperatures of Bear Lake demonstrated a weak thermocline with a temperature difference of 0.9°F in the shallower basin and a temperature difference of 4.4°F from the surface to the bottom in the deepest basin. During the July 3, 2017 sampling event, the shallow basin demonstrated a temperature difference of 3°F from the surface to the bottom and the deep basin demonstrated a temperature difference of 5.2°F from the surface to the bottom. The water temperatures of the tributaries were slightly lower due to higher flow.

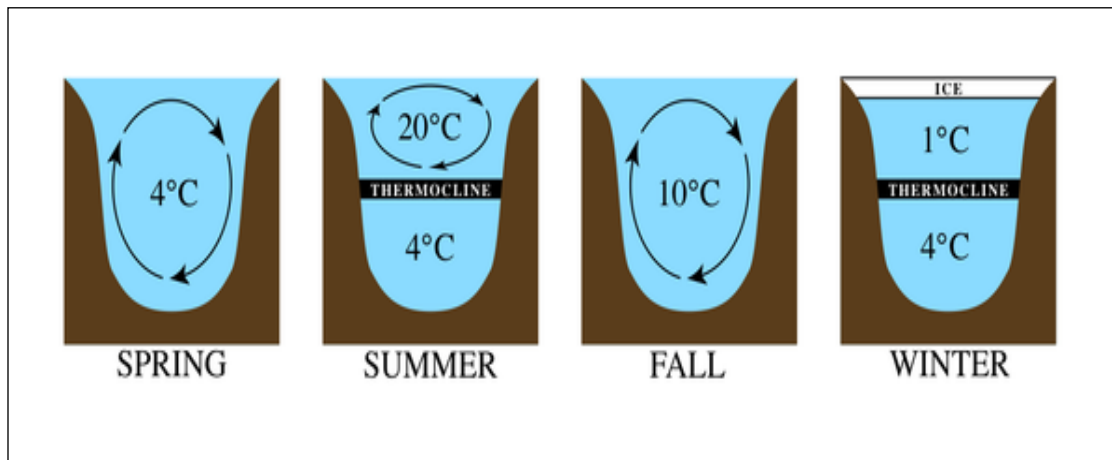


Figure 13. Diagram showing the process of stratification and turnover in lakes. Note: Bear Lake likely has multiple turn-over events in a given season due to the shallow depths and wind that induces constant mixing of the lake water.

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. Conductivity generally increases with the amount of dissolved minerals and salts in a lake. Specific conductivity was measured in micro Siemens per centimeter ($\mu\text{S cm}^{-1}$) with the use of a calibrated conductivity probe meter. The range in specific conductivity for Bear Lake deep basins was 325-372 mS cm^{-1} during the two sampling events. The range of specific conductivity for the tributaries was 304-464 mS cm^{-1} . These values are moderate for an inland lake and mean 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 Bear 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.

4.1.4 Total Dissolved Solids and Total Suspended Solids

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^{-1} . Spring values are usually higher due to increased watershed inputs from spring runoff and/or increased planktonic algal communities. The range in TDS in Bear Lake was 223-236 mg L^{-1} for the deep basins during the two sampling events, which is moderate for an inland lake. The TDS of the tributaries averaged 244 mg L^{-1} with the highest value recorded at Bear Creek in April, 2017. It is not uncommon for shallow waters to have higher values due to concentration of

dissolved solids in less water volume. The preferred range for TDS in surface waters is between 0-1,000 mg L⁻¹.

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 TSS samples measured in the Bear Lake tributaries were all <10 mg L⁻¹ which were favorable.

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 Bear Lake water has been stable over time and ranged from 7.6-8.8 S.U. during the two 2017 sampling events. The lower pH values were noted at the bottom of the deep basins. The mean pH of the tributaries during the two sampling events ranged from 7.6-8.4 S.U.

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⁻¹ of CaCO₃) are able to tolerate larger acid inputs with less change in water column pH. Many Michigan lakes contain high concentrations of CaCO₃ and are categorized as having “hard” water. Total alkalinity was measured in milligrams per liter of CaCO₃ through an acid titration method. The total alkalinity of Bear Lake is considered “moderate” (≤ 120 mg L⁻¹ of CaCO₃), and indicates that the water is neither hard nor soft. Total alkalinity in the deep basins ranged from 89-120 mg L⁻¹ of CaCO₃ during the two sampling events in 2017. Historical data on this parameter is lacking. 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.

4.1.7 Total Nitrogen

Total Kjeldahl Nitrogen (TKN) is the sum of nitrate (NO₃⁻), nitrite (NO₂⁻), ammonia (NH₄⁺), 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^{-1} may be classified as oligotrophic, those with a mean TKN value of 0.75 mg L^{-1} may be classified as mesotrophic, and those with a mean TKN value greater than 1.88 mg L^{-1} may be classified as eutrophic. The mean TKN concentration in Bear Lake during the June 3, 2017 sampling event averaged 1.0 mg L^{-1} , which is moderately low for an inland lake. That number rose to 1.8 mg L^{-1} for the July 3, 2017 sampling event, which is still favorable. The fraction of ammonia nitrogen however, was abundant at a mean of 0.060 mg L^{-1} which means that an abundance of ammonia nitrogen is present to fuel blue-green algae growth and is also produced by the blue-green algae during nitrogen fixation. The tributaries had a mean of 0.6 mg L^{-1} of nitrogen and a mean of 0.011 mg L^{-1} of ammonia which was lower than the concentrations present in the lake. Historical data on this parameter is lacking.

4.1.8 Total 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 $20 \text{ } \mu\text{g L}^{-1}$ 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 micrograms per liter (mg L^{-1}) with the use of a chemical auto analyzer. The mean TP concentration in the deep basins of Bear Lake was 0.038 mg L^{-1} on June 3, 2017 and 0.061 mg L^{-1} on July 3, 2017. The mean TP concentration in the tributaries was 0.013 mg L^{-1} on April 19, 2017 and 0.036 mg L^{-1} on July 3, 2017. Historical mean TP concentrations ranged from $0.027\text{-}0.070 \text{ mg L}^{-1}$ in previous studies by GVSU (2006 and 2007 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 $6 \text{ } \mu\text{g L}^{-1}$ are found in eutrophic or nutrient-enriched aquatic systems, whereas chlorophyll-*a* concentrations less than $2.2 \text{ } \mu\text{g L}^{-1}$ are found in nutrient-poor or oligotrophic lakes. Chlorophyll-*a* is measured in micrograms per liter ($\mu\text{g L}^{-1}$) with the use of an acetone extraction method and a spectrometer.

The chlorophyll-*a* concentrations in Bear Lake were determined by collecting composite samples of the algae throughout the water column at each of the deep basin sites from just above the lake bottom to the lake surface. The chlorophyll-*a* concentrations in the deep basins ranged from $5.0\text{-}11.0 \text{ } \mu\text{g L}^{-1}$ during the June and July sampling events. Additionally, the chlorophyll-*a* concentrations

in the tributaries ranged from 1.0-12.0 $\mu\text{g L}^{-1}$ with the highest value recorded at Bear Creek in April, 2017. These values indicate that planktonic algae are prominent in the water column and will likely increase during the summer due to significantly warmer water temperatures. It is also likely that these values are high in the spring after spring runoff. Previous studies by GVSU (2006 and 2007 data) reported a mean range of 9.0-35.0 $\mu\text{g L}^{-1}$ of chlorophyll-a which is quite high. In the canals, the filamentous form of algae is most prevalent. The presence of Zebra Mussels that filter green algae from the water may also increase the prevalence of blue-green algae since they expel those algae in favor of more palatable green algae. Note: Zebra Mussels are an invasive species and further introduction into Bear Lake should be reduced. Previous studies on Bear Lake have noted elevated chlorophyll-a concentrations (GVSU, MDEQ data).

Algal genera from a composite water sample collected over the deep basins of Bear 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 below. The dominant algal genera found in the deep basins consisted of single-celled, multi-celled, and filamentous algae. The dominant filamentous algae, *Lyngbya* resembles a hairy mat and was found in high densities in samples.

The blue-green algae, *Microcystis* sp. was the most prevalent algae in the lake which is an indicator of poor water quality (Figures 14 and 15). The colonies are a few micrometers in diameter and are evenly distributed throughout a gelatinous matrix. Younger colonies are spherical and older ones are more irregularly shaped. There are numerous gas vesicles and the algae can thrive at the surface with minimal photo-degradation (breaking down) by the sun. When the sunlight is excessive, the algae can break down and release toxins and lower the dissolved oxygen in the water column. The algae are the only type known to fix nitrogen gas into ammonia for growth. *Microcystis* has also been shown to overwinter in lake sediments (Fallon et al., 1981). In addition, it may thrive in a mucilage layer with sediment bacteria that can release phosphorus under anaerobic conditions (Brunberg, 1995). They assume a high volume in the water column (Reynolds, 1984) compared to diatoms and other single-celled green algae. The blue-green algae have been on the planet nearly 2.15 billion years and have assumed strong adaptation mechanisms for survival. In general, calm surface conditions will facilitate enhanced growth of this type of algae since downward transport is reduced. *Microcystis* may also be toxic to zooplankton such as *Daphnia* which was a zooplankton present in Bear Lake and in most lakes (Nizan et al., 1986). Without adequate grazers to reduce algae, especially blue-greens, the blue-green population will continue to increase and create negative impacts to water bodies. Filamentous algae (Figures 16 and 17) will also continue to increase in stagnant areas due to high nutrient levels in the lake.

The aforementioned species indicate an algal flora low in biodiversity and quality and represent an imbalanced freshwater ecosystem not capable of supporting a strong zooplankton community at this time.

Table 3. Dominant algal taxa found in the Bear Lake deep basins (June and July, 2017).

Algae Sample Location	Dominant Algal Genera
DB #1	<i>Microcystis</i> sp., <i>Chlorella</i> sp., <i>Lyngbya</i> sp.,
DB #2	<i>Microcystis</i> sp., <i>Scenedesmus</i> sp., <i>Lyngbya</i> sp.,



Figure 14. A *Microcystis* algal scum on the surface of Bear Lake (photo courtesy of PLM).



Figure 15. A *Microcystis* algal scum on the surface of Bear Lake (photo courtesy of PLM).



Figure 16. Nuisance filamentous algae in Bear Lake (RLS, 2017).



Figure 17. Nuisance filamentous algae in Bear Lake (RLS, 2017).

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 is 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 Bear Lake ranged 3.9-4.0 feet in June and 2.0-2.5 feet in July of 2017. This transparency is very poor and may be inadequate to allow abundant growth of 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. Prior recording of Secchi transparency on the lake have ranged 2.0-3.3 feet (GVSU, 2006 and 2007 data).



Figure 18. A Secchi disk

Bear Lake Deep Basin Water Quality Data:

Table 4. Bear Lake physical/biological water quality parameter data collected over the Deep Basin #2 on June 3, 2017.

<i>Depth ft.</i>	<i>Water Temp °F</i>	<i>DO mg L⁻¹</i>	<i>pH S.U.</i>	<i>Cond. μS cm⁻¹</i>	<i>TDS mg L⁻¹</i>	<i>Chl-a μg L⁻¹</i>	<i>Secchi ft.</i>
0	69.2	9.0	8.1	335	235	5.0	4.0
1.0	69.3	8.8	8.0	328	224	5.0	--
2.0	69.2	8.8	8.1	331	230	5.0	--
3.0	69.0	8.8	8.1	329	227	6.0	--
4.0	69.0	8.6	8.2	331	231	6.0	--
5.0	69.0	8.6	8.1	330	223	5.0	--
6.0	68.5	8.4	8.1	327	227	7.0	--
7.0	68.5	8.5	8.1	327	225	7.0	--
8.0	68.5	8.5	8.2	329	227	9.0	--
9.0	68.7	7.8	8.0	329	228	9.0	--
10.0	68.5	7.1	8.1	325	223	9.0	--
11.0	68.3	6.1	8.1	328	228	8.0	--
12.0	68.3	5.9	7.9	331	230	8.0	--

Table 5. Bear Lake chemical water quality parameter data collected over the Deep Basin #2 on June 3, 2017.

<i>Depth ft.</i>	<i>Talk mg L⁻¹ CaCO₃</i>	<i>TP mg L⁻¹</i>	<i>Nitrate N mg L⁻¹</i>	<i>TKN mg L⁻¹</i>	<i>Ammonia N mg L⁻¹</i>
0	110	0.038	<0.35	0.95	0.016
6.0	110	0.046	<0.35	1.2	0.022
12.0	110	0.035	<0.35	0.9	0.029

Table 6. Bear Lake physical/biological water quality parameter data collected over the Deep Basin #1 on June 3, 2017.

<i>Depth ft.</i>	<i>Water Temp °F</i>	<i>DO mg L⁻¹</i>	<i>pH S.U.</i>	<i>Cond. μS cm⁻¹</i>	<i>TDS mg L⁻¹</i>	<i>Chl-a μg L⁻¹</i>	<i>Secchi ft.</i>
0	68.9	6.8	8.1	339	236	7.0	3.9
1.0	68.9	6.3	8.2	332	226	7.0	--
2.0	68.6	6.0	8.2	331	232	9.0	--
3.0	68.7	5.5	8.1	328	223	11.0	--
4.0	68.7	5.2	8.2	329	226	11.0	--
5.0	68.7	5.1	8.1	326	227	11.0	--
6.0	68.0	4.8	8.2	331	232	10.0	--
7.0	68.1	4.4	8.3	329	225	11.0	--
8.0	68.1	4.0	8.2	324	227	10.0	--
9.0	67.4	3.6	8.1	325	226	11.0	--
10.0	67.4	3.4	8.2	326	228	11.0	--
11.0	67.6	3.4	8.1	327	227	11.0	--
12.0	68.0	3.1	8.2	324	226	11.0	--
13.0	67.6	3.1	8.2	323	226	10.0	--
14.0	67.6	2.8	8.2	324	226	10.0	--
15.0	67.6	2.4	8.2	324	224	11.0	--
16.0	67.6	2.1	8.1	309	224	11.0	--
17.0	66.7	1.9	8.1	326	225	10.0	--
18.0	65.4	1.6	8.2	326	228	10.0	--
19.0	66.0	1.6	8.1	338	235	11.0	--
20.0	64.9	1.6	8.3	336	232	10.0	--
21.0	64.9	1.6	8.2	336	232	10.0	--
22.0	64.9	1.4	8.2	341	231	10.0	--
23.0	64.4	1.4	8.3	340	234	10.0	--
24.0	64.4	1.4	8.4	328	233	10.0	--
25.0	64.5	1.2	8.4	328	228	10.0	--

Table 7. Bear Lake chemical water quality parameter data collected over the Deep Basin #1 on June 3, 2017.

<i>Depth ft.</i>	<i>Talk mg L⁻¹ CaCO₃</i>	<i>TP mg L⁻¹</i>	<i>Nitrate N mg L⁻¹</i>	<i>TKN mg L⁻¹</i>	<i>Ammonia N mg L⁻¹</i>
0	110	0.040	<0.35	0.96	0.017
12.5	93	0.034	<0.35	0.83	0.021
25.0	110	0.036	<0.35	1.4	0.260

Table 8. Bear Lake physical/biological water quality parameter data collected over the Deep Basin #2 on July 3, 2017.

<i>Depth ft.</i>	<i>Water Temp °F</i>	<i>DO mg L⁻¹</i>	<i>pH S.U.</i>	<i>Cond. µS cm⁻¹</i>	<i>TDS mg L⁻¹</i>	<i>Chl-a µg L⁻¹</i>	<i>Secchi ft.</i>
0	74.7	10.0	8.8	361	231	6.0	2.5
1.0	74.7	9.6	8.8	361	231	6.0	--
2.0	74.6	8.0	8.7	361	230	7.0	--
3.0	74.6	8.0	8.6	360	231	7.0	--
4.0	74.6	8.0	8.6	362	232	7.0	--
5.0	74.6	8.1	8.6	362	232	6.0	--
6.0	72.6	8.6	8.6	362	231	7.0	--
7.0	72.6	8.2	8.6	361	232	7.0	--
8.0	72.0	8.2	8.2	362	232	7.0	--
9.0	72.0	6.9	8.2	369	231	7.0	--
10.0	71.9	6.0	8.0	369	236	6.0	--
11.0	71.7	5.7	7.9	369	236	5.0	--
12.0	71.7	5.4	7.9	369	236	5.0	--

Table 9. Bear Lake chemical water quality parameter data collected over the Deep Basin #2 on July 3, 2017.

<i>Depth ft.</i>	<i>Talk mg L⁻¹ CaCO₃</i>	<i>TP mg L⁻¹</i>	<i>TKN mg L⁻¹</i>
0	120	0.068	1.3
6.0	87	0.056	2.0
12.0	89	0.060	2.1

Table 10. Bear Lake physical/biological water quality parameter data collected over the Deep Basin #1 on July 3, 2017.

<i>Depth ft.</i>	<i>Water Temp °F</i>	<i>DO mg L⁻¹</i>	<i>pH S.U.</i>	<i>Cond. µS cm⁻¹</i>	<i>TDS mg L⁻¹</i>	<i>Chl-a µg L⁻¹</i>	<i>Secchi ft.</i>
0	76.1	10.2	8.8	361	231	6.0	2.0
1.0	76.1	9.6	8.8	363	232	6.0	--
2.0	76.0	9.5	8.8	360	231	7.0	--
3.0	75.8	8.8	8.8	361	231	10.0	--
4.0	75.4	8.8	8.8	361	232	9.0	--
5.0	75.3	8.8	8.7	362	232	10.0	--
6.0	75.3	8.6	8.6	360	232	9.0	--
7.0	75.2	8.6	8.6	362	231	9.0	--
8.0	75.2	8.6	8.6	361	233	11.0	--
9.0	74.5	8.6	8.6	360	231	8.0	--
10.0	74.1	8.6	8.6	361	230	8.0	--
11.0	73.4	8.6	8.6	362	232	9.0	--
12.0	72.9	8.6	8.5	363	232	9.0	--
13.0	72.6	8.6	8.5	366	232	8.0	--
14.0	72.6	8.4	8.5	365	233	10.0	--
15.0	72.6	7.5	8.5	366	233	9.0	--
16.0	72.4	7.1	8.5	368	231	9.0	--
17.0	72.4	7.1	8.2	367	234	7.0	--
18.0	72.1	6.3	8.2	367	234	7.0	--
19.0	72.0	6.0	8.2	367	233	8.0	--
20.0	71.6	4.9	8.2	370	235	8.0	--
21.0	71.5	4.9	8.0	371	235	8.0	--
22.0	71.0	4.1	7.9	371	235	8.0	--
23.0	70.9	3.5	7.6	372	235	9.0	--
24.0	70.9	3.0	7.6	372	235	9.0	--
25.0	70.9	3.0	7.6	372	235	9.0	--

Table 11. Bear Lake chemical water quality parameter data collected over the Deep Basin #1 on July 3, 2017.

<i>Depth ft.</i>	<i>Talk mg L⁻¹ CaCO₃</i>	<i>TP mg L⁻¹</i>	<i>TKN mg L⁻¹</i>
0	110	0.066	1.3
12.5	110	0.043	2.3
25.0	110	0.075	1.9

Bear Lake Tributary Water Quality Data:

Table 12. Bear Lake water quality parameter data collected in the Bear Lake Tributaries on April 19, 2017.

<i>Trib Name</i>	<i>Water Temp °F</i>	<i>DO mg L⁻¹</i>	<i>pH S.U.</i>	<i>Cond. µS cm⁻¹</i>	<i>TDS mg L⁻¹</i>	<i>TP mg L⁻¹</i>	<i>TKN mg L⁻¹</i>	<i>TSS mg L⁻¹</i>	<i>Chl-a µg L⁻¹</i>	<i>Ammonia N mg L⁻¹</i>
Bear Creek	61.0	9.5	8.2	464	338	0.015	0.50	<10	12.0	<0.010
Fenner's Ditch	58.6	9.8	8.4	304	210	0.010	0.63	<10	5.0	0.012

Table 13. Bear Lake water quality parameter data collected in the Bear Lake Tributaries on July 3, 2017.

<i>Trib Name</i>	<i>Water Temp °F</i>	<i>DO mg L⁻¹</i>	<i>pH S.U.</i>	<i>Cond. µS cm⁻¹</i>	<i>TDS mg L⁻¹</i>	<i>TP mg L⁻¹</i>	<i>TSS mg L⁻¹</i>	<i>Chl-a µg L⁻¹</i>
Bear Creek	65.0	8.6	7.9	353	226	0.037	<10	4.0
Fenner's Ditch	64.9	9.3	7.6	400	200	0.036	<10	1.0

4.2 Sediment Quality Parameters

A total of twenty sediment samples were collected from Bear Lake on July 3, 2017 using an Ekman hand dredge (Figure 19). Sampling locations were randomly selected throughout the lake basin to avoid sampling bias. Each sediment sample was poured into sterile glass jars and kept on ice until transported to the laboratory within 72 hours. The sample locations were marked with a GPS system and the jars were labelled with the corresponding sample location number. Sediments were analyzed at TRACE Analytical Laboratories, Inc. in Muskegon, Michigan. Sediment samples were analyzed for sediment organic matter percentage (organic carbon) and also sediment total phosphorus.

4.2.1 Sediment Organic Matter

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. There are two major biochemical pathways for the reduction of organic matter to forms which may be purged as waste. First, the conversion of carbohydrates and lipids via hydrolysis are converted to simple sugars or fatty acids and then fermented to alcohol, CO₂, or CH₄. Second, proteins may be proteolyzed to amino acids, deaminated to NH₃⁺, nitrified to NO₂⁻ or NO₃⁻, and denitrified to N₂ gas. Bacteria are the major factor in the degradation of organic matter in sediments (Fenchel and Blackburn, 1979).

The organic content averaged 25.4±11.8% and ranged from 0.6-37% organic matter which is highly variable and not uncommon in post-glacial lakes. Site 17 had the highest percentage of organic matter, followed by site 13.

4.2.2 Sediment Total Phosphorus

Sediment total phosphorus (TP) is a measure of the amount of phosphorus present in the lake sediment. Phosphorus is the primary nutrient necessary for abundant algae and aquatic plant growth. The TP concentrations in lake sediments are often up to several times higher than those in the water column since phosphorus tends to adsorb onto sediment particles and sediments thus act as a “sink” or reservoir of nutrients. TP concentrations are usually higher at increased depths due to higher release rates of phosphorus from lake sediments under low oxygen (anoxic) conditions. Sediment TP was measured in milligrams per kilogram (mg kg⁻¹) with EPA Method 6010B. The sediment total phosphorus in the lake sediments averaged 360±174.6 mg kg⁻¹. The concentrations

ranged from 61-810 mg kg⁻¹. This represents a high variability in the concentrations of sedimentary phosphorus and may explain some variation in the abundance of rooted, submersed aquatic vegetation throughout Bear Lake.

Table 14. Sediment TP and % OM in Bear Lake sediments (July 3, 2017).

<i>Sediment Sample</i>	<i>Sediment Total Phosphorus</i>	<i>Sediment Organic Matter</i>
<i>Site #</i>	<i>(mg kg⁻¹)</i>	<i>(%)</i>
1	160	0.6
2	290	18
3	540	25
4	290	29
5	270	32
6	310	30
7	520	34
8	390	34
9	810	35
10	350	32
11	200	34
12	340	26
13	390	36
14	230	2.5
15	61	0.6
16	360	19
17	560	37
18	330	35
19	600	26
20	200	23

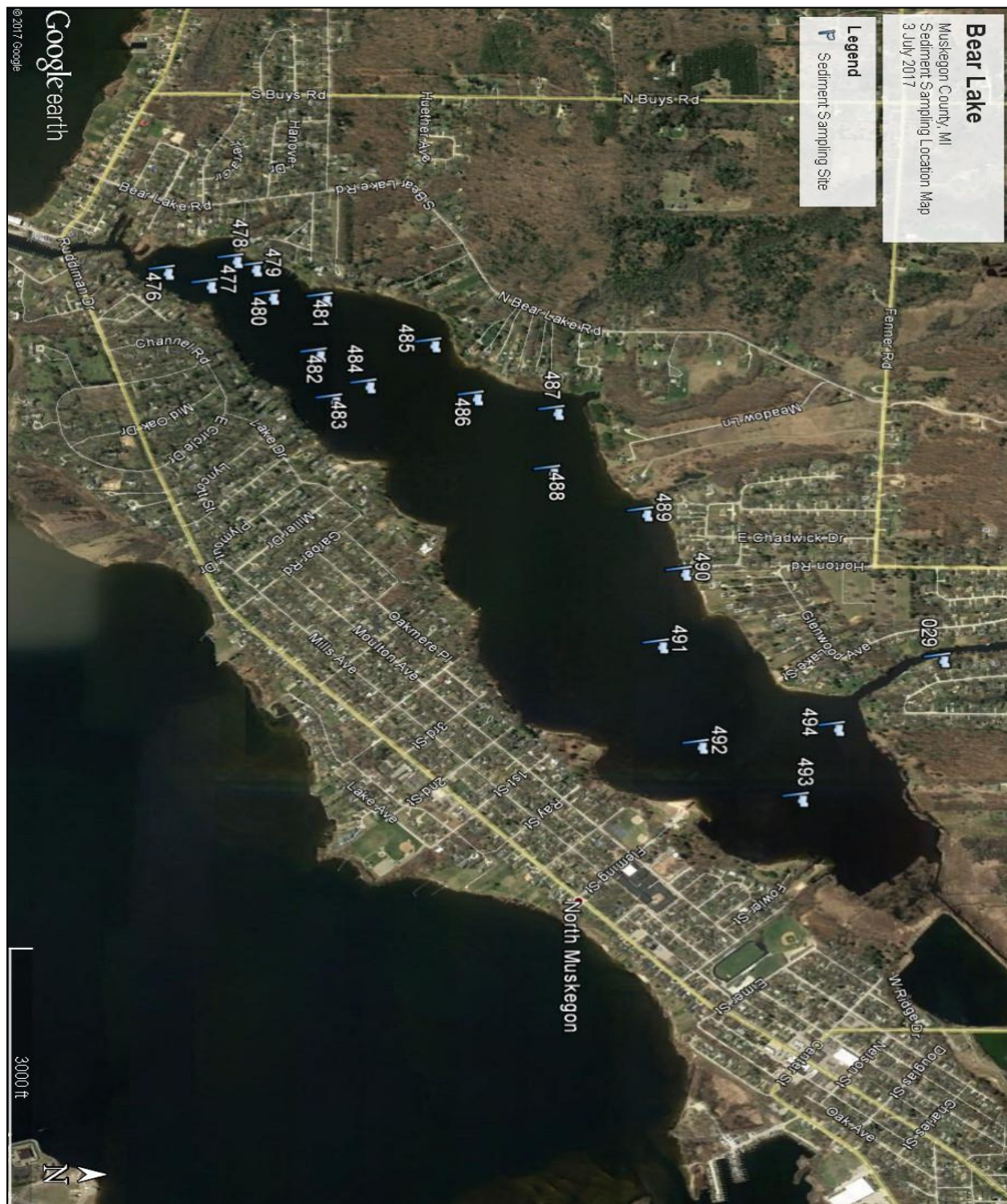


Figure 19. Sediment sampling locations for organic matter and TP in Bear Lake (RLS, 2017).

4.2.3 Sediment Petroleum

Since oil was found in the Fenner's Ditch canal on the surface, RLS decided to sample the bottom sediment of the canal in the center of the ditch out from where the oil boom is currently in place. A single sediment sample was collected with an Ekman hand dredge and placed in a sterile glass jar and kept on ice until transported to TRACE Analytical Laboratories, Inc. in Muskegon, Michigan. The sample was analyzed for "Diesel Range Organics (DRO)" and "Oil Range Organics (ORO)". The DRO was 7.3 mg/kg and the ORO was 28 mg/kg. These values are well above the RDL values of 5.2 mg/kg for DRO and 6.0 mg/kg for ORO.

In addition, there was a petroleum odor emitted from a benthic sediment sample collected in the deepest basin of the lake. These findings raise a possible concern that there could be oil seepage occurring in areas along the lake bottom. If this is occurring, it could be reducing the aquatic vegetation, zooplankton, and macroinvertebrate biodiversity throughout the lake. RLS will be proposing a rigorous sediment sampling program that will detect if seepage is occurring in other areas and to what extent or if there is petroleum residue in the lake sediments. The presence of petroleum in the sediments may significantly impact how restoration technologies are utilized in the lake. For example, aeration of the whole-lake will be recommended in future years, but only after the extent of petroleum residue has been determined. If residue is present, it can be released from the lake sediments during destratification and create possible release of free product which would be a statutory environmental violation and would be detrimental to lake health.

5.0 BEAR LAKE ZOOPLANKTON & BENTHIC MACROINVERTEBRATE COMMUNITIES

5.1 Bear Lake Zooplankton

At the base of the lake food chain are the zooplankton which serve as food for smaller invertebrates and small fish. There are different types and sizes of zooplankton and an inland lake such as Bear Lake may harbor many different species of zooplankton. Zooplankton samples are collected from the water column using a specialized plankton net (Figure 20) that is towed throughout the water column for a few minutes to collect a representative sample of zooplankton at different lake depths. Figures 21 and 22 show common zooplankton found in inland lakes.

A zooplankton tow using a pelagic plankton net with collection jar was conducted by RLS scientists on July 3, 2017 over the deep basins of Bear Lake. Plankton sub-samples (in 1 ml aliquots) were analyzed under a Meiji® dissection scope with the use of a Bogorov counting chamber. The most abundant zooplankton genera included *Daphnia* (approximately 4 organisms per 1 ml aliquot), and *Mesocyclops* (approximately 2 organisms per 1 ml aliquot). Overall, the zooplankton community was scarce and low in biodiversity.

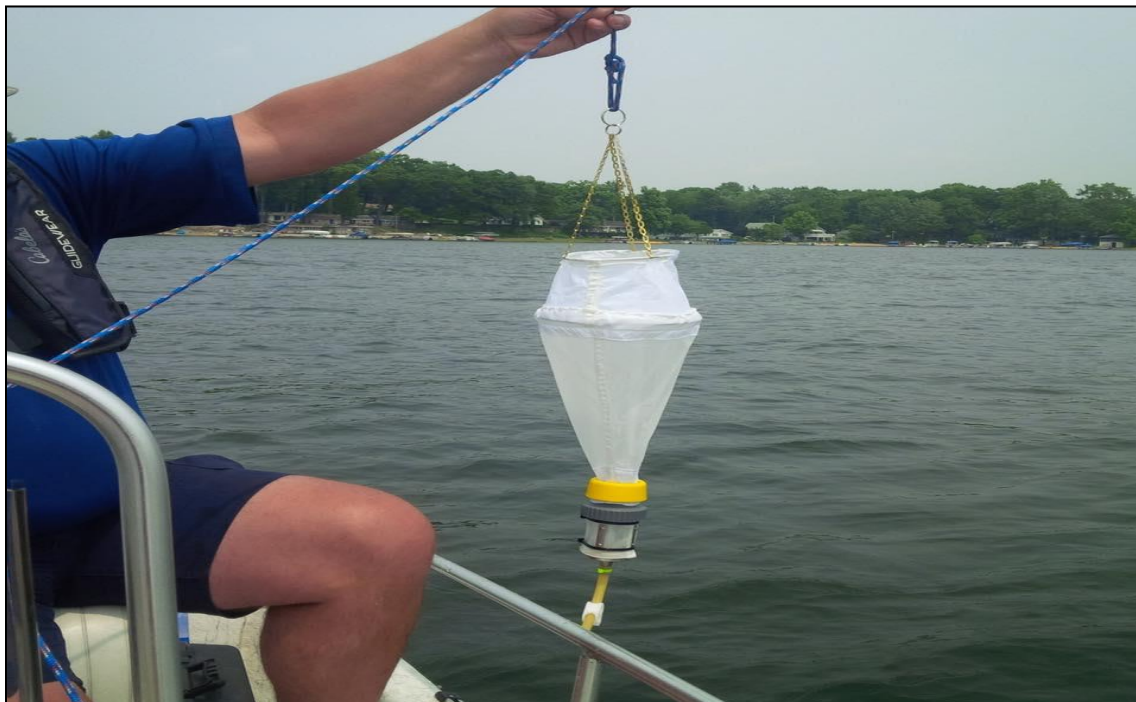


Figure 20. A zooplankton net with collection bottle and line (RLS, 2017).

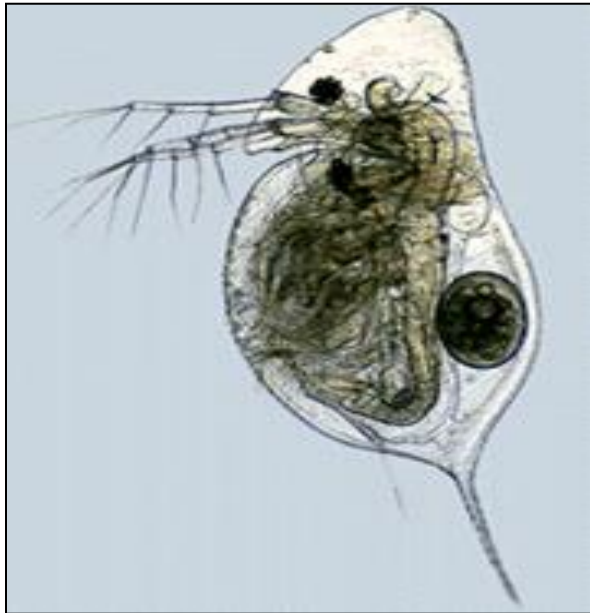


Figure 21. *Daphnia*-A Zooplankton
(photo courtesy of the EPA).



Figure 22. A Copepod Zooplankton
(photo courtesy of the USGS).

5.2 Bear Lake Benthic 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 algae 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.

Restorative Lake Sciences collected two aquatic macroinvertebrate samples at the two deep basins of the lake on July 3, 2017 (Table 15). The study found very low counts of each macroinvertebrate and very low biodiversity. Additionally, the taxa found were indicative of poor water quality.

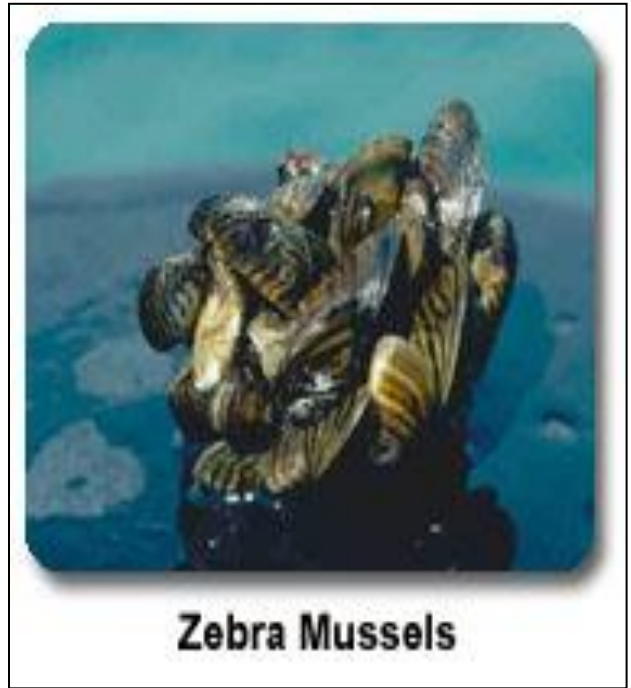
Taxa found included a single midge larvae (Chironomidae), a single wheel snail (Planorbidae), two Pond snails (Lymnaeidae), four Zebra Mussels (Dreissenidae) and two mosquito larvae. Of all the species found, all were native except for the Zebra Mussels. While the majority of the species were native, 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).

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 ten-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. The moderate alkalinity of Bear Lake can support continued growth of Zebra Mussels since they need ample alkalinity (calcium carbonate) for their shells.

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. If petroleum, chlorides, or metals are abundant in the lake sediments, it may explain the low biodiversity and abundance of macroinvertebrates. RLS proposes to evaluate these parameters in the Bear Lake sediments in the next few years. A few photos of different macroinvertebrates found in Bear Lake are shown in Figures 23 and 24 below.



Figure 23. A Pond Snail macroinvertebrate



Zebra Mussels
Figure 24. A Zebra Mussel macroinvertebrate (USGS)

Table 15. Bear Lake Benthic Macroinvertebrates (July 3, 2017).

Sample 1	Sample type – Sediment Grab	Order	Class/Family/Genus/Species	Number	Common name
		Diptera	Cironomidae	1	Midge larvae
		Gastropoda	Physidae	1	Pond snails
		Bivalvia	Dreissenidae	4	Zebra mussels
		Diptera	Culicidae	2	Mosquito larvae
		Gastropoda	Planorbidae	1	Wheel snail
			Total	9	
Sample 2	Sample type Sediment Grab				
		Gastropoda	Physidae	1	Pond snails
			Total	1	

6.0 BEAR LAKE AQUATIC VEGETATION COMMUNITIES

6.1 Overview of Aquatic Vegetation and the Role in Lake Health

The overall health of Bear 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) 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.

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. The Michigan Department of Environmental Quality (MDEQ) prefers that an Aquatic Vegetation Assessment Site (AVAS) Survey, or a GPS Point-Intercept survey (or both) be conducted on most inland lakes following large-scale aquatic herbicide treatments to assess the changes in aquatic vegetation structure and to record the relative abundance and locations of native aquatic plant species. Due to the large size and shallow mean depth of Bear Lake, whole-lake GPS Point-Intercept grid matrix survey (Figure 25) was conducted on July 3, 2017 to assess all aquatic plants including submersed, floating-leaved, and emergent species. The lake scan consisted of over 16,000 GPS points and the aquatic vegetation sampling survey utilized 445 points with the main lake and canals combined. Based on this data, Bear Lake lacks aquatic vegetation in 77% of the lake (Restorative Lake Sciences, 2017). The use of a side-scan sonar GPS device to scan the aquatic plant bio volume, bathymetric contours, and sediment bottom hardness of the lake was conducted using a Lowrance® HDS 8 unit with BioBase® software. Figures 26 and 27 below shows the aquatic vegetation bio volume in Bear Lake in April and June of 2017, respectively.

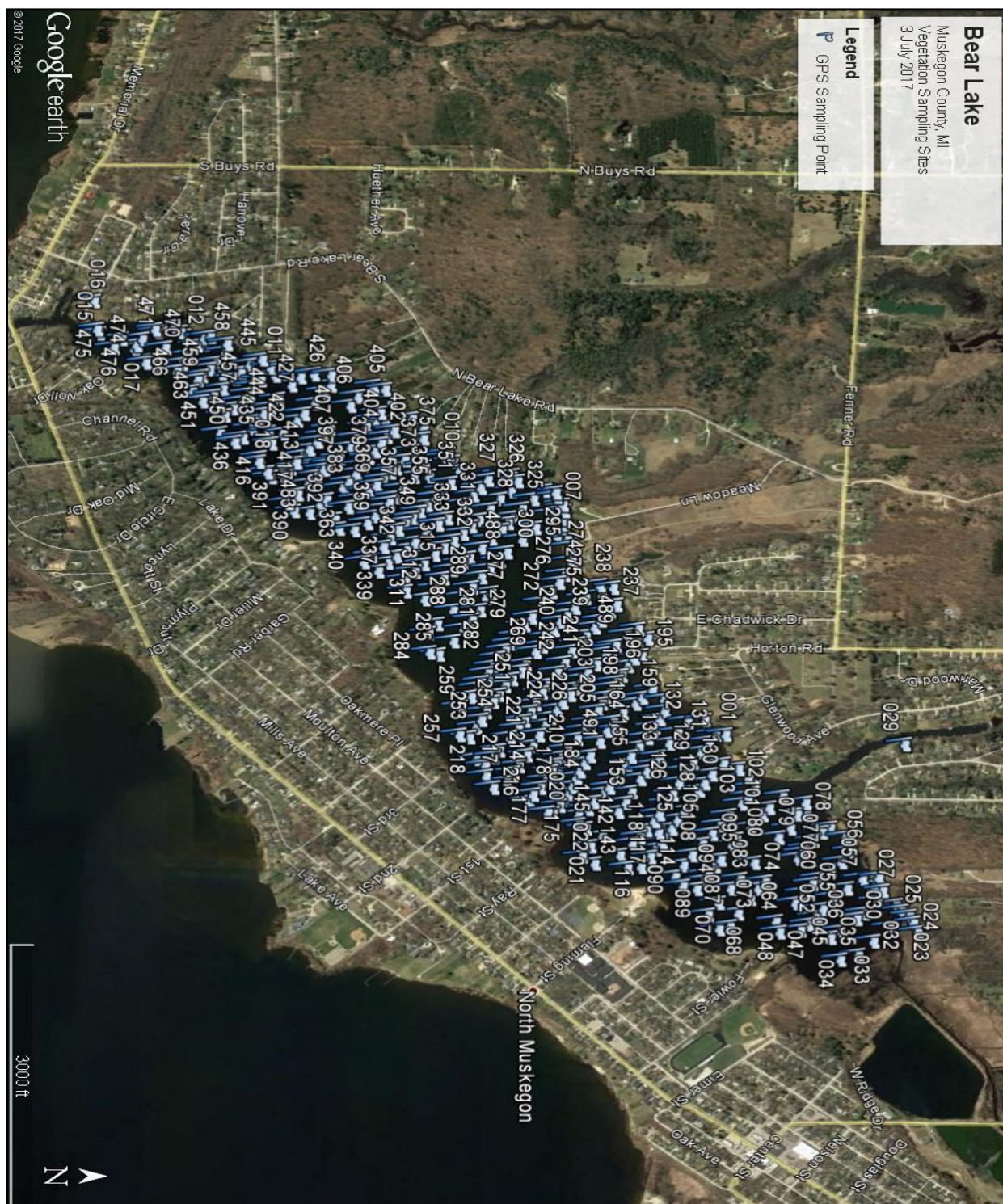


Figure 25. Aquatic vegetation sampling point locations in Bear Lake (July 3, 2017).

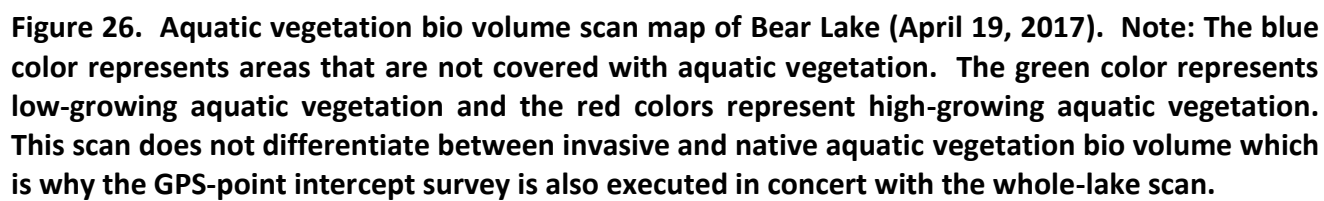




Figure 27. Aquatic vegetation bio volume scan map of Bear Lake (June 3, 2017). Note: The blue color represents areas that are not covered with aquatic vegetation. The green color represents low-growing aquatic vegetation and the red colors represent high-growing aquatic vegetation. This scan does not differentiate between invasive and native aquatic vegetation bio volume which is why the GPS-point intercept survey is also executed in concert with the whole-lake scan.

6.3 Bear Lake Exotic Aquatic Plant Species

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 28) is an exotic aquatic macrophyte that is a serious problem in Michigan inland lakes and has been genetically determined in Bear 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). Furthermore, the required dose of 2,4-D 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. This plant was found in a few areas of Bear Lake.

Curly-leaf Pondweed (*Potamogeton crispus*; Figure 29) is an exotic, submersed, rooted aquatic plant that was introduced into the United States in 1807 but was abundant by the early 1900's. It is easily distinguished from other native pondweeds by its wavy leaf margins. It grows early in the spring and as a result may prevent other favorable native aquatic species from germinating. The plant reproduces by the formation of fruiting structures called turions. It does not reproduce by fragmentation as invasive watermilfoil does; however, the turions may be deposited in the lake sediment and germinate in following seasons. Fortunately, the plant naturally declines around mid-July in many lakes and is also amenable to mechanical harvesting. Curly-leaf Pondweed is a pioneering aquatic plant species and specializes in colonizing disturbed habitats. It is highly invasive in aquatic ecosystems with low biodiversity and unique sediment characteristics. This plant was found only in a few areas of the lake which includes the canals. It is not considered a threat to the Bear Lake ecosystem at the present time.

Starry stonewort (*Nitellopsis obtusa*; Figure 30) is an invasive macro alga that has invaded many inland lakes of Michigan and was originally discovered in the St. Lawrence River. Only a few fragments of this invasive alga were found in the Bear Lake Canal during the summer 2017 survey. The “leaves” appear as long, smooth, angular branches of differing lengths. The alga has been observed in dense beds at depths beyond several meters in clear inland lakes and can grow to heights in excess of a few meters. It prefers clear alkaline waters and has been shown to cause significant declines in water quality and fishery spawning habitat. It is not likely to be a strong threat for the lake due to the low water clarity and moderate alkalinity.

Purple loosestrife (*Lythrum salicaria*; Figure 31) is an invasive (i.e. exotic) emergent aquatic plant that inhabits wetlands and shoreline areas. It has showy magenta-colored flowers that 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 Bear 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 six areas around the lake shoreline.

Lastly, the Giant Common Reed (*Phragmites australis*; Figure 32) was also found in several locations along the shoreline of Bear 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 and their relative abundance found in and around Bear Lake in 2017 is shown below in Table 16. The distribution of invasive aquatic plant species in 2017 is shown in Figures 33 and 34. Figures 35 and 36 demonstrate the advancement of invasive *Phragmites* from the shoreline out towards the open waters of Bear Lake.

Table 16. Exotic invasive aquatic plant species found in Bear Lake (July 3, 2017).

<i>Exotic Aquatic Plant</i> <i>Species Name</i>	<i>Exotic Aquatic Plant</i> <i>Common Name</i>	<i>Exotic Aquatic</i> <i>Plant Growth Habit</i>	<i>Abundance in or</i> <i>around Bear Lake</i>
<i>Myriophyllum spicatum</i>	Eurasian Watermilfoil	Submersed; Rooted	3.6%
<i>Potamogeton crispus</i>	Curly-leaf Pondweed	Submersed; Rooted	0.5%
<i>Lythrum salicaria</i>	Purple Loosestrife	Emergent	0.2%
<i>Phragmites australis</i>	Giant Common Reed	Emergent	2.5%



Figure 28. Eurasian Watermilfoil
©RLS



Figure 29. Curly-leaf Pondweed ©RLS



Figure 30. Starry Stonewort ©RLS



Figure 31. Purple Loosestrife ©RLS



Figure 32. Phragmites ©RLS

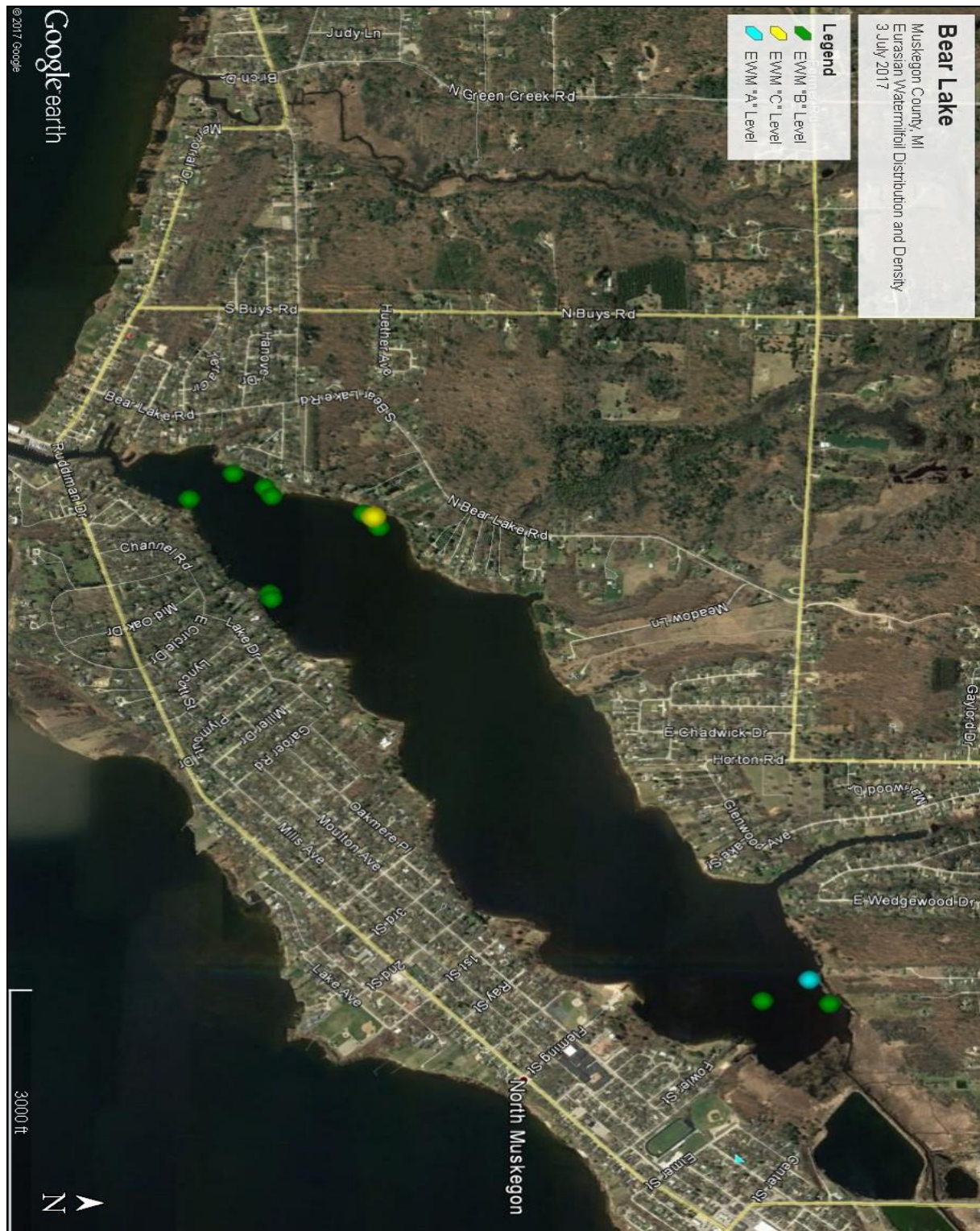


Figure 33. Locations of invasive Eurasian Watermilfoil in Bear Lake (RLS, 2017).

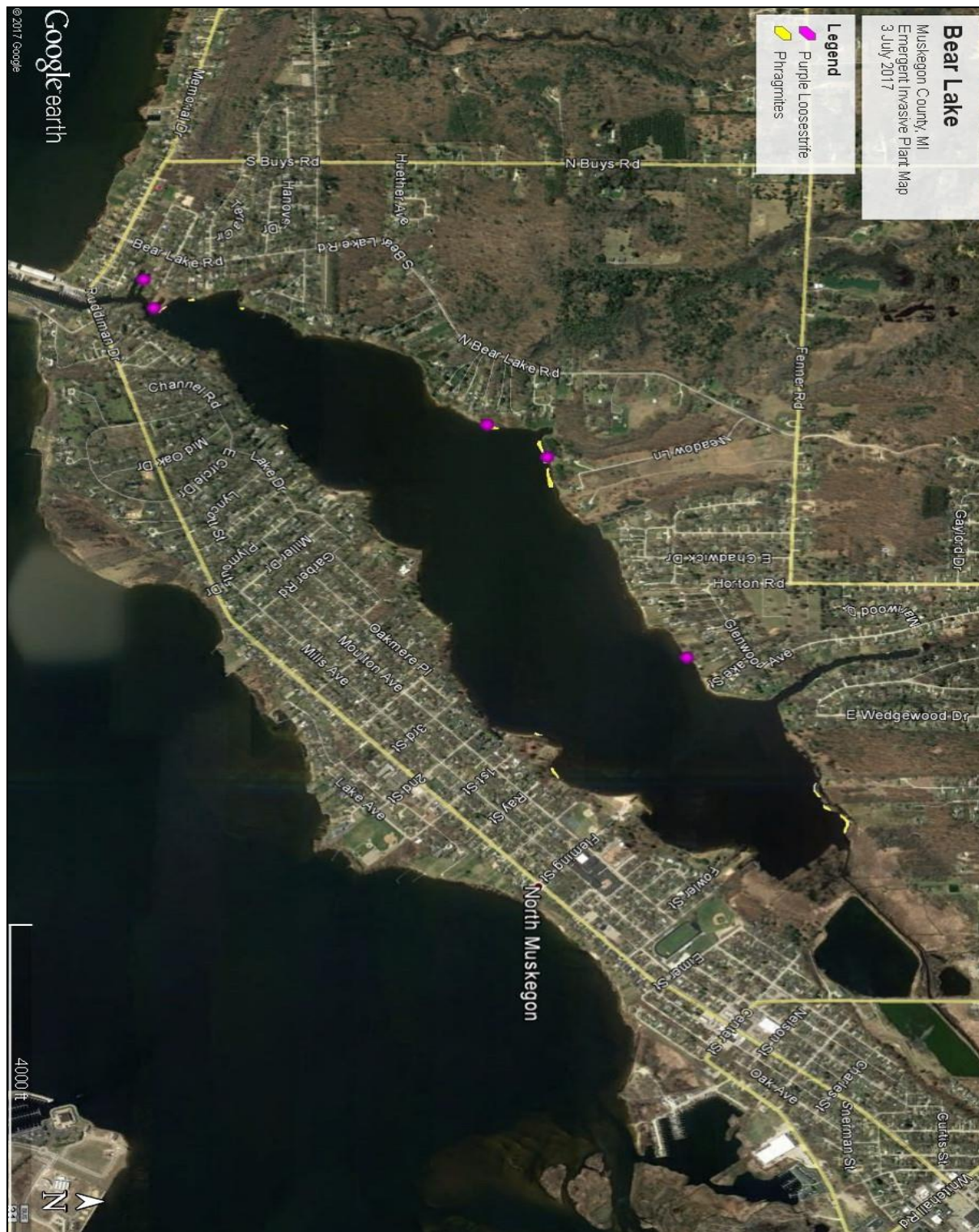


Figure 34. Locations of invasive emergent aquatic plants around Bear Lake (RLS, 2017).



Figure 35. *Phragmites* in Bear Lake advancing towards the water (RLS, 2017).



Figure 36. A dense stand of *Phragmites* in Bear Lake (RLS, 2017).

6.4 Bear Lake Native Aquatic Plant Species

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 those 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.

Bear Lake contained 10 native submersed, 2 floating-leaved, and 4 emergent aquatic plant species, for a total of 16 native aquatic macrophyte species (Table 17). Photos of all native aquatic plants are shown below in Figures 37-52. The majority of the emergent macrophytes may be found along the shoreline of the lake. Additionally, the majority of the floating-leaved macrophyte species can be found near the shoreline and in the canals. This is likely due to enriched sediments and shallower water depth with reduced wave energy that facilitates the growth of aquatic plants with various morphological forms.

The most dominant aquatic plant in the main part of the lake included the rootless aquatic plant, Coontail (*Ceratophyllum demersum*). This plant may hover above the lake bottom or aggregate in shallow areas. It has reticulated leaves that feel brittle to the touch and resembles a coon's tail in shape. The second most abundant native aquatic plant species was Wild Celery (*Vallisneria spiralis*) which was tied with Claspingleaf Pondweed (*Potamogeton richardsonii*). The Wild Celery resembles long, green ribbons attached to a single tuber. The plant undergoes a unique fertilization process and then a coil is formed in the center of the plant. It also grows along a stolon and can become prolific in clear waters. Fortunately, the waters of Bear Lake are not clear enough for it to become a nuisance. Also, Claspingleaf Pondweed can be found in shallow waters to the lake drop off and has curved, green leaves that arise on opposite sides of the stem. The plant is excellent fish forage habitat and rarely becomes a problem in inland lakes. Due to the fact that only approximately 77% of the lake is not vegetated, protection of these native aquatic plants is very important.

There were also two floating-leaved macrophyte species, including *Nymphaea odorata* (White-Waterlily), which are 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 (Cattails), and *Scirpus acutus* (Bulrushes) are critical for shoreline stabilization as well as for wildlife and fish spawning habitat. The presence of invasive emergent such as Purple Loosestrife around the Bear Lake shoreline is currently low in abundance but could become a threat to the native emergent macrophyte populations if not controlled. Additionally, the presence of Phragmites in dense stands should be reduced to protect further displacement of native emergent aquatic plant species.

Table 17. Bear Lake native aquatic plant species (July 3, 2017).

<i>Native Aquatic Plant Species Name</i>	<i>Aquatic Plant Common Name</i>	<i>% Cover</i>	<i>Aquatic Plant Growth Habit</i>
<i>Chara vulgaris</i>	Muskgrass	0.9	Submersed, Rooted
<i>Potamogeton pectinatus</i>	Thin-leaf Pondweed	4.0	Submersed, Rooted
<i>Potamogeton zosteriformis</i>	Flat-stem Pondweed	1.6	Submersed, Rooted
<i>Potamogeton gramineus</i>	Variable-leaf Pondweed	0.2	Submersed, Rooted
<i>Potamogeton richardsonii</i>	Clasping-leaf Pondweed	6.5	Submersed, Rooted
<i>Zosterella dubia</i>	Water Stargrass	1.6	Submersed, Rooted
<i>Vallisneria americana</i>	Wild Celery	6.5	Submersed, Rooted
<i>Elodea canadensis</i>	Common Waterweed	0.2	Submersed, Rooted
<i>Ceratophyllum demersum</i>	Coontail	21.0	Submersed, Non-Rooted
<i>Utricularia vulgaris</i>	Bladderwort	3.8	Submersed, Non-Rooted
<i>Nymphaea odorata</i>	White Waterlily	3.6	Floating-Leaved, Rooted
<i>Nuphar variegata</i>	Yellow Waterlily	0.9	Floating-Leaved, Rooted
<i>Typha latifolia</i>	Cattails	3.6	Emergent
<i>Scirpus acutus</i>	Bulrushes	1.3	Emergent
<i>Iris sp.</i>	Iris	0.4	Emergent
<i>Sagittaria sp.</i>	Arrowhead	0.2	Emergent



**Figure 37. Chara
(Muskgrass) ©RLS**



**Figure 38. Thin-leaf
Pondweed ©RLS**



**Figure 39. Claspingleaf
Pondweed**



**Figure 40. Variable-leaf
Pondweed ©RLS**



**Figure 41. Water
Stargrass ©RLS**



**Figure 42. Wild Celery
©RLS**



Figure 43. Coontail
©RLS



Figure 44. Bladderwort
©RLS



Figure 45. Elodea
©RLS

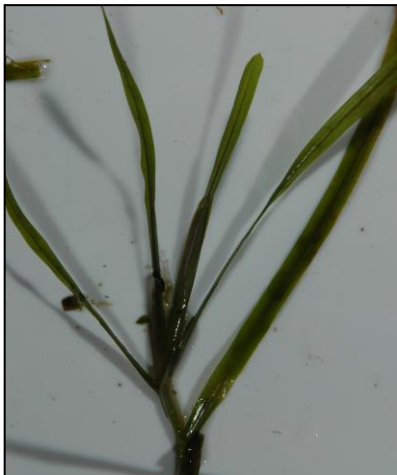


**Figure 46. Flat-stem
Pondweed** ©RLS



Figure 47. White Waterlily
©RLS

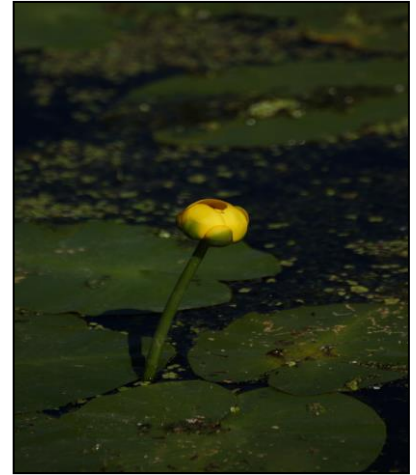


**Figure 48. Yellow
Waterlily** ©RLS



Figure 49. Cattails ©RLS



**Figure 50. Bulrushes
©RLS**



**Figure 51. Yellow Iris
©RLS**



Figure 52. Sagittaria sp.

7.0 BEAR LAKE MANAGEMENT IMPROVEMENT METHODS

7.1 Bear Lake Aquatic Plant Management Methods

The goals of a lake improvement program relative to aquatic vegetation communities 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, scientific, and environmental components of the lake management plan.

The management of invasive submersed and emergent invasive aquatic plants is necessary in and around Bear 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 Bear Lake Improvement Board (BLLB) should pursue relative to vegetation management: 1) reduction of submersed and emergent invasive aquatic plant species such as hybrid watermilfoil and *Phragmites*, and 2) protection of the native aquatic plant species found throughout the lake. These two objectives are critical for the health and balance of Bear 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 treatment 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.

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 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 Bear Lake, the use of systemic herbicides (granular) is recommended for the control of invasive Hybrid Watermilfoil since the plant can be locally controlled without harmful impacts to native aquatic plant species.

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 Bear Lake can be effectively spot-treated with granular triclopyr nearshore and granular 2,4-D in offshore areas. Triclopyr must be used in near shore areas with shallow well (< 30 feet deep) restrictions.

Treatment of the invasive *Phragmites* can include a combination of contact herbicides along with cutting of the plants. These processes may take multiple years to effectively reduce the populations of *Phragmites* around the lake due to the stoloniferous nature of the plant which allows it to send up new shoots from underground at a rapid rate.

Although there are an abundance of blue-green and green algae in Bear Lake, treatment of the algae with algaecides is not recommended. This can exacerbate the blue-green algae population growth and cause further blooms. The best way to reduce algae is with nutrient reduction into the lake. That process may take considerable time but restoration efforts should greatly reduce future blooms post-implementation.



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 watermilfoil 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 or canals to reduce nuisance aquatic vegetation biomass. At this time, there is not enough vegetation to necessitate mechanical harvesting but it is a method to consider if the lake vegetation grows out of control in the future which may be possible if the water clarity improves and the aquatic vegetation has access to more light for increased growth.



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

7.1.3 Diver Assisted Suction Harvesting (DASH)

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 the 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 in the future to remove nuisance invasives that may be resistant to herbicide treatment. 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 increased turbidity and reduced clarity of the water. It may offer relief in canals by reducing lily pads and other vegetation without the use of herbicides if desired.



Figure 55. A DASH boat for hand-removal of watermilfoil or other nuisance vegetation.

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7.1.4 Biological Control

In the past, the use of the aquatic weevil, *Euhrychiopsis lecontei* (Figure 56) to control Eurasian Watermilfoil was implemented in some inland lakes to reduce milfoil infestations. Unfortunately they were not very effective and are no longer commercially available.

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 (examples include nearby Mona Lake and Lake Mitchell in Cadillac, Michigan). However, these beetles usually prefer a large stand of Purple Loosestrife to promote their population. Fortunately, only a small area around Bear Lake contained this plant and hand-pulling is recommended at this time over biological control due to the overall low abundance and biomass. The beetle may be used in the future if sizeable stands are found in bordering wetlands.



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



Figure 57. *Galerucella* sp. The “Loosestrife” Beetle

7.1.5 Benthic Barriers and Nearshore Management Methods

The use of benthic barrier mats (Figure 58) or Weed Rollers (Figure 59) 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.

Weed Rollers are electrical devices which utilize a rolling arm that 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.

Both methods are useful in recreational lakes such as Bear Lake and work best in beach areas and near docks to reduce nuisance aquatic vegetation growth. These technologies could be used in beach areas on the main lake or in the canals if the bottom substrate is consolidated (firm).

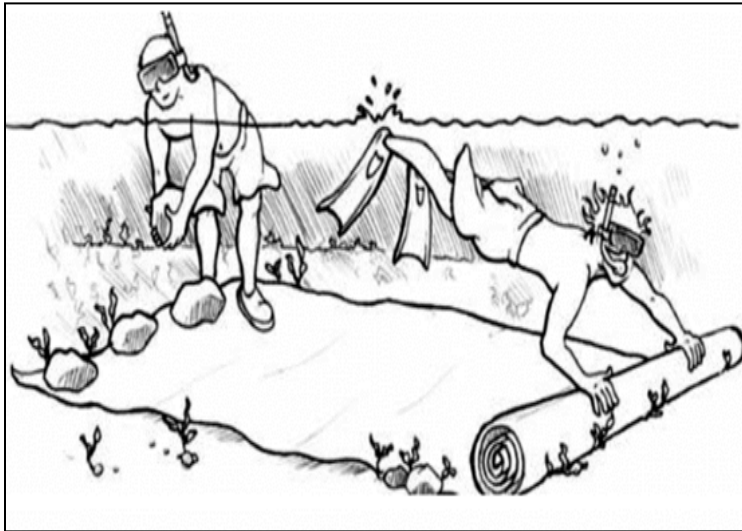


Figure 58. A Benthic Barrier. Photo courtesy of Cornell Cooperative Extension.



Figure 59. A Weed Roller.

7.1.6 Boat Launch Washing Station

The Bear Lake Association (BLA) and the Bear Lake Lake Board (BLLB) should consider working on plans with the MDNR for a boat washing station at the launching site. With over 13 million registered boaters in the U.S. alone, the need for reducing transfer of aquatic invasive species (AIS) has never been greater. The Minnesota Sea Grant program identifies five major boat wash scenarios which include: 1) Permanent washing stations at launch sites, 2) Portable drive-thru or transient systems, 3) Commercial car washes, 4) Home washing, and 5) Mandatory vs. volunteer washing. A boat wash can include a permanent structure or have some washing materials (Figure 60). Both of these station types are voluntary for incoming and exiting boaters. Boat washing stations promote the Clean Waters Clean Boats volunteer education program by educating boaters to wash boating equipment (including trailers and bait buckets) before entry into every lake. Critical elements of this education include: 1) how to approach boaters, 2) demonstration of effective boat and trailer inspections and cleaning techniques, 3) the recording of important information, 4) identification of high-priority invasive species, and 5) sharing findings with others. If a boat washing station is constructed on Bear Lake, the BLA and the BLLB should work together to educate the public and lake users on proper cleaning techniques and other invasive species information.

A “Landing Blitz” can be held once the station is in place and the public can be invited to a field demonstration of how to use the washing station.

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



Figure 60. A simple boat washing station on a Michigan inland lake. Note: these stations can be this simple or may include permanent structures and sprayers.

7.1.7 Bear Lake Invasive Species Prevention

An exotic species is a non-native species that does not originate from a particular location. When international commerce and travel became prevalent, many of these species were transported to areas of the world where they did not originate. Due to their small size, insects, plants, animals, and aquatic organisms may escape detection and be unknowingly transferred to unintended habitats. The first ingredient to successful prevention of unwanted transfers of exotic species to Bear Lake is awareness and education. The majority of the exotic species of concern have been listed in this report. Other exotic species on the move would be introduced to the riparians around Bear Lake through the use of a professionally developed educational newsletter. In addition, signs such as Figure 61 below can be ordered by the MDNR and placed near the boat launch and entry sites to alert the public of invasive species prevention.



Figure 61. An MDNR sign reminding launch site users to check boats and trailers prior to entry into a lake.

Zebra Mussels

Zebra Mussels (*Dreissena polymorpha*) were first discovered in Lake St. Clair in 1988 (Herbert et al. 1989) and likely arrived in ballast water or on shipping vessels from Europe (McMahon 1996). They are easily transferred to other lakes because they inherit a larval (nearly microscopic) stage where they can easily avoid detection. The mussels then grow into the adult (shelled) form and attach to substrates (i.e. boats, rafts, docks, pipes, aquatic plants, and lake bottom sediments) with the use of byssal threads. The fecundity (reproductive rate) of female zebra mussels is high, with as many as 40,000 eggs laid per reproductive cycle and up to 1,000,000 in a single spawning season (Mackie and Schlosser 1996). Although the mussels only live 2-3 years, they are capable of great harm to aquatic environments. In particular, they have shown selective grazing capabilities by feeding on the preferred zooplankton food source (green algae) and expulsion of the non-preferred blue green algae (cyanobacteria). This is a likely contributor to the blue-green algae problem in Bear Lake along with nutrient loading. Additionally, the mussels may decrease the abundance of beneficial diatoms in aquatic ecosystems (Holland 1993). Such declines in favorable algae, can decrease zooplankton populations and ultimately the biomass of planktivorous fish populations. Zebra Mussels are viewed by some as beneficial to lakes due to their filtration capabilities and subsequent contributions to increased water clarity. However, such water clarity may allow other photosynthetic aquatic plants to grow to nuisance levels (Skubinna et al. 1995).

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

Invasive Aquatic Plants

In addition to Eurasian watermilfoil (*M. spicatum*), many other invasive aquatic plant species are being introduced into waters of the North Temperate Zone. The majority of exotic aquatic plants do not depend on high water column nutrients for growth, as they are well-adapted to using sunlight and minimal nutrients for successful growth. These species have similar detrimental impacts to lakes in that they decrease the quantity and abundance of native aquatic plants and associated macroinvertebrates and consequently alter the lake fishery. Such species include *Hydrilla verticillata* and *Trapa natans* (Water Chestnut). *Hydrilla* was introduced to waters of the United States from Asia in 1960 (Blackburn et al. 1969) and is a highly problematic submersed, rooted, aquatic plant in tropical waters. In previous years, *Hydrilla* was found in Lake Manitou (Indiana, USA) and the lake public access sites were immediately quarantined in an effort to eradicate it. *Hydrilla* retains many physiologically distinct reproductive strategies which allow it to colonize vast

areas of water and to considerable depths, including fragmentation, tuber and turion formation, and seed production. Currently, the methods of control for *Hydrilla* include the use of chemical herbicides, rigorous mechanical harvesting, and Grass Carp (*Ctenopharyngodon idella* Val.), with some biological controls currently being researched. However, use of the Grass Carp in Michigan is currently not permitted by the Michigan Department of Natural Resources (MDNR).

Water Chestnut (*Trapa natans*) is a non-native, annual, submersed, rooted aquatic plant that was introduced into the United States in the 1870's yet may be found primarily in the northeastern states. The stems of this aquatic plant can reach lengths of 12-15 feet, while the floating leaves form a rosette on the lake surface. Seeds are produced in July and are extremely thick and hardy and may last for up to twelve years in the lake sediment. If stepped on, the seed pods may even cause deep puncture wounds to those who recreate on the lake. Methods of control involve the use of mechanical removal and chemical herbicides. Biological controls are not yet available for the control of this aquatic plant.

The riparian community around Bear Lake is encouraged to become acquainted with the native aquatic plant and invasive aquatic plant communities in Bear Lake to assist with rapid identification of new invasives that have not been seen before in or around the lake. RLS recommends rigorous whole-lake aquatic vegetation surveys to map the existing plant species, their locations, and the relative abundance of each. This is useful in determining if native aquatic plant communities are stable or if they are being threatened by invasives.

7.2 Bear Lake Basin Improvement Methods

There are a few technologies available to reduce the presence of blue-green algal blooms, increase water clarity, reduce nutrients within the lake, and improve the overall health of Bear Lake. Such technologies have been used on many other lakes in Michigan and around the world and have been shown to significantly improve lake water quality.

7.2.1 Laminar Flow Aeration and Bioaugmentation

Laminar flow aeration systems (Figure 62) are retrofitted to a particular lake or water body and account for variables such as water depth and volume, bottom 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^+ 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 $2.6 \pm 0.80 \text{ mg N g dry wt. day}^{-1}$ for aerated mesocosms and $0.48 \pm 0.20 \text{ mg N g dry wt. day}^{-1}$ in controls.

Although this is a relatively new application to inland lakes, 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 increase in water clarity and decrease in blue-green algae and excessive filamentous green algae in eutrophic ecosystems (Jermalowicz-Jones, 2010-2017, various restoration case studies). 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 organic nutrient is removed from the sediments and excessive sediments are reduced to yield a greater water depth. Nutrients in the water column are also reduced which decreases algae.

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 an area of interest. The system has several components which consists of in-water components such as micro-porous ceramic diffusers, 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.

Recommendations for Laminar Flow Aeration Implementation

Due to the high quantity of algae and low bottom dissolved oxygen concentrations in Bear Lake, the use of aeration with bioaugmentation (addition of microbes) is recommended. Baseline sediment organic matter samples have shown a moderate quantity of organic matter which should respond favorably to the technology. There is a potential for some petroleum residues to be detected in lake bottom sediments given the recent findings and thus caution is recommended prior to installation of any lake mixing (de-stratification) technology as this could transfer oil to the lake surface if too much organic matter is degraded and not able to complex petroleum residues. RLS recommends that a minimum of 30 sediment cores (4-6 feet in thickness) be collected throughout the entire lake basin with top, middle, and bottom sections of each core analyzed for petroleum, chlorides (present in brine), and heavy metals. This data is important for possible future implementation of a whole-lake aeration system. Additionally, the overlying water column should also be sampled for petroleum during the sediment core sampling to determine if it is present in the water column. The duration of this sampling should be at least one but preferably two years.

The aeration technology has demonstrated significant reductions in sediment ammonia and ammonia nitrogen (Jermalowicz-Jones, 2017; *manuscript in progress*). This nutrient is an excellent food source for submersed aquatic plants and is also produced by blue-green algae that can fix nitrogen gas.

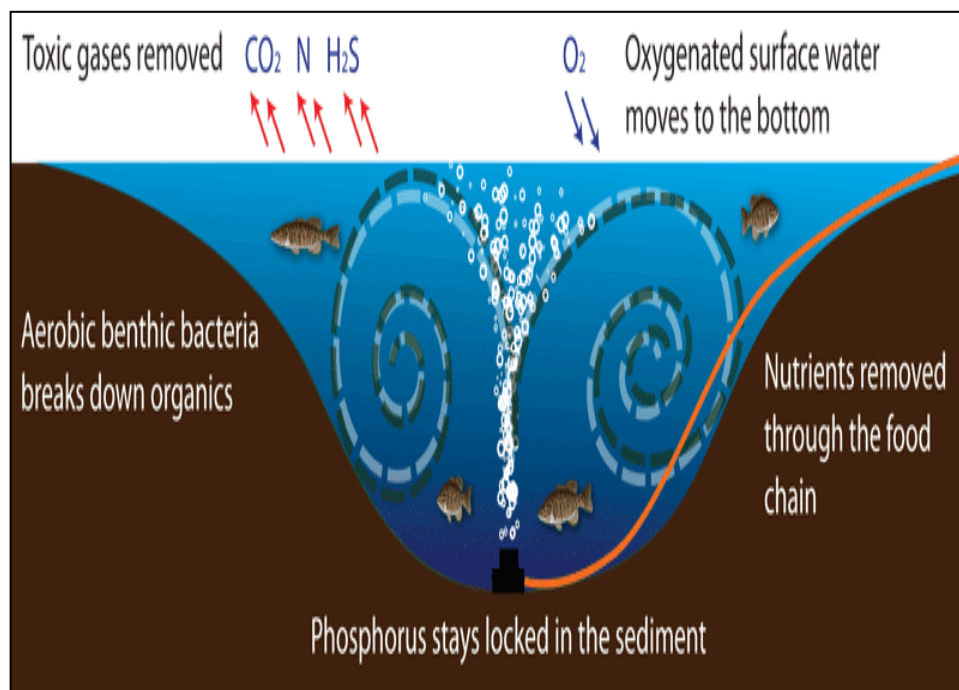


Figure 62. A diagram showing the laminar flow aeration mechanisms. ©Restorative Lake Sciences, LLC

7.2.2 Other Improvement Technologies

There are a few products on the lake improvement market that aim to reduce phosphorus in the water column and the release of phosphorus from a lake bottom. Such products are usually applied as a slurry by a special dose-metered vessel to the water column or just above the lake bottom. Most of these formulas can be applied in aerobic (oxygenated) or anaerobic (oxygen-deficient) conditions. In lakes that lack ample dissolved oxygen at depth, this product may help prevent phosphorus release from the sediments. A few disadvantages include cost, inability to bind high concentrations of phosphorus especially in lakes that receive high external loads of phosphorus, and the addition of an aluminum floc to the lake sediments which may impact benthic macroinvertebrate diversity and relative abundance. Some formulas utilize a clay base with the P-inactivating lanthanum (Phoslock®) which may reduce sediment toxicity of alum.

If this treatment is desired in the future, RLS recommends sampling the lake sediments for sediment pore water phosphorus concentrations to determine internal releases of phosphorus pre-alum and then monitoring post-alum implementation. Additionally, RLS would recommend that external phosphorus loads be significantly reduced since these inputs would compromise phosphorus-inactivation formulas (Nurnberg, 2017). Some recent case studies (Brattebo et al., 2017) are

demonstrating favorable results with alum application in hypereutrophic waters that are also experiencing high external nutrient loads. At this time, a lake mixing technology would be preferred over application of alum since a higher dissolved oxygen concentration is desired throughout the water column and on the lake bottom to reduce internal release of phosphorus and also decrease blue-green algal blooms and increase water clarity while improving the zooplankton and benthic macroinvertebrate biodiversity.

7.3 Bear Lake Immediate Watershed Management Methods

In addition to the in-basin technologies described above, protection and improvements in the Bear Lake immediate watershed are critical. There are excellent on-going improvements that have been implemented due to recommendations by WMSRDC, GVSU, and the MLWP. These improvements are currently supported by municipalities including Dalton Township, Laketon Township, Muskegon Township, and the City of North Muskegon. This section describes additional strategies that individual riparians on Bear Lake can implement to further protect its water quality. Note: For a full description of recommended watershed improvement methods, it is recommended that one read the comprehensive Bear Creek and Bear Lake Watershed Management Plan developed by the MDEQ Nonpoint Source Program and the Muskegon Conservation District (March, 2004, 174 pp). The guidance below is for riparians around the lake to take part in lake protection.

7.3.1 Bear Lake Best Management Practices (BMP's)

The following Best Management Practices (BMP's) are recommended to Bear Lake riparians to help 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 as identified in the Bear Lake shoreline soil survey)
- 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 and thus erosion potential (Note: this may be tough for Bear Lake but could be enforced in canals and nearshore areas)
- 4) Encouraging the growth of dense shrubs or emergent shoreline vegetation to control erosion
- 5) Using only native genotype plants (those native to Bear 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>.

7.3.2 Bear 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 Bear 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 Bear Lake. The emergent aquatic plant, *Scirpus* sp. (Bulrushes) present around Bear Lake offers satisfactory stabilization of shoreline sediments and assists in the minimization of sediment release into the lake. A natural shoreline (Figure 63) is always preferred over a non-natural shoreline (Figure 64) for better wave energy absorption, erosion control, and filtration of runoff.



Figure 63. A natural shoreline on Bear Lake (RLS, 2017).



Figure 64. A non-natural shoreline on Bear Lake (RLS, 2017).

7.3.3 *Bear Lake Nutrient Source Control*

Additional inputs of phosphorus to the lake are likely to create additional blue-green algae and aquatic plant growth. Accordingly, RLS recommends the following procedures to protect the water quality of Bear 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 (Note: This is now the law effective January 1, 2012). If possible, also use low nitrogen (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.

- 2) Preserve riparian vegetation buffers around lake (such as those that consist of Cattails, Bulrushes, and 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. A vegetation strip of 20-30 feet wide (greenbelt) is ideal. Figure 65 demonstrates a lake property with no buffer where any runoff from the land would likely enter the lake.
- 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 that drain into the lake from the surrounding land are vegetated and that no fertilizers are used in areas with saturated soils (see soil table above).
- 5) If septic tank systems are in use, then annual pumping and cleaning is recommended since drain field water eventually enters the groundwater and enters the lake. This can also lead to accelerated aquatic weed growth. For complete guidance download and read the EPA guidebook on septic tanks for homeowners at:
https://www3.epa.gov/npdes/pubs/homeowner_guide_short.pdf
- 6) Do not feed geese or other waterfowl as they defecate often and their droppings are high in nutrients, bacteria, and possibly lead to increased swimmer's itch events.
- 7) Water the lawn with lake water if at all possible since the nutrients in the water are ample and reduce the need for fertilizers.
- 8) Do not dump any leaves into the lake or any debris in nearby wetlands. The wetlands are there to filter incoming water and the leaves break down very slowly in the water.
- 9) Increase the presence of rain gardens and other pervious surfaces to allow rain and storm water to filter through vegetation prior to entering the lake.



Figure 65. A lush lawn in front of a lakefront property without a buffer (RLS, 2017).

7.3.4 Bear Lake Tributary Management Methods

The tributaries that contribute water to Bear Lake are vital resources for maintaining the quantity of water in Bear Lake. There is a tributary at the terminal end of Fenner's Ditch (Figure 66) and the Bear Creek inlet (Figure 67). The tributaries are also a source of nutrients and solids to the lake and thus are critical factors in protecting the water quality of Bear Lake. In April and July of 2017, scientists from RLS collected multiple water quality parameters from the tributaries to evaluate the health of the tributaries. Both tributaries contained elevated phosphorus concentrations that can contribute significant nutrient loads to Bear Lake during moderate to high water flow. These tributaries would benefit from a biological charcoal filter that can help adsorb phosphorus and reduce sediments and other nutrients that enter Bear Lake. The filters are placed along the width of the tributaries and may last up to five years before replacement is needed. Figure 68 demonstrates what the filters may look like.



Figure 66. Inlet #1: Terminal end of Fenner's Ditch Canal (RLS, 2017).



Figure 67. Inlet #2: Bear Creek and the flooded Celery Flats (RLS, 2017).



Figure 68. A tributary filter strip (photo courtesy of Lake Savers, LLC).

8.0 BEAR LAKE COMMUNITY INVOLVEMENT/CITIZEN ENGAGEMENT

A sustainable lake improvement/restoration program will include the riparians around the lake since their daily activities can have a marked impact on the lake progress and health. The following sections are intended to facilitate engagement of riparians who can be effective lake stewards for sustained lake improvements. Even without a scientific background, individual riparians can learn about basic lake and watershed principles and how they can make a difference with simple BMP's and other lake improvement methods.

8.1 Why Citizen Involvement is Recommended

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

a community). In other words, these two capitals are not mutually exclusive once a person has interacted with an environment (lake). Thus, riparians have both the capacity to degrade water quality and improve water quality.

8.2 How the Bear Lake Community Can Participate in Lake Improvements

Bear Lake riparians are encouraged to attend regular BLLB meetings that are held regularly to discuss data trends and evaluate lake improvement progress. Additionally, riparians would be encouraged to attend the annual lake workshop. Education alone (i.e. meetings, brochures, etc.) will not adequately introduce all riparians to lake issues as many people are participatory learners. There is therefore a need to incorporate different educational strategies into this lake restoration program. RLS proposes to develop an annual lake workshop where new data is presented (including post-BMP implementation data) to the public and new research information is disseminated. Riparian BMP's would be openly discussed with attendants. There would be handouts at the workshop with modernized lake maps, water quality graphs, and other updated lake information. Lastly, there would be water quality sampling demonstrations along with key Bear Lake biota present in the lake available for learning.

9.0 BEAR LAKE RESTORATION PROJECT CONCLUSIONS & RECOMMENDATIONS

The information given above for the long-term management and restoration of Bear Lake should be considered for effective management and ultimate protection of the lake biota and water quality. The overall goal of this proposed management/restoration program is to measurably improve the water quality of Bear Lake through implementation of BMP's around the lake while immediate watershed improvements are made. Table 18 below describes the primary and secondary goals and locations for the proposed improvement methods. The following recommendations can be made for the proposed five year program:

- 1) A whole-lake survey and scan will be executed each year to accurately compare the changes in weed bed size and invasive species polygons in the lake over time. These surveys will result in lake scans of aquatic vegetation bio volume, sediment hardness, and maps showing the locations of all invasive species and their relative abundance. These surveys will be instrumental for determining the efficacy of aquatic plant control activities and for measuring lake restoration goals relative to native aquatic plant communities.

- 2) 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 Bear Lake. An overall goal should be to have as many of the original weed beds restored on the lake as possible since the lake only contains 23% cover. 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.
- 3) Thirty Bear Lake sediment cores (4-6 feet in thickness) will be collected from the bottom sediments in Bear Lake to evaluate for possible petroleum residues. Each core will be analyzed in the top, middle, and bottom sections for petroleum residue, chlorides, and heavy metals.
- 4) Lake and tributary water quality sampling will be conducted in spring and summer of each year for parameters such as water temperature, pH, dissolved oxygen, conductivity, total dissolved solids, total (and ortho-phosphorus), total nitrogen, chlorophyll-a, Secchi transparency, algal community composition and zooplankton.
- 5) If laminar flow aeration is implemented in future years of the program, monitoring per the MDEQ protocol guidelines consist of the water quality parameters above at eight different sampling locations to determine how the system would be affecting the water quality, algae, biota, and vegetation in Bear Lake.
- 6) Implementation of tributary buffers at the two inlets to improve lake water quality through reduction of nutrients and solids to the lake. Determination of efficacy of the filters would be determined through action item #4.
- 7) If a boat washing station is implemented, then an educational program executed by both the BLA and the BLLB is recommended. This program would include the elements described above that support the Clean Waters Clean Boats program.
- 8) Benthic macroinvertebrates would be sampled again during years 4 and 5 post-BMP implementation to determine impacts of these improvements on benthic macroinvertebrate biodiversity.
- 9) Community Engagement through an annual hands-on Bear Lake learning workshop and numerous BLLB meetings with an annual report presented each year showing trend data and measurement of BMP efficacy and restoration program progress.

Table 18. Proposed lake restoration methods for Bear Lake's Five-year plan.

Lake Management Activity/Duration	Primary Goal	Secondary Goal	Best Locations to Use
Lake Vegetation Surveys/Scans (Annually)	To determine % cover by invasives and use as data tool	To compare year to year reductions in invasive vegetation areas	Main Lake, Canal
Aquatic herbicide treatment of hybrid milfoil/<i>Phragmites</i>/Invasives (Annually)	To reduce areas where the milfoil/ <i>Phragmites</i> are dense	To prevent further spread in/around lake	Main Lake and shoreline (only dense areas of growth)
Sampling of sediment for petroleum, chlorides, metals (First two years)	To determine if oil residues are present throughout Bear Lake bottom	To determine if aeration technology can be safely used in lake	Main Lake, Canal (?)
Sampling of lake water quality for parameters similar to this study (Annually)	To measure changes in lake water quality with time	To determine if BMP implementation is improving water quality	Main Lake/Tribs/Canal
Laminar Flow Aeration/Bioaugmentation (If approved, begin in Year 3 to on-going)	To aerate lake, reduce blue-green algae, increase water clarity	Reduce hypereutrophic state of lake	Main Lake (possibly Canal)
Tributary Nutrient Barriers (Year 1-on-going)	To reduce nutrients and solids entering Bear Lake	To reduce blue-green algae growth associated with incoming nutrients	In front of the Flats/Bear Creek
Boat Washing Station (Year 2-ongoing)	To clean boats of invasives before entering the lake	To educate boaters on the proper cleaning of boats and on invasives	At main access site on lake
Macroinvertebrate Sampling (Years 4-5)	To compare post-implementation biodiversity to baseline	To create an IBI for the lake to measure changes in lake health	Main Lake
Community Engagement/Riparian Education/Workshop (As scheduled)	To empower local riparians/stakeholders to better understand Bear Lake ecosystem	To educate riparians/stakeholders on lake BMP's for better lake protection	Annual lake meeting w/Report/Workshop and regular BLLB Meetings

9.1 Cost Estimates for Bear Lake Improvements

The proposed lake management and restoration program for the improvements of Bear Lake would begin during the 2018 season and continue through 2022. Implementation of items listed in Table 18 above would take place in the years listed so the annual budget will vary among years. A breakdown of estimated costs associated with the proposed improvements for Bear Lake is presented in Table 19. 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) or other costs such as administrative tasks.

Table 19. Proposed lake improvement costs for the five year Bear Lake restoration program.

<i>Proposed Bear Lake Management Improvement Item</i>	<i>Estimated 2018 Cost</i>	<i>Estimated 2019 Cost</i>	<i>Estimated 2020 Cost</i>	<i>Estimated 2021-2022 Cost</i>
Herbicides for removal of invasives, Permit Fees ¹	\$20,000	\$20,000	\$18,000	\$18,000
Professional Limnologist Services (limnologist surveys, all lake sampling, meetings, workshops reports, contractor oversight, education) ²	\$50,000	\$50,000	\$38,000	\$38,000
Attorney Fees	\$5,000	\$5,000	\$5,000	\$5,000
Assessment Appeals	\$3,000	\$3,000	\$3,000	\$3,000
Lake-Wide Aeration System/Bioaugmentation	\$0	\$0	\$90,000	\$75,000
Tributary Filter Buffers/Maintenance	\$45,000	\$5,000	\$5,000	\$5,000
Boat Washing Station/Maintenance	\$20,000	\$3,000	\$3,000	\$3,000
Audit, Bond, Insurance	\$1,400	\$1,400	\$1,400	\$1,400
Professional Memberships	\$100	\$100	\$100	\$100
Mailings, Publication	\$2,000	\$0	\$0	\$2,000
Contingency (15%) ³	\$14,640	\$8,750	\$16,350	\$15,050
TOTAL ANNUAL ESTIMATED COST	\$161,040	\$96,250	\$179,850	\$165,550
APPROX. ANNUAL COST PER UNIT OF BENEFIT⁴	\$TBD	\$TBD	\$TBD	\$TBD

¹ Herbicide treatment scope for the treatment of Hybrid watermilfoil and *Phragmites* is proposed to decline annually due to aggressive treatment with the use 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 all regularly scheduled Bear Lake Improvement Board meetings, annual lake engagement workshop, all water quality sampling, sediment sampling, zooplankton and macroinvertebrate sampling, annual lake progress report. 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 15% 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.

⁴ Current study estimates based on XYZ units of benefit. This value is subject to change as the SAD is refined or changed by the BLLB.

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11.0 GLOSSARY OF TERMS

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

Anaerobic: The absence of oxygen (also anoxic).

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Zooplankton: Microscopic animals that live in lakes.