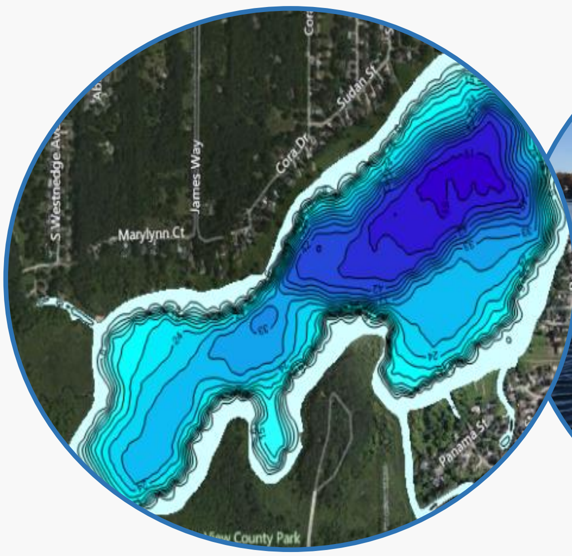
Gourdneck/Hogsett Lakes Improvement Feasibility Study & Management Plan Kalamazoo County, Michigan



Provided for the Gourdneck Lake Improvement Board
Pursuant to P.A. 451 of 1994, as amended

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December, 2016

1.0 EXECUTIVE SUMMARY

Gourdneck Lake, comprising 218 acres, is of natural glacial origin with nearly 5.22 miles of shoreline (including the canals) and a maximum depth of 52 feet and a mean depth of 21.3 feet. The lake has a water volume of approximately 4,860 acre-feet. The major inlet and outlet of the lake is Gourdneck Creek which enters the lake on the west region and exits the lake at the southeast region and drains to Portage Creek. Another inlet enters the lake at the northwest corner from the Sugarloaf Lakes. Based on the current study, Gourdneck Lake contains an excellent native aquatic plant biodiversity (26 native species) but the exotic submersed macrophyte Eurasian Watermilfoil (*Myriophyllum spicatum* L.; EWM) growth threatens the biodiversity of the submersed native aquatic macrophyte communities, may threaten navigation and recreational activities, and also may harbor bacteria and other nuisance algae that are not beneficial to the lake's ecosystem. It currently occupies approximately 17.4 acres of the lake surface area. Additionally, three other invasives were found in and around the lake and include Curly-leaf Pondweed, Purple Loosestrife, and *Phragmites*, and were all very low in abundance but are still an ecosystem threat.

Gourdneck Lake's overall water quality was measured as good with moderate to low nutrients such as phosphorus and moderate to high nitrogen which means the lake is P-limited. The lake water also had high water clarity. The bottom phosphorus concentration in the deepest basin was quite high and is a reason that algae and submersed aquatic vegetation can be problematic.

Hogsett Lake comprising 81 acres, is of natural glacial origin with nearly 1.55 miles of shoreline. The average depth of Hogsett Lake was 13.4 feet and the maximum depth was 30 feet. It also contained approximately 11.9 acres of Eurasian Watermilfoil as well as sparse amounts of Curly-leaf Pondweed, Phragmites, and Purple Loosestrife. The water quality in Hogsett was excellent with low nutrients and high water clarity.

The lakes share an immediate watershed of approximately 5,197 acres and receive water from precipitation, inlets, and springs. The large size of the immediate watershed may compromise water quality. Additionally, the primary soils around the lake are mucks that are prone to saturation and ponding and thus runoff management is critical.

The lakes contains 24 different species of fish and thus contains a very high biodiversity of lake fish (Michigan Department of Natural Resources, 2001).

Restorative Lake Sciences, LLC recommends that spot-treatments using systemic aquatic herbicides for the invasive watermilfoil and contact herbicides for nuisance native aquatic plants be used for aquatic plant management. The quantity of organic matter in the lake sediments is highly variable among sampling sites and thus the use of aeration to biodegrade muck would yield differential results among these locations. Gourdneck Lake is a good candidate for whole-lake aeration with bio augmentation (microbes and enzyme addition) for the primary purpose of destratification of the lake water which would increase dissolved oxygen throughout the lake or aeration technology may be placed in the deep basins to reduce phosphorus release at the lake bottom and prevent anoxic (low dissolved oxygen) conditions at the lake bottom.

Since both lakes are surrounded by highly mucky soils, it is important for waterfront property residents to execute proper Best Management Practices (BMP’s) to reduce ponding on the soils which can contribute runoff with soils and nutrients to the lakes.

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 riparians with a better understanding of the forthcoming lake management recommendations for Gourdneck Lake.

2.1.1 Lake Hydrology

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

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

Some lakes (seepage lakes) contain closed basins and lack inlets and outlets, relying solely on precipitation or groundwater for a water source. Seepage lakes generally have small watersheds with long hydraulic retention times which render them sensitive to pollutants. Drainage lakes receive significant water quantities from tributaries and rivers. Drainage lakes contain at least one inlet and an outlet and generally are confined within larger watersheds with shorter hydraulic retention times. As a result, they are less susceptible to pollution. Spring-fed lakes rarely contain an inlet but always have an outlet with considerable flow. The majority of water in this lake type originates from groundwater and is associated with a short hydraulic retention time. Drained lakes are similar to seepage lakes, yet rarely contain an inlet and have a low-flow outlet. The groundwater and seepage from surrounding wetlands supply the majority of water to this lake type and the hydraulic retention times are rather high, making these lakes relatively more vulnerable to pollutants. The water quality of a lake may thus be influenced by the quality of both groundwater and precipitation, along with other internal and external physical, chemical, and biological processes. Gourdneck Lake is categorized as a drainage lake since it receives water from inlets and contains an outlet. It also has springs that contribute water at the north and east shores. Hogsett

Lake is categorized as a drainage lake since it has numerous intermittent inflows and flows out to Gourdneck Lake.

2.1.2 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 man and development, while preserving sensitive or rare habitats. As a result of this, undisturbed or protected areas generally contain a greater number of biological species and are considered more diverse. A highly diverse aquatic ecosystem is preferred over one with less diversity because it allows a particular ecosystem to possess a greater number of functions and contribute to both the intrinsic and socio-economic values of the lake. Healthy lakes have a greater biodiversity of aquatic macroinvertebrates, aquatic macrophytes (plants), fishes, phytoplankton, and may possess a plentiful yet beneficial benthic microbial community (Wetzel, 2001).

2.1.3 Watersheds and Land Use

A watershed is defined as an area of land that drains to a common point and 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 eco-system, 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.

Land use activities, such as residential land use, industrial land use, agricultural land use, water supply land use, wastewater treatment land use, and stormwater management, can influence the watershed of a particular lake. All land uses contribute to the water quality of the lake through the influx of pollutants from non-point sources or from 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. 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 GOURDNECK & HOGSETT LAKES PHYSICAL & WATERSHED CHARACTERISTICS

3.1 The Gourdneck & Hogsett Lake Basins

Gourdneck Lake is located in Section 3 of Schoolcraft Township (T4S, R11W) in Kalamazoo County, Michigan. The lake has a surface area of approximately 218 acres (Michigan Department of Natural Resources, 2001; Figure 1) and is classified as a mesotrophic aquatic ecosystem with two deep basins and a small-sized littoral (shallow) zone. Gourdneck Lake has a mean (average) depth of 21.3 feet and maximum depth of 52 feet and contains two inlets at the west end of the lake that empty from the Sugarloaf Lakes and from Hogsett Lake and an outlet which empties at the south end of the lake to Sunset Lake via Gourdneck Creek. There are also some springs present near shore along the north and east shores. The lake bottom consists primarily of marl (calcium carbonate which is common in hard waters) and also of muck, fibrous peat, sand, pulpy peat, and gravel. Gourdneck Lake has a lake perimeter of approximately 5.22 miles which includes the canals (RLS, 2016).

Hogsett Lake is located in Sections 3 and 4 of Schoolcraft Township and the City of Portage (T4S, R11W) in Kalamazoo County, Michigan. The lake has a surface area of approximately 81 acres (Michigan Department of Natural Resources, 2001; Figure 2) and is classified as a mesotrophic aquatic ecosystem with a single deep basin and a small-sized littoral (shallow) zone. Hogsett Lake has a mean (average) depth of 13.4 feet and maximum depth of 30 feet and contains multiple intermittent inlets around the lake and flows into Gourdneck Lake. The lake bottom consists primarily of pulpy peat, marl (calcium carbonate which is common in hard waters) and sand. Hogsett Lake has a lake perimeter of approximately 1.55 miles (RLS, 2016),

RLS performed whole-lake scans of both lakes on November 4, 2016. A WAAS-enabled Lowrance HDS 9 GPS unit with transducers was used to send signals to the lake bottom to detect relative hardness, depth contours, and aquatic vegetation biovolume (discussed later). The data was then uploaded to a BioBase algorithm-derived software to compute these parameters and create statistics. Figures 3 and 4 below demonstrate the modernized depth contours of both lakes.

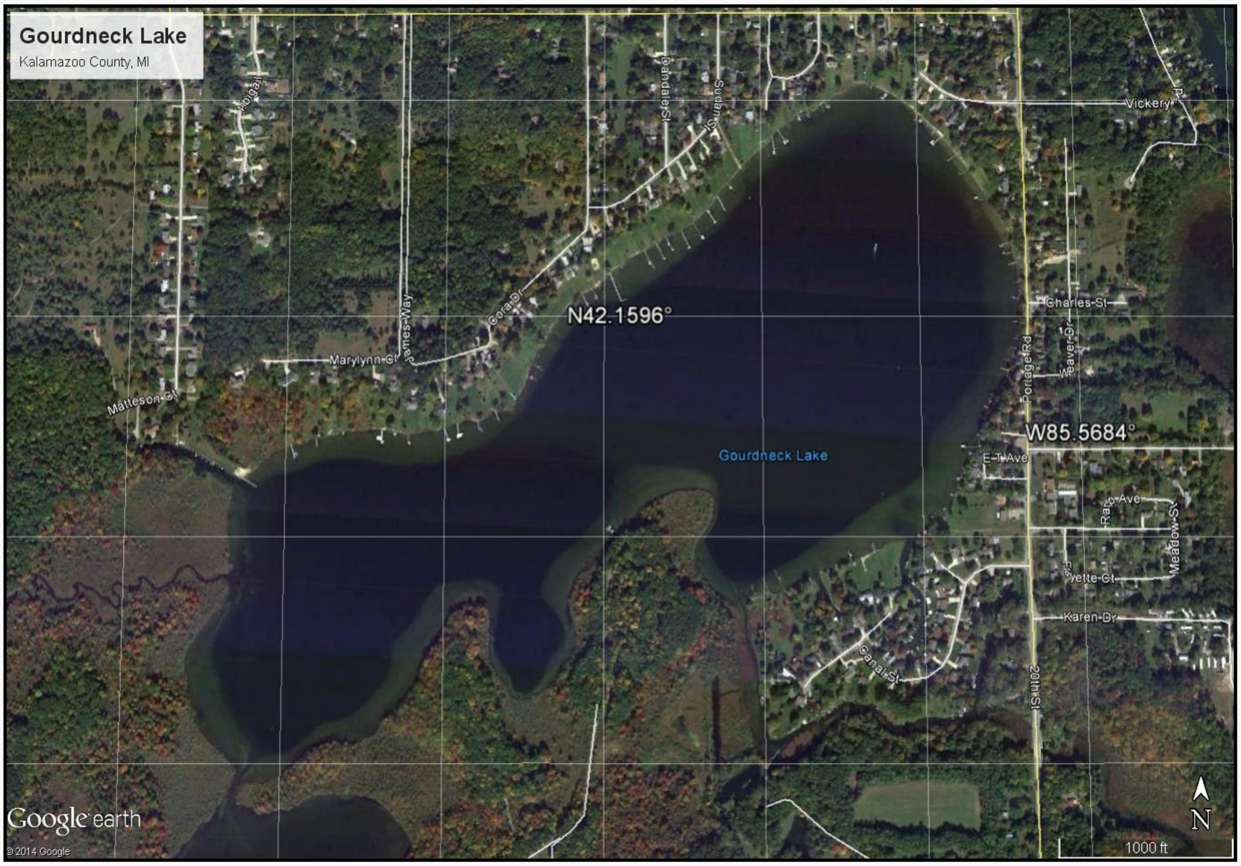

Figure 1. Gourdneck Lake, Schoolcraft Township and City of Portage, Kalamazoo County, Michigan.

Figure 2. Hogsett Lake, Schoolcraft Township, Kalamazoo County, Michigan.

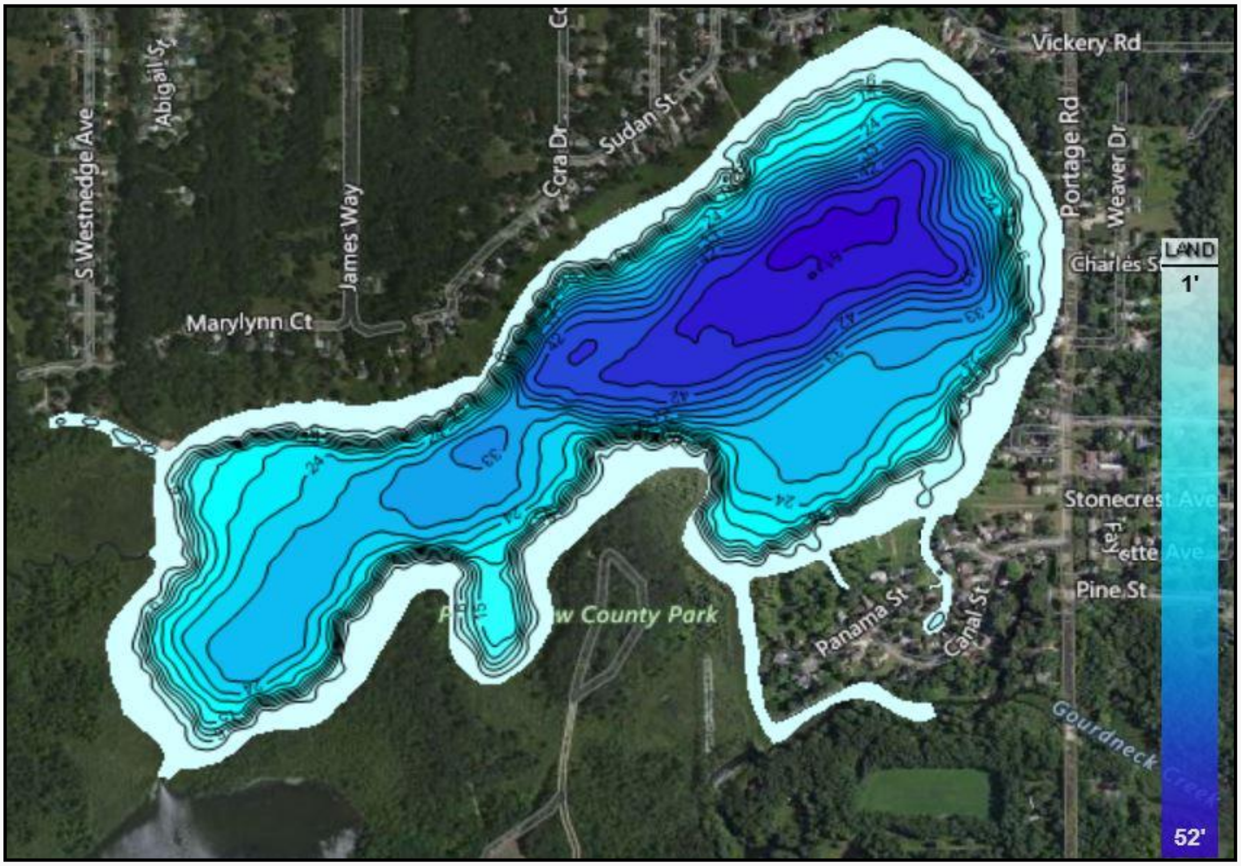

Figure 3. Gourdneck Lake depth contour map (November, 2016).

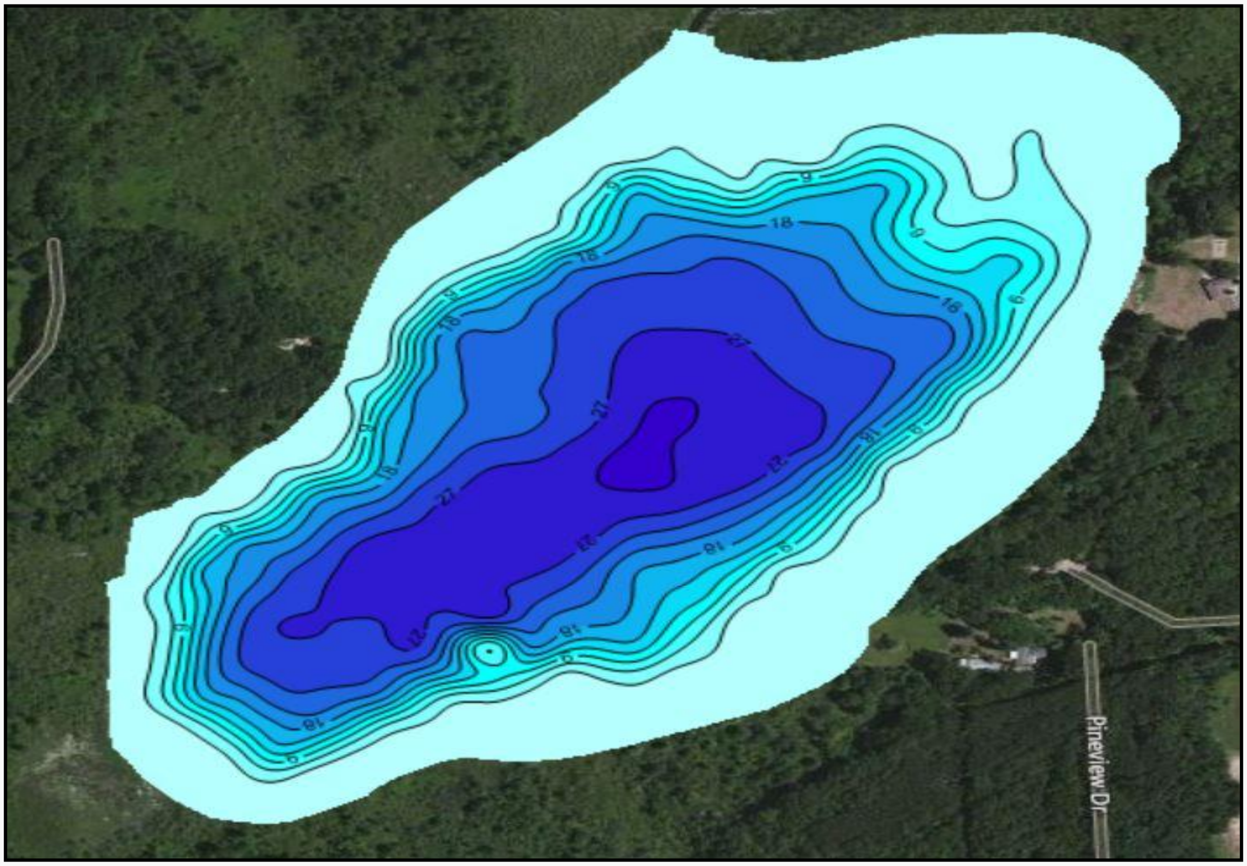

Figure 4. Hogsett Lake depth contour map (November, 2016).

3.2 Gourdneck/Hogsett Lakes Extended and Immediate Watershed

Gourdneck Lake is located within the Portage River sub-watershed which is approximately 125,539 acres (approximately 196 mi^2) in area and includes portions of Kalamazoo and St. Joseph counties, (Michigan Department of Environmental Quality, 2008). The Portage River Watershed is a sub watershed of the St. Joseph River Watershed which drains 4,685 mi^2 from 15 counties, including Berrien, Branch, Calhoun, Cass, Hillsdale, Kalamazoo, St. Joseph, and Van Buren in the state of Michigan, and De Kalb, Elkhart, Kosciusko, Lagrange, Noble, St. Joseph, and Steuben in the state of Indiana. The majority of the extended watershed is agricultural, with 25-50% remaining forested.

Gourdneck Lake's immediate watershed consists of the area around the lake which directly drains to the lake and measures approximately 5,197 acres (8.1 mi^2) in size (Figure 5). The moderate amount of development around the lake reduces pollutant runoff during rain events due to less impervious cover. Additionally, the wetlands near the west end of the lake assist with the filtration of nutrients that exit the land to the lake during heavy rain events. Furthermore, the immediate watershed is approximately 23.4 times larger than the size of Gourdneck Lake, which indicates the presence of a large immediate watershed. Large watersheds are often associated with more abundant nutrients that can compromise water quality and lead to accelerated algae and aquatic plant growth.

The Gourdneck State Game Area located is located along a portion of the west shore of the lake, whereas the north and eastern regions of the shoreline are developed by the City of Portage.

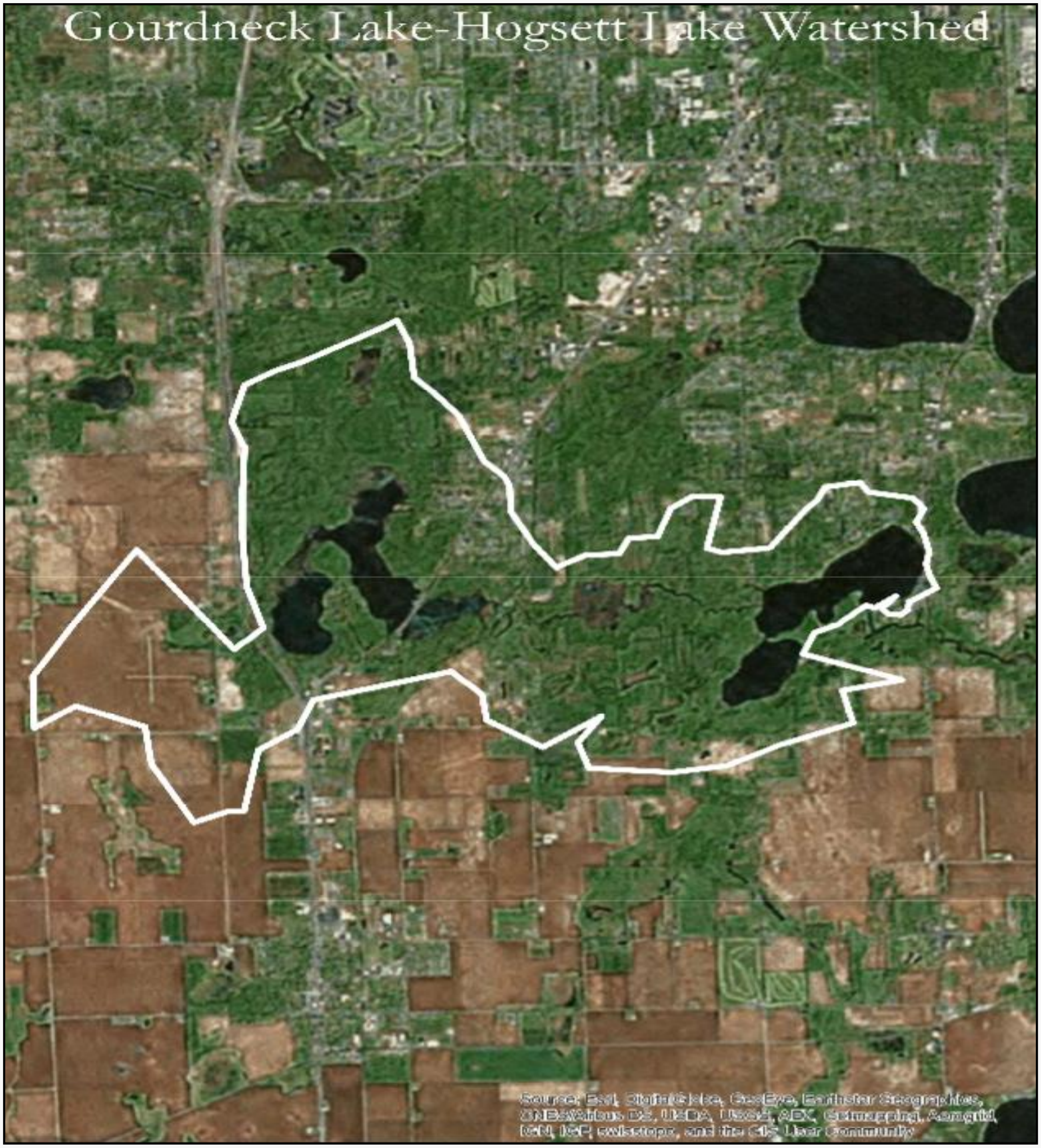

Figure 5. Gourdneck/Hogsett Lakes Immediate Watershed boundary.

3.3 Gourdneck/Hogsett Lakes Shoreline Soils

There are 3 major soil series types immediately surrounding Gourdneck Lake which may impact the water quality of the lake and may dictate the particular land use activities within the area. Figures 6 and 7 (created with data from the United States Department of Agriculture and Natural Resources Conservation Service, 1999) demonstrates the precise soil types and locations around Gourdneck and Hogsett lakes. Major characteristics of the dominant soil types directly surrounding the Gourdneck Lake and Hogsett Lake shorelines are listed in Tables 1 and 2 below, respectively.

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

USDA-NRCS Soil Series	***Gourdneck Lake Location***	***Prominent Soil Type Characteristics***
Houghton Muck (0-1% slopes); Hn	north, west, south shores	poorly drained soils; prone to ponding
Oshtemo Sandy Loam (1-6% slopes);OsB	east shore	very deep well drained soils; low slope
Oshtemo Sandy Loam (6-12% slopes);OsC	south shore	very deep well drained soils; high slope

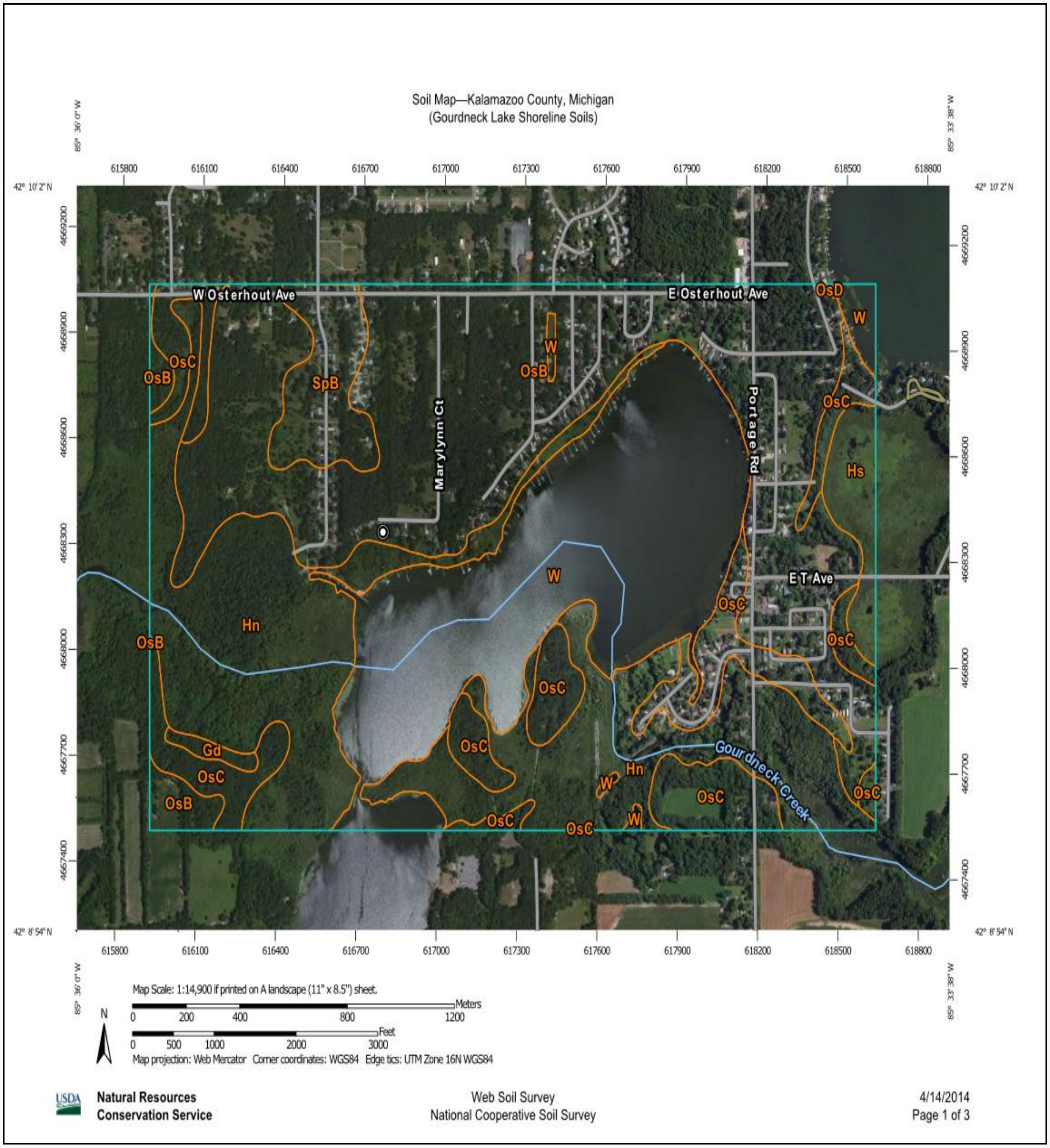

Figure 6. NRCS-USDA soils map for Gourdneck Lake shoreline soils (NRCS-USDA data).

Table 2. Hogsett Lake Shoreline Soil Types (USDA-NRCS, 1999).

USDA-NRCS Soil Series	***Hogsett Lake Location***	***Prominent Soil Type Characteristics***
Houghton Muck (0-1% slopes); Hn	north, west, south, east shores	poorly drained soils; prone to ponding
Oshtemo Sandy Loam (1-6% slopes);OsB	east shore	very deep well drained soils; low slope
Oshtemo Sandy Loam (6-12% slopes);OsC	north, east shores	very deep well drained soils; high slope

Figure 7. NRCS-USDA soils map for Hogsett Lake shoreline soils (NRCS-USDA data).

The majority of Hogsett Lake and Gourdneck Lake are immediately surrounded by mucky soils (Houghton mucks) that are prone to saturation or ponding. Ponding occurs when water cannot permeate the soil and accumulates on the ground surface which then may runoff into nearby waterways and carry nutrients and sediments into the water. Excessive ponding of such soils may lead to flooding of some low-lying shoreline areas, resulting in nutrients entering the lake via surface runoff since these soils do not promote adequate drainage or filtration of nutrients. Sandy soils are however vulnerable to septic tank effluent since the drain field discharge can enter the sands and eventually migrate to the water table into the lake. However, in areas around the lakes where the slopes are greater than 6% (the north and east shores), surface runoff may be a factor, transporting sediments and nutrients to the lakes. Accordingly, every effort to implement low impact development (LID) techniques for construction of pervious surfaces and construction of septic systems close to the lake should be followed. Tips on this are offered in section 6.2 of this report.

Many of the shoreline protection structures around the lakes consisted of either seawalls or tall emergent grasses that help stabilize soils and prevent erosion. Metal and concrete seawall structures that may absorb wave energy and minimize shoreline recession but do not provide wildlife benefits of natural shoreline vegetation. A “natural” shoreline is always encouraged for optimal lake health.

4.0 GOURDNECK/HOGSETT LAKES WATER QUALITY

Water quality is highly variable among Michigan's inland lakes, although some characteristics are common among particular lake classification types. The water quality of each lake is affected by both 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 3). 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. Gourdneck Lake is classified as mesotrophic. Hogsett Lake is also classified as mesotrophic.

Table 3. Lake Trophic Status Classification Table (MDNR).

Lake Trophic Status	***Total Phosphorus ($\mu g\ L^{-1}$)***	***Chlorophyll-a ($\mu g\ L^{-1}$)***	***Secchi Transparency (feet)***
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, turbidity and total dissolved solids, pH, total alkalinity, total phosphorus, total Kjeldahl nitrogen, sediment percentage of organic matter, chlorophyll-*a*, algal species, and Secchi transparency, respond to changes in water quality and consequently serve as indicators of lake health. On November 4, 2016, water samples from two lake deep basins of Gourdneck Lake and from one basin in Hogsett Lake. Samples were also collected from the inlets to both lakes. Sediment samples were collected previously by RLS in 2014 from Gourdneck Lake and this data is discussed below in terms of relevancy to recommended improvements. The results are discussed below and are presented in Tables 4-8. A map showing the sampling locations for all beep basin water quality samples is shown below in Figure 8.

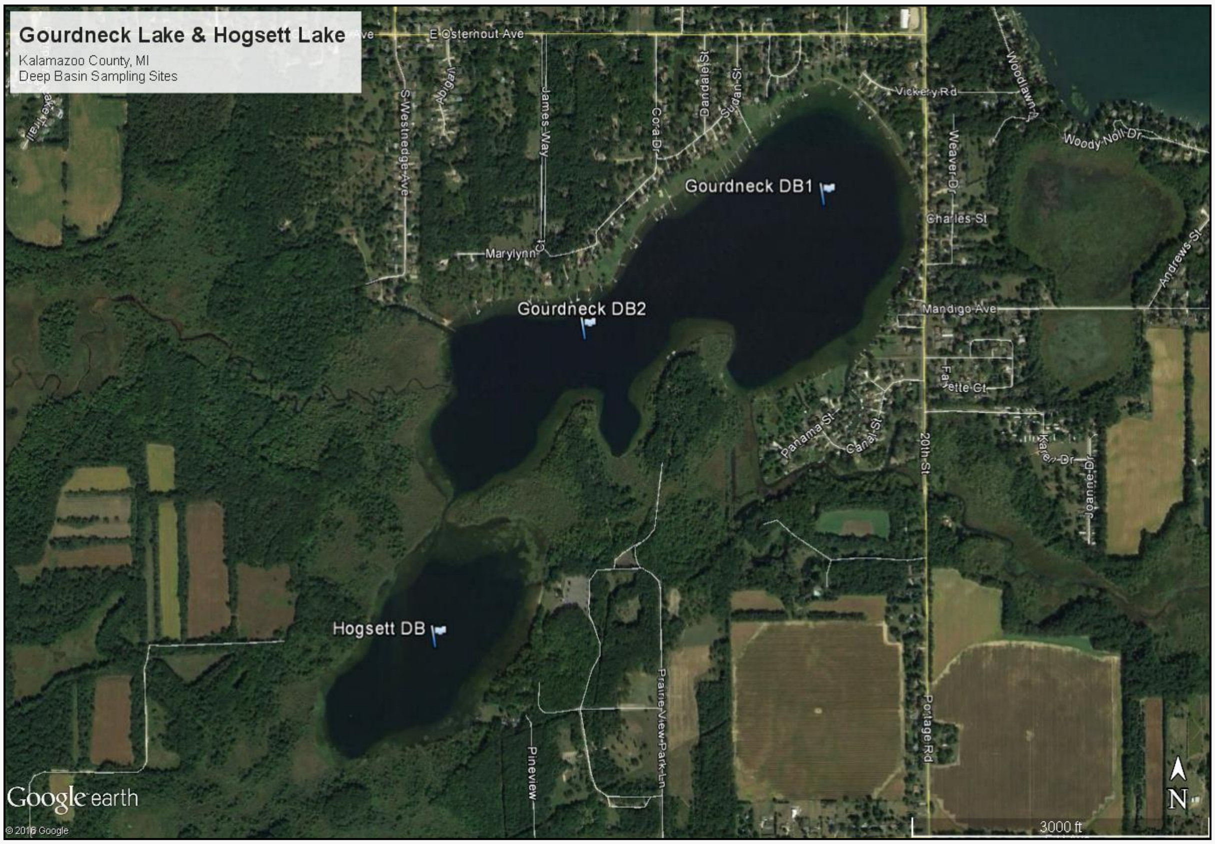

Figure 8. Deep basin water quality sampling sites in Gourdneck and Hogsett Lake, Kalamazoo County, Michigan (November 4, 2016).

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 on November 4, 2016 in milligrams per liter (mg L^{-1}) with the use of a calibrated dissolved oxygen meter. Dissolved oxygen concentrations in the deep basins of Gourdneck Lake ranged from 8.5–1.5 mg L^{-1}, with concentrations lower at depth and at the bottom of deep basin 1. The dissolved oxygen concentrations in Hogsett Lake ranged from 8.2-6.1 mg L^{-1} from the surface to the bottom. The dissolved oxygen concentration in the Hogsett Lake inlet was 8.0 mg L^{-1} and the dissolved oxygen concentrations in the Gourdneck Lake inlet from Sugarloaf Lakes ranged from 8.4-8.6 mg L^{-1}. Thus, the dissolved oxygen concentrations are all favorable except for in Gourdneck Lake beyond a depth of 40 feet. A value above 5.0 mg L^{-1} is preferred by the warm water fishery. 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. Historical review of legacy data collected by the MDEQ in 1996 revealed that Gourdneck Lake quickly loses dissolved oxygen below a depth of 25 feet during warm summer months. A decline in the dissolved oxygen concentrations to near zero may result in an increase in the release rates of phosphorus (P) from lake bottom sediments.

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. 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 Celsius (ºC) with the use of a submersible thermometer. The November 4, 2016 water temperatures of Gourdneck and Hogsett Lakes demonstrated the lack of a thermocline (a transition zone of change in water temperature from top to bottom) between the surface and depth in the deep basins. During that sampling event, water temperatures ranged from 14.5-10.2°C with the higher temperatures near the first two meters and the lower temperatures near the lake bottom. Both lakes had similar temperatures but the surface water in Hogsett Lake was slightly warmer, presumably due to being more sheltered from winds. Historical review of legacy data collected by the MDEQ in 1996 revealed that Gourdneck Lake experiences a temperature difference of 10°C from surface to bottom during summer months. A thermocline exists around 27 feet during late summer.

4.1.3 Conductivity

Conductivity is a measure of the amount of mineral ions present in the water, especially those of salts and other dissolved inorganic substances. Conductivity generally increases with water temperature and the amount of dissolved minerals and salts in a lake. Conductivity was measured in micro ohms per centimeter (µmho cm^{-1}) with the use of a calibrated conductivity probe and meter. Conductivity values for Gourdneck Lake ranged from 397-423 mS cm^{-1}, which was moderately high for an inland lake. Conductivity values for Hogsett Lake ranged from 350-419 mS cm^{-1} , which is also moderately high. The conductivity of the inlets ranged from 417-427 mS cm^{-1} which is slightly higher than the lakes and this is not uncommon for tributaries. Baseline parameter data such as conductivity are important to measure the possible influences of land use activities (i.e. road salt influences) on Gourdneck 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. Historical review of legacy data collected by the MDEQ in 1996 revealed that the conductivity in Gourdneck Lake ranged from 381-465 mS cm^{-1}. This range is slightly higher than the recent values and indicates that conductivity may be slightly declining in Gourdneck Lake.

4.1.4 Turbidity and Total Dissolved Solids

Turbidity is a measure of the loss of water transparency due to the presence of suspended particles. The turbidity of water increases as the number of total suspended particles increases. Turbidity may be caused by erosion inputs, phytoplankton blooms, stormwater discharge, urban runoff, re-suspension of bottom sediments, and by large bottom-feeding fish such as carp. Particles suspended in the water column absorb heat from the sun and raise water temperatures. Since higher water temperatures generally hold less oxygen, shallow turbid waters are usually lower in dissolved oxygen. Turbidity was measured in Nephelometric Turbidity Units (NTU's) with the use of a calibrated Lutron® turbidimeter. The World Health Organization (WHO) requires that drinking water be less than 5 NTU's; however, recreational waters may be significantly higher than that. The turbidity of Gourdneck Lake was favorably low and ranged from 1.1 – 4.1 NTU's during the sampling event. The turbidity of Hogsett Lake ranged from 1.9-3.9 NTU's. The turbidity of the inlets ranged from 2.0-4.1 NTU's. The lake bottoms are usually comprised of soft sediments which is easily moved from water turbulence and wave action and thus bottom readings tend to be higher in most lakes. RLS could not find any historical data for this parameter.

Total Dissolved Solids

Total dissolved solids (TDS) is the 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. Total dissolved solids were measured with the use of a calibrated TDS meter and 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 TDS in Gourdneck Lake ranged from 69-85 mg L^{-1}. The TDS in Hogsett Lake ranged from 75-85 mg L^{-1} which is slightly higher than in Gourdneck Lake. This may be due to an increase in wetlands around the lake that may contribute tannins or other dissolved solids to the lake water. The TDS of the inlets ranged from 60-85 mg L^{-1} which is similar to the lake values. All of these values are considered favorable for an inland lake. RLS could not find any historical data for this parameter for either of the lakes.

4.1.5 pH

pH is the measure of acidity or basicity of water. 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 was measured with a calibrated pH electrode and pH-meter in Standard Units (S.U). The pH of Gourdneck Lake water samples were all at 8.4 S.U. which is favorable and very consistent with depth. The pH of water in Hogsett Lake was more variable and ranged from 8.0-8.5 S.U. The pH of the inlets ranged from 8.3-8.5 S.U. Historical review of legacy data collected by the MDEQ in 1996 revealed that the pH in Gourdneck Lake ranged from 7.5-8.4 S.U. From a water quality perspective, Gourdneck Lake is considered slightly basic or "alkaline" on the pH scale. RLS could not find any historical data for this parameter for Hogsett Lake.

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 $CaCO_3$) are able to tolerate larger acid inputs with less change in water column pH. Many Michigan lakes contain high concentrations of $CaCO_3$ and are categorized as having "hard" water. Total alkalinity was measured in milligrams per liter of $CaCO_3$ through an acid titration method. The total alkalinity of Gourdneck Lake is considered "elevated" (> 150 mg L^{-1} of $CaCO_3$), and indicates that the water is alkaline. Total alkalinity in Gourdneck Lake ranged from 130-210 mg L^{-1} of $CaCO_3$ during the sampling event. Total alkalinity in Hogsett Lake was 150 mg L^{-1} of $CaCO_3$ at all depths. Historical review of legacy data collected by the MDEQ in 1996 revealed that the total alkalinity of Gourdneck Lake ranged from 147-196 mg L^{-1} of $CaCO_3$. This value indicates a moderately high alkalinity which means that Gourdneck Lake is a "hardwater" system. 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 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 0.20 mg 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 milligrams per liter (mg L^{-1}) with the use of a chemical auto analyzer. TP concentrations in Gourdneck Lake <0.010-0.140 mg L^{-1} which is a very broad range and indicates some internal loading of phosphorus at the lake bottom. During periods of low dissolved oxygen, this TP can be released into the water column and exacerbate algae and aquatic plant growth. The TP concentrations in Hogsett Lake were all <0.010 mg L^{-1} which is quite low. This may be due to the ability of surrounding wetlands to absorb phosphorus and also lack of much development and associated nutrients from septage or sewers. The TP concentrations in the inlets ranged from <0.010-0.015 mg L^{-1}, which is quite low. These numbers indicate a low to moderately nutrient-rich lake but are low relative to most lakes of the same size and depth with the exception of the deepest basin in Gourdneck Lake which exhibits some internal loading of phosphorus.

4.1.8 Total Kjeldahl Nitrogen

Total Kjeldahl Nitrogen (TKN) is the sum of nitrate (NO_3^-), nitrite (NO_2^-), ammonia (NH_4^+), and organic nitrogen forms in freshwater systems. Much nitrogen (amino acids and proteins) also comprises the bulk of living organisms in an aquatic ecosystem. Nitrogen originates from atmospheric inputs (i.e. burning of fossil fuels), wastewater sources from developed areas (i.e. runoff from fertilized lawns), agricultural lands, septic systems, and from waterfowl droppings. It also enters lakes through groundwater 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. TKN was measured in milligrams per liter (mg L^{-1}) with the use of a chemical auto analyzer. Gourdneck Lake contained variable concentrations of TKN that ranged from 0.6-3.2 mg L^{-1}. Thus, the N: P ratio in Gourdneck Lake is 36 which indicates a P-deficient system and one higher in nitrogen. P-deficient lakes are highly vulnerable to increased runoff inputs of phosphorus. The TKN in Hogsett Lake ranged from 0.8-1.2 mg L^{-1}. The N: P ratio of in Hogsett Lake was 100 which indicates a highly P-deficient lake with high nitrogen concentrations. Historical review of legacy data collected by the MDEQ in 1996 revealed that the TKN of Gourdneck Lake ranged from 0.4-1.5 mg L^{-1} which is within the range sampled during this study. No data were available for historical TKN concentrations in Hogsett Lake.

4.1.9 Chlorophyll-a and Algae

Chlorophyll-*a* is a measure of the amount of green plant pigment present in the water, often in the form of planktonic algae. High chlorophyll-*concentrations* are indicative of nutrient-enriched lakes. Chlorophyll-*a* concentrations greater than 6 µg L^{-1} are found in eutrophic or nutrient-enriched aquatic systems, whereas chlorophyll-*a* concentrations less than 2.2 µg L^{-1} are found in nutrient-poor or oligotrophic lakes. Chlorophyll-*a* was measured in micrograms per liter (µg L^{-1}) with the use of a calibrated in situ fluorimeter (Turner Designs). The chlorophyll-*a* concentrations in Gourdneck and Hogsett Lakes were collected as a composite sample of the algae throughout the water column at each of the two deep basin sites from just above the lake bottom to the lake surface. The chlorophyll-*a* concentration in deep basin was 0 µg L^{-1} and deep basin 2 had a value of 1.0 µg L^{-1} during the sampling event. The chlorophyll-*a* concentration in deep basin of Hogsett Lake was 1.0 µg L^{-1}. These values are quite low for inland lakes of similar size and depth. It is likely that these values are higher in the spring after spring runoff or in late summer when water temperatures increase and lead to the growth of algae in the water column (planktonic form) or on the surface (filamentous form).

Algal genera from a composite water sample collected over the deep basins of Gourdneck and Hogsett Lakes and were analyzed under a compound brightfield microscope. The genera present in both lakes included the Chlorophyta (green algae): *Scenedesmus* sp., *Haematococcus* sp., *Chlorella* sp., *Ulothrix* sp., *Rhizoclonium* sp., *Zygnema* sp., *Spirogyra* sp., *Gleocystis* sp., *Pandorina* sp., *Protococcus* sp., *Ankistrodesmus* sp., and *Chroococcus* sp., and *Chloromonas* sp. the Cyanophyta (blue-green algae): *Gleocapsa* sp., *Microcystis* sp., and *Oscillatoria* sp.; the Bascillariophyta (diatoms): *Synedra* sp., *Cymbella* sp., *Navicula* sp., *Tabellaria* sp., *Melosira* sp., *Fragilaria* sp., *Nitzschia* sp., and *Asterionella* sp., The aforementioned species indicate a diverse algal flora and represent a relatively balanced freshwater ecosystem, capable of supporting a strong zooplankton community in favorable water quality conditions. These algae indicate a tendency towards green algae and diatoms which are good indicators of a healthy and productive lakes. There were some blue-green algae found in both samples but they were quite rare and there was an active blue-green algae bloom in the largest Gourdneck Lake canal during the study (Figure 9).

Figure 9. A nuisance blue green algae bloom in the Gourdneck Lake Canal (November, 2016).

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. Secchi transparency is measured in feet (ft.) or meters (m) 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 allow for more aquatic plant and algae growth. Eutrophic systems generally have Secchi transparency measurements less than 7.5 feet due to turbidity caused by excessive planktonic algae growth. The Secchi transparency of Gourdneck Lake was 15.0 feet in deep basin #1 and 17.5 feet in deep basin #2. The Secchi transparency in Hogsett Lake was 15.0 feet. All samples were collected under clear skies and low winds. This is another indicator of clear water. This transparency is adequate to allow abundant growth of algae and aquatic plants in the majority of the littoral 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.

4.1.11 Oxidative Reduction Potential

The oxidation-reduction potential (E_h) of lake water describes the effectiveness of certain atoms to serve as potential oxidizers and indicates the degree of reductants present within the water. In general, the Eh level (measured in millivolts) decreases in anoxic (low oxygen) waters. Low E_h values are therefore indicative of reducing environments where sulfates (if present in the lake water) may be reduced to hydrogen sulfide (H_2S). Decomposition by microorganisms in the hypolimnion may also cause the E_h value to decline with depth during periods of thermal stratification. The E_h (ORP) values for Gourdneck Lake ranged from 5.9-171 mV with lowest values near the bottom. The E_h (ORP) values for Hogsett Lake ranged from 69.2-155.5 mV with lowest values near the bottom. These values are within the normal range for most inland lakes in Michigan.

4.1.12 Sediment % Organic Matter

Organic matter (OM) contains a high amount of carbon that 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 allochthonus 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. Gourdneck Lake bottom sediment samples were collected at the sampling locations with the use of an Ekman hand dredge. The upper horizons of the sediment were kept intact for accurate evaluation of organic matter content in the upper layers. On April 16, 2014, RLS collected seven sediment samples from Gourdneck Lake which were placed on ice and taken to a laboratory for analysis of sediment total percentage of organic matter. Percentage of OM ranged from 5.5%-73%, which indicates highly variable sediments that contribute nutrients to rooted aquatic vegetation. The mean % of OM was 26.4% which is moderate. 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. Much of the organic matter present in Gourdneck Lake originates from glacial deposits and decayed aquatic vegetation. This information may be used for determining the probability of laminar flow aeration and bioaugmentation in reducing sediment muck and ultimately sediment nutrients that accelerate aquatic vegetation growth.

4.1.13 Sediment Bottom Hardness

RLS performed a benthic scan of both lake bottoms on November 4, 2016. A WAAS-enabled Lowrance HDS 9 GPS unit with transducers was used to send signals to the lake bottom to detect relative hardness, depth contours, and aquatic vegetation biovolume (discussed later). The data were then uploaded to a BioBase algorithm-derived software to compute these parameters and create statistics. Figures 10 and 11 below show the sediment bottom relative hardness in Gourdneck and Hogsett Lake, respectively. The red color represents firmer bottom whereas the orange color represents intermediate substrate and the light beige color represents soft mucky bottom. Both lakes have a high amount of soft bottom with firmer bottom being located nearshore and softer bottom occurring in offshore areas.

Table 4. Gourdneck Lake water quality parameter data collected in deep basin #1 (November 4, 2016).

Depth ft.	*Water Temp ºC*	*DO mg L^{-1}*	*pH S.U.*	*Cond. µS cm^{-1}*	*Turb. NTU*	*Total Kjeldahl Nitrogen mg L^{-1}*	*Total Alk. mgL^{-1} $CaCO_3$*	*Total Phos. mg L^{-1}*	*TDS mg L^{-1}*	*ORP*	*Chl-a µg L^{-1}*
0	13.5	8.5	8.4	421	1.1	0.6	160	<0.010	70	162.7	0
10	12.5	8.2	8.4	417	1.9	--	--	--	75	138.6	--
20	13.8	8.2	8.4	423	2.0	--	--	--	71	140.1	--
30	15.1	8.3	8.4	414	2.4	0.8	160	0.013	69	111.2	--
40	14.2	5.2	8.4	417	2.6	--	--	--	70	56.9	--
50	13.1	1.5	8.4	411	4.1	3.2	210	0.140	75	5.9	--

Table 5. Gourdneck Lake water quality parameter data collected in deep basin #2 (November 4, 2016).

Depth ft.	*Water Temp ºC*	*DO mg L^{-1}*	*pH S.U.*	*Cond. µS cm^{-1}*	*Turb. NTU*	*Total Kjeldahl Nitrogen mg L^{-1}*	*Total Alk. mgL^{-1} $CaCO_3$*	*Total Phos. mg L^{-1}*	*TDS mg L^{-1}*	*ORP*	*Chl-a µg L^{-1}*
0	13.6	8.2	8.4	420	1.4	0.6	170	<0.010	85	171.1	1.0
10	14.1	8.3	8.4	412	1.8	--	--	--	79	166.0	--
20	14.2	6.5	8.4	397	2.9	0.9	130	0.012	79	123.4	--
30	10.2	2.5	8.4	398	3.3	1.0	180	<0.010	70	80.1	--

Table 6. Hogsett Lake water quality parameter data collected in deep basin #1 (November 4, 2016).

Depth ft.	*Water Temp ºC*	*DO mg L^{-1}*	*pH S.U.*	*Cond. µS cm^{-1}*	*Turb. NTU*	*Total Kjeldahl Nitrogen mg L^{-1}*	*Total Alk. mgL^{-1} $CaCO_3$*	*Total Phos. mg L^{-1}*	*TDS mg L^{-1}*	*ORP*	*Chl-a µg L^{-1}*
0	14.0	8.2	8.5	419	1.9	0.8	150	<0.010	85	155.5	1.0
10	14.5	8.2	8.4	390	2.7	--	--	--	81	136.1	--
20	13.7	8.0	8.4	370	3.6	0.9	150	<0.010	80	114.6	--
30	13.1	6.1	8.0	350	3.9	1.2	150	<0.010	75	69.2	--

Table 7. Lake water quality parameter data collected in Gourdneck Lake Outlet to Sugarloaf (November 4, 2016).

Site #	*Water Temp ºC*	*DO mg L^{-1}*	*pH S.U.*	*Cond. µS cm^{-1}*	*Turb. NTU*	*Total Kjeldahl Nitrogen mg L^{-1}*	*Total Phos. mg L^{-1}*	*TDS mg L^{-1}*	*ORP* mV	*Chl-a µg L^{-1}*	*TSS mg L^{-1}*
1	12.7	8.5	8.4	427	2.0	--	--	60	146.1	1.0	--
2	13.1	8.6	8.4	420	4.1	0.6	<0.010	62	122.7	1.0	<10
3	13.2	8.4	8.3	417	2.9	0.9	0.012	69	119.1	1.0	<10

Table 8. Lake water quality parameter data collected in the Hogsett Lake Inlet (November 4, 2016).

Site #	*Water Temp ºC*	*DO mg L^{-1}*	*pH S.U.*	*Cond. µS cm^{-1}*	*Turb. NTU*	*Total Kjeldahl Nitrogen mg L^{-1}*	*Total Phos. mg L^{-1}*	*TDS mg L^{-1}*	*ORP*	*Chl-a µg L^{-1}*	*TSS mg L^{-1}*
1	14.4	8.0	8.5	421	3.9	1.0	0.015	85	155.5	1.0	<10

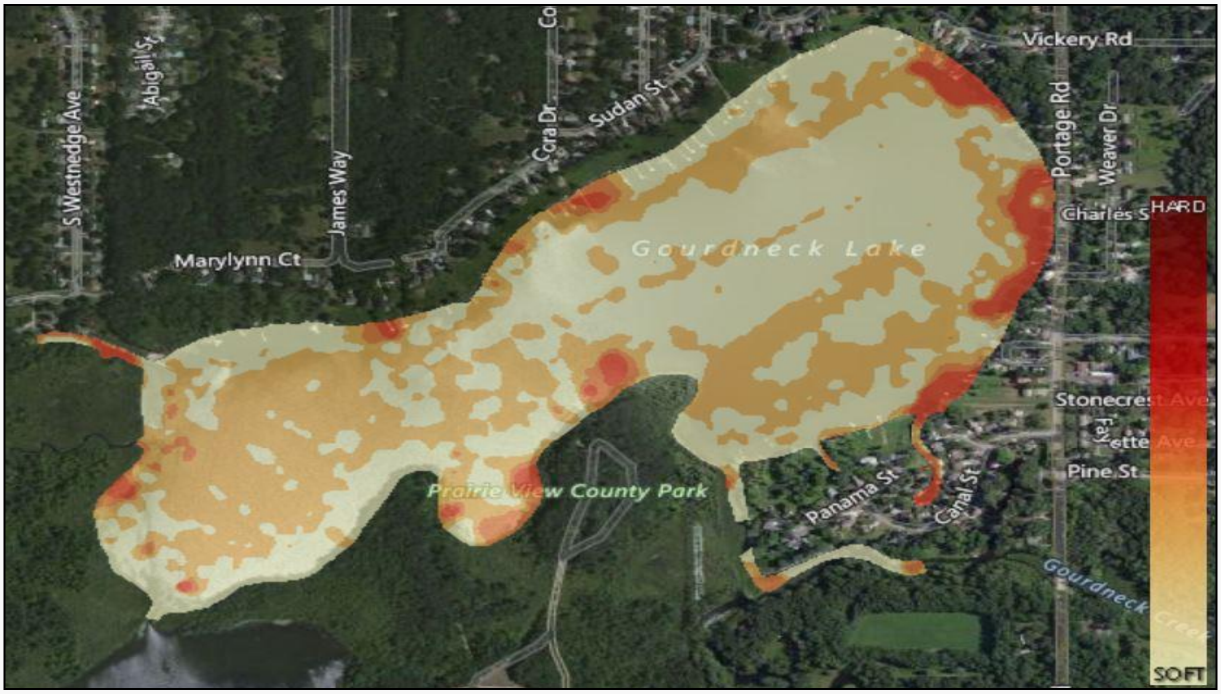

Figure 10. Gourdneck Lake sediment bottom hardness map (RLS, November, 2016).

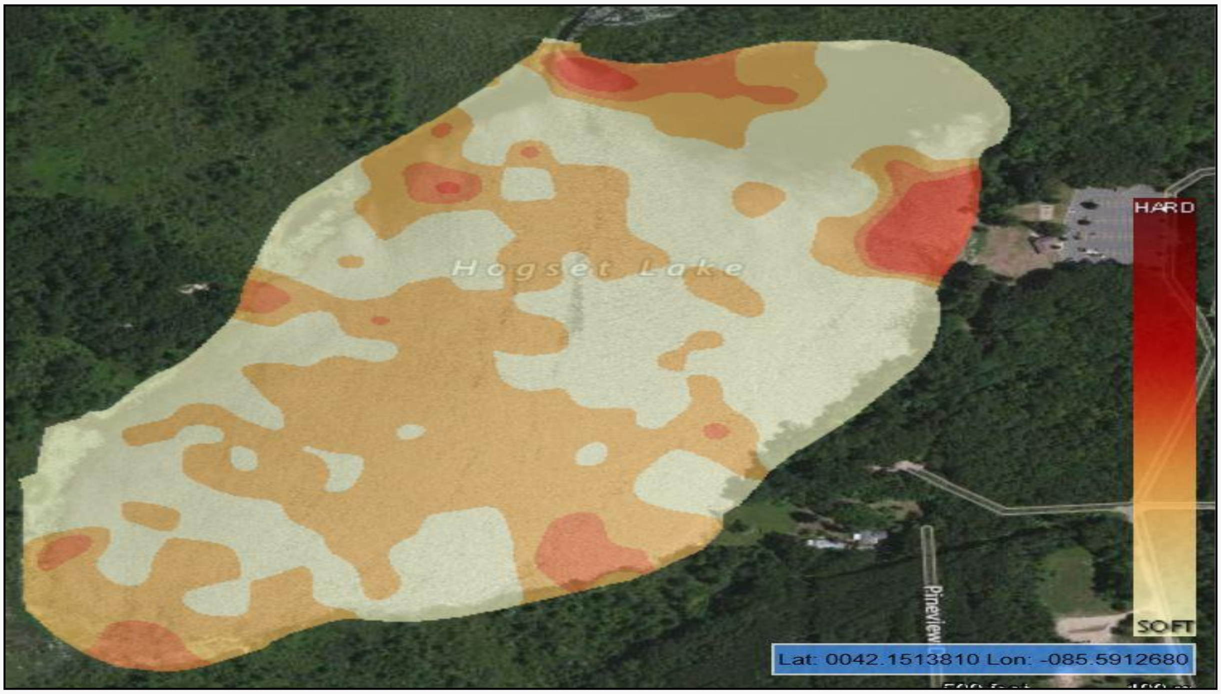

Figure 11. Hogsett Lake sediment bottom hardness map (RLS, November, 2016).

4.2 Gourdneck/Hogsett Lakes Aquatic Vegetation Communities

Aquatic plants (macrophytes) are an essential component in the littoral zones of most lakes in that they serve as suitable habitat and food for macroinvertebrates, contribute oxygen to the surrounding waters through photosynthesis, stabilize bottom sediments (if in the rooted growth form), and contribute to the cycling of nutrients such as phosphorus and nitrogen upon decay. In addition, decaying aquatic plants contribute organic matter to lake sediments which further supports healthy growth of successive aquatic plant communities that are necessary for a balanced aquatic ecosystem. An overabundance of aquatic vegetation may cause organic matter to accumulate on the lake bottom faster than it can break down.

Aquatic plants generally consist of rooted submersed, free-floating submersed, floating-leaved, and emergent growth forms. The emergent growth form (i.e. Cattails, Native Loosestrife) is critical for the diversity of insects onshore and for the health of nearby wetlands. Submersed aquatic plants can be rooted in the lake sediment (i.e. Milfoils, Pondweeds), or free-floating in the water column (i.e. Coontail). 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. Figures 12 and 11 below show the GPS sampling locations for both aquatic vegetation sampling of both lakes.

4.2.1 Gourdneck/Hogsett Lakes Exotic Aquatic Macrophytes

Exotic aquatic plants (macrophytes) are not native to a particular site, but are introduced by some biotic (living) or abiotic (non-living) vector. Such vectors include the transfer of aquatic plant seeds and fragments by boats and trailers (especially if the lake has public access sites), waterfowl, or by wind dispersal. In addition, exotic species may be introduced into aquatic systems through the release of aquarium or water garden plants into a water body. An aquatic exotic species may have profound impacts on the aquatic ecosystem. Eurasian Watermilfoil (*Myriophyllum spicatum*; EWM; Figure 13) is an exotic aquatic macrophyte first documented in the United States in the 1880's (Reed 1997), although other reports (Couch and Nelson 1985) suggest it was first found in the 1940's. EWM has since spread to thousands of inland lakes in various states through the use of boats and trailers, waterfowl, seed dispersal, and intentional introduction for fish habitat. EWM is a major threat to the ecological balance of an aquatic ecosystem through causation of significant declines in favorable native vegetation within lakes (Madsen et *al*. 1991), and may limit light from reaching native aquatic plant species (Newroth 1985; Aiken et *al*. 1979). Additionally, EWM can alter the macroinvertebrate populations associated with particular native plants of certain structural architecture (Newroth 1985).

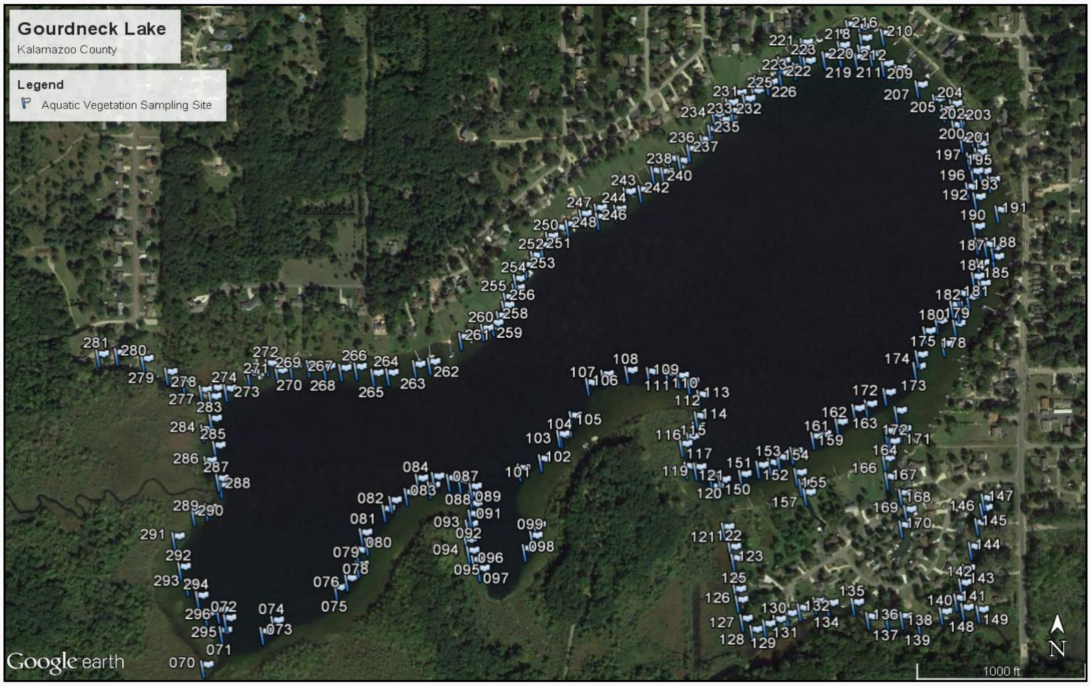

Figure 12. Aquatic vegetation sampling locations on Gourdneck Lake (November, 2016).

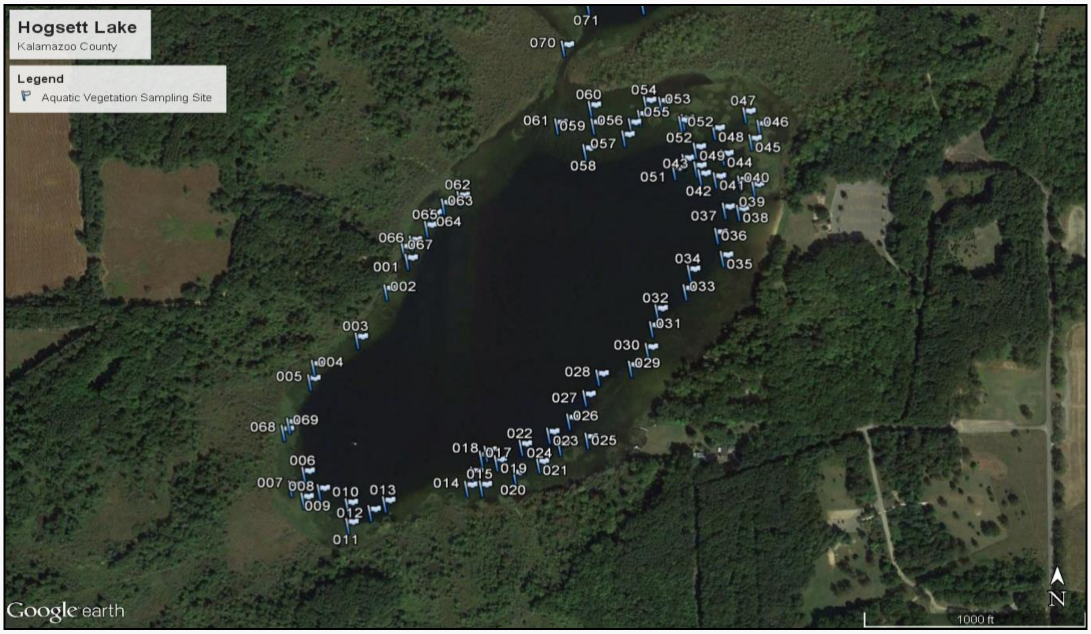

Figure 13. Aquatic vegetation sampling locations on Hogsett Lake (November, 2016).

The results of a detailed aquatic vegetation assessment site (AVAS)/GPS Point-Intercept survey of Gourdneck and Hogsett Lakes on November 4, 2016 demonstrated that approximately 17.4 acres of EWM were found at depths of approximately 6-13 feet with the majority of the growth located at depths between 6-10 feet. In Hogsett Lake, approximately 11.85 acres of EWM growth were found, primarily along the 6-10 foot contour as well. In addition, Gourdneck and Hogsett Lakes contained the invasive submersed Curly-leaf Pondweed (Figure 15) in a few areas along with the invasive emergent Purple Loosestrife (Figure 16) and *Phragmites* (Figure 17). All of these species should be managed. Fortunately, there were only a few plants of Curly-leaf Pondweed and a few individual plants of the Purple Loosestrife and Phragmites. Figure 18 shows the general distribution of the EWM and other invasives that were scattered among the littoral zone and shorelines of Gourdneck Lake and Hogsett Lake. Figure 19 shows the location around the shoreline of Hogsett Lake (northeast) that contains a stand of dense Phragmites.

These methods assess the presence and relative abundance of submersed, floating-leaved, and emergent aquatic vegetation within and around the littoral zones of Michigan lakes. With this survey method, the littoral zone areas of the lake are divided into lakeshore sections approximately 100 - 300 feet in length. The species of aquatic macrophytes present and relative abundance of each macrophyte are recorded and then the amount of cover in the littoral zone is calculated. Additional points out from shore are also selected and marked with GPS.

Figure 14. Eurasian Watermilfoil stems and seed head ©RLS

Figure 15. Curly-leaf Pondweed ©RLS

Figure 16. Purple Loosestrife ©RLS

Figure 17. Phragmites ©RLS

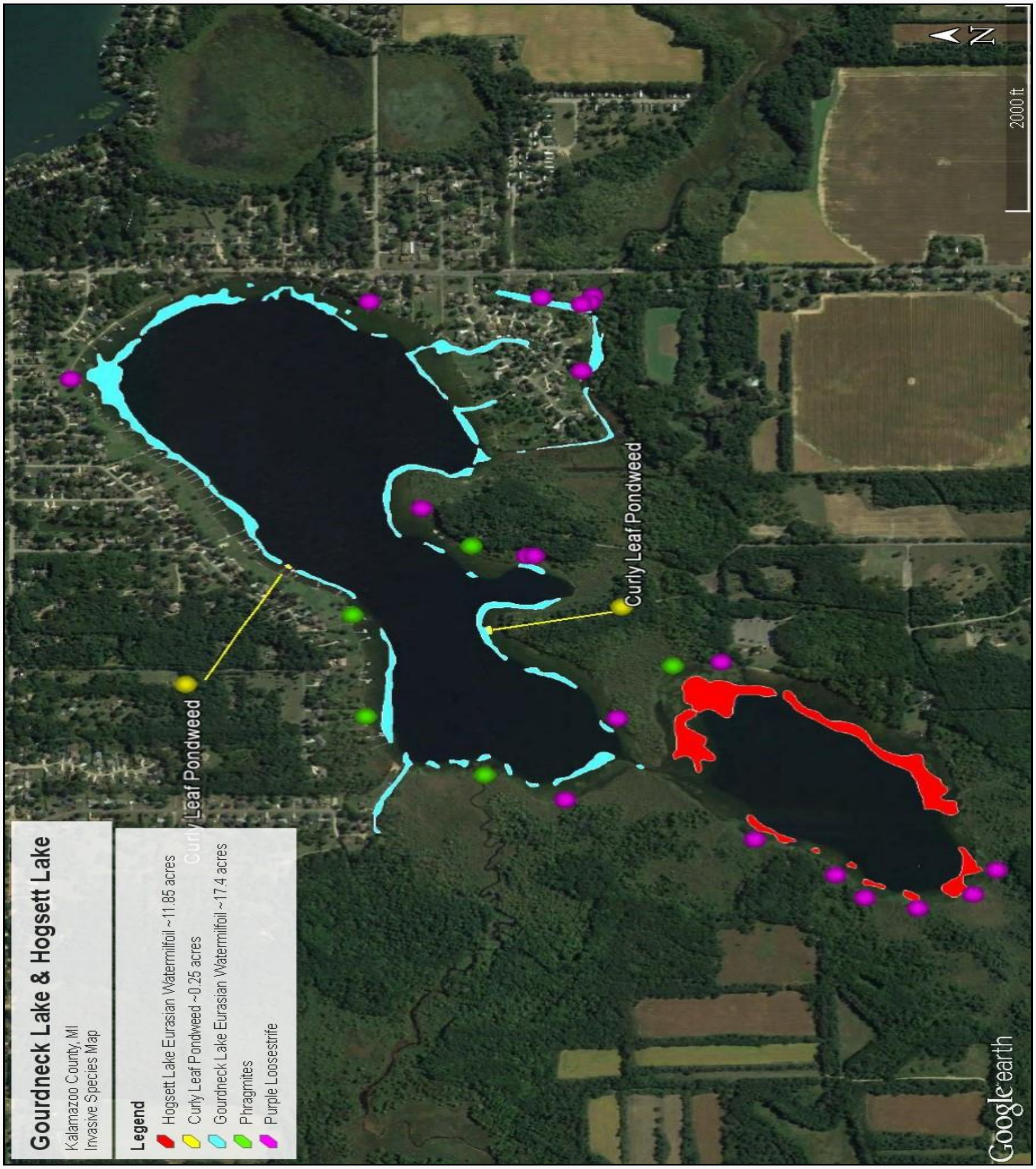

Figure 18. A map showing the locations of all invasive aquatic plants in and around Gourdneck and Hogsett Lakes, Kalamazoo County (2016).

Figure 19. A large stand of the emergent invasive Phragmites around the northeast shoreline of Hogsett Lake, Kalamazoo County, Michigan (November, 2016).

4.2.2 Gourdneck/Hogsett Lakes Native Aquatic Macrophytes

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

Gourdneck Lake contained 16 native submersed, 4 floating-leaved, and 6 emergent aquatic plant species, for a total of 26 native aquatic macrophyte species which represents an excellent biodiversity (Table 9). Hogsett Lake contained 14 native submersed, 3 floating-leaved, and 6 emergent aquatic plant species, for a total of 23 native aquatic macrophyte species which represents a good biodiversity (Table 10). The floating-leaved plants (White Waterlily), Yellow Waterlily, and Watershield typically grow near wetlands and protected areas of lakes. This is likely due to enriched sediments and shallower water depth with reduced wave energy that facilitates the growth of aquatic plants with floating-leaved morphological forms. The floating-leaved plant is critical for housing macroinvertebrates and should be protected and preserved in non-recreational areas to serve as food sources for the fishery and wildlife around the lake. Duckweed is a rootless, floating-leaved aquatic plant that was found in the southeast Gourdneck Lake canals. The dominant native aquatic plants in the lake included the macroalga Chara and the Pondweeds such as Thin-leaf Pondweed. Both are capable of forming dense stands that can interfere with navigation and recreation activities but are also important fish forage habitat. Figure 20 below shows how the Thin-leaf Pondweed has reached problematic density in Hogsett Lake.

The relative abundance of rooted aquatic plants (relative to non-rooted plants) in the lake suggests that the lake sediments are the primary source of nutrients (relative to the water column), since these plants obtain most of their nutrition from the sediments. This is also supported by the overall low phosphorus concentrations except for at the bottom of Gourdneck Lake.

The emergent plants, such as *Typha latifolia* (Cattails), and *Scirpus acutus* (Bulrushes) are critical for shoreline stabilization as well as for wildlife and fish spawning habitat. Of particular interest was the discovery of a rarer emergent plant, Wild Rice (*Zizania aquatica*; Figure 21) which houses seeds that are a great nutritional benefit to waterfowl and other wildlife. This plant should always be protected and is often considered sacred by Native American Indian tribes.

Figures 22 and 23 show the aquatic vegetation biovolume in both Gourdneck and Hogsett Lakes, respectively. The blue color represents a lack of vegetation (often due to depth and/or substrate), whereas the green color represents low-growing aquatic vegetation and the red color represents taller plants that grow high off of the lake bottoms.

Figure 20. Nuisance thin-leaf (Sago Pondweed) in Hogsett Lake, Kalamazoo County, Michigan (November, 2016).

Figure 21. Wild Rice in Hogsett Lake, Kalamazoo County, Michigan (November, 2016).

Table 9. Gourdneck Lake native aquatic plants (November, 2016).

Native Aquatic Plant Species	*Aquatic Plant Common Name*	*Abundance in/around Gourdneck Lake (% cover)*	*Aquatic Plant Growth Habit*
Chara vulgaris	Muskgrass	4.9	Submersed, Rooted
Potamogeton pectinatus	Thin-leaf Pondweed	1.9	Submersed, Rooted
Potamogeton zosteriformis	Flat-stem Pondweed	0.1	Submersed, Rooted
Potamogeton gramineus	Variable-leaf Pondweed	0.1	Submersed, Rooted
Potamogeton robbinsii	Fern-leaf Pondweed	0.1	Submersed, Rooted
Potamogeton praelongus	White-stem Pondweed	0.3	Submersed, Rooted
Potamogeton illinoensis	Illinois Pondweed	0.6	Submersed, Rooted
Potamogeton natans	Floating-leaf Pondweed	0.1	Submersed, Rooted
Vallisneria americana	Wild Celery	0.2	Submersed, Rooted
Ceratophyllum demersum	Coontail	0.4	Submersed, Non-Rooted
Elodea canadensis	Common Elodea	0.1	Submersed, Rooted
Ranunculus aquatilis	White Water Crowfoot	0.1	Submersed, Rooted
Utricularia vulgaris	Common Bladderwort	0.1	Submersed, Non-Rooted
Najas guadalupensis	Southern Naiad	0.6	Submersed, Rooted
Nymphaea odorata	White Waterlily	0.1	Floating-Leaved, Rooted
Nuphar lutea	Yellow Waterlily	0.1	Floating-Leaved, Rooted
Brasenia schreberi	Watershield	0.1	Floating-Leaved, Rooted
Typha latifolia	Cattails	0.3	Emergent
Pontedaria cordata	Pickerelweed	0.1	Emergent
Schoenoplectus acutus	Bulrushes	0.1	Emergent
Decodon verticillatus	Swamp Loosestrife	0.1	Emergent
Arrow arum	Arrowhead	0.1	Emergent
Zizania aquatica	Wild Rice	0.1	Emergent

Table 10. Hogsett Lake native aquatic plants (November, 2016).

Native Aquatic Plant Species	***Aquatic Plant Common Name***	***Abundance in/around Hogsett Lake (% cover)***	***Aquatic Plant Growth Habit***
Chara vulgaris	Muskgrass	20.4	Submersed, Rooted
Potamogeton pectinatus	Thin-leaf Pondweed	3.4	Submersed, Rooted
Potamogeton zosteriformis	Flat-stem Pondweed	0.2	Submersed, Rooted
Potamogeton gramineus	Variable-leaf Pondweed	0.1	Submersed, Rooted
Potamogeton robbinsii	Fern-leaf Pondweed	0.1	Submersed, Rooted
Potamogeton illinoensis	Illinois Pondweed	0.7	Submersed, Rooted
Potamogeton praelongus	White-stem Pondweed	0.1	Submersed, Rooted
Potamogeton richardsonii	Clasping-leaf Pondweed	0.1	Submersed, Rooted
Potamogeton natans	Floating-leaf Pondweed	0.2	Submersed, Rooted
Vallisneria americana	Wild Celery	0.4	Submersed, Rooted
Ceratophyllum demersum	Coontail	0.3	Submersed, Non-Rooted
Elodea canadensis	Common Elodea	0.1	Submersed, Rooted
Myriophyllum sibiricum	Northern Watermilfoil	0.1	Submersed, Rooted
Ranunculus aquatilis	White Water Crowfoot	0.1	Submersed, Rooted
Utricularia vulgaris	Common Bladderwort	0.1	Submersed, Non-Rooted
Najas guadalupensis	Southern Naiad	0.2	Submersed, Rooted
Nuphar lutea	Yellow Waterlily	0.9	Floating-leaved, Rooted
Nymphaea odorata	White Waterlily	0.4	Floating-leaved, Rooted
Brasenia schreberi	Watershield	0.1	Floating-leaved, Rooted
Lemna minor	Duckweed	0.1	Floating-leaved, Non-Rooted
Typha latifolia	Cattails	3.5	Emergent
Arrow arum	Arrowhead	0.1	Emergent
Pontedaria cordata	Pickerelweed	0.9	Emergent
Schoenoplectus acutus	Bulrushes	0.1	Emergent
Decodon verticillatus	Swamp Loosestrife	0.1	Emergent
Zizania aquatica	Wild Rice	0.1	Emergent

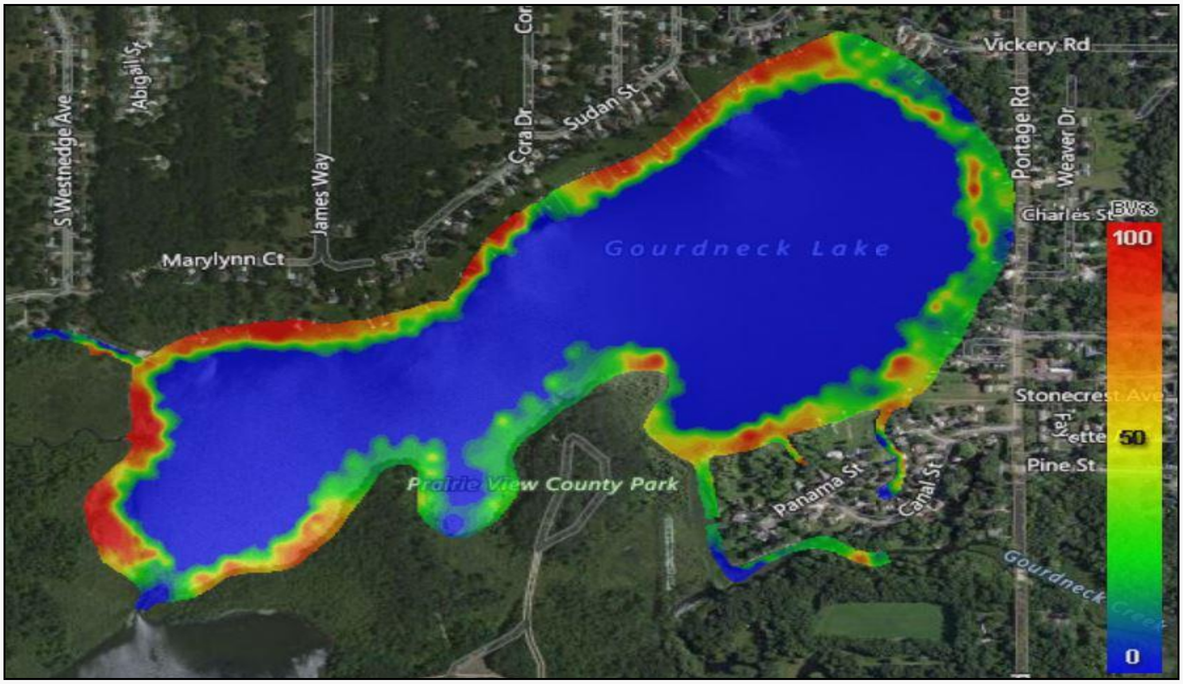

Figure 22. Gourdneck Lake aquatic vegetation biovolume (November, 2016).

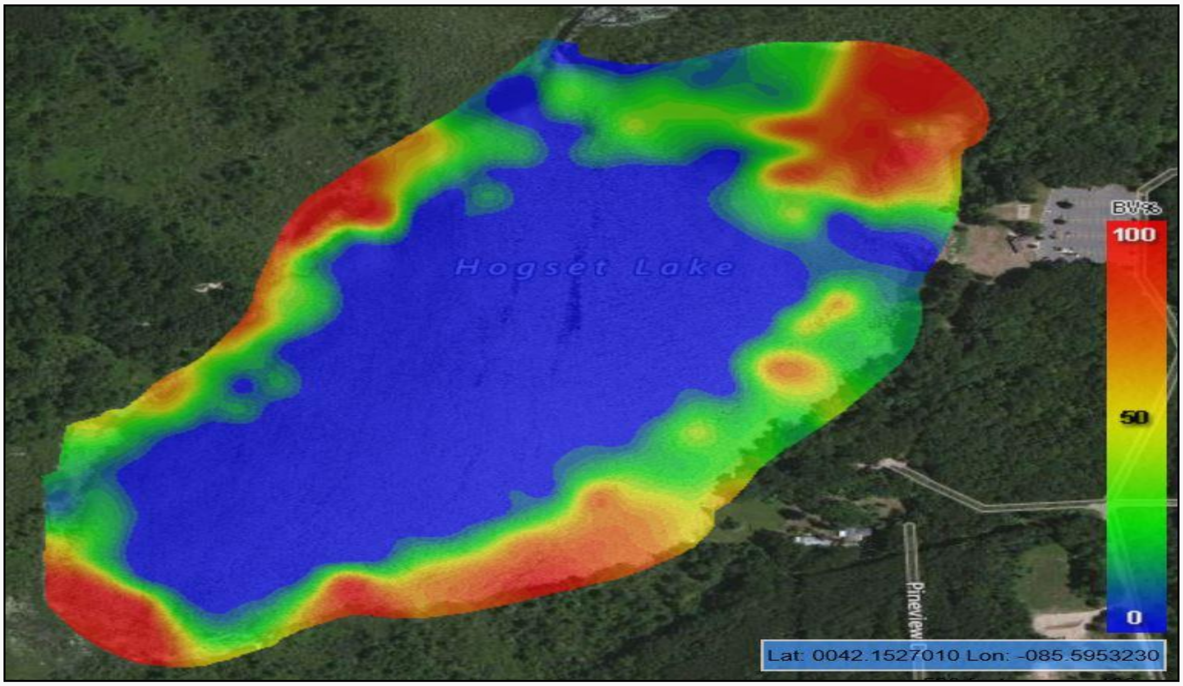

Figure 23. Hogsett Lake aquatic vegetation biovolume (November, 2016).

Figure 24. Chara (Muskgrass) ©RLS

Figure 25. Thin-leaf Pondweed ©RLS

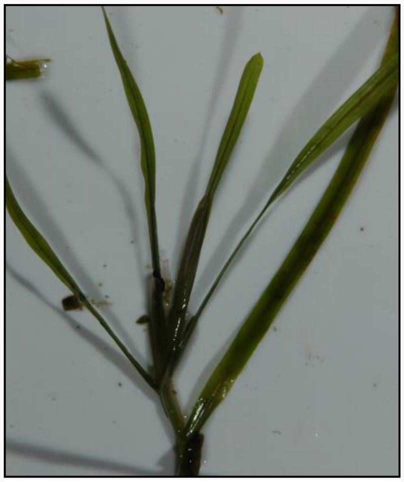

Figure 26. Flat-stem Pondweed ©RLS

Figure 27. Variable-leaf Pondweed ©RLS

Figure 28. Southern Naiad ©RLS

Figure 29. Illinois Pondweed ©RLS

Figure 30. Wild Celery ©RLS

Figure 31. Northern Watermilfoil ©RLS

Figure 32. Coontail ©RLS

Figure 33. Elodea ©RLS

Figure 34. White Water Crowfoot

Figure 35. White Waterlily ©RLS

Figure 36. Wild Rice ©RLS

Figure 37. Pickerelweed ©RLS

Figure 38. Cattails ©RLS

Figure 39. Bulrushes ©RLS

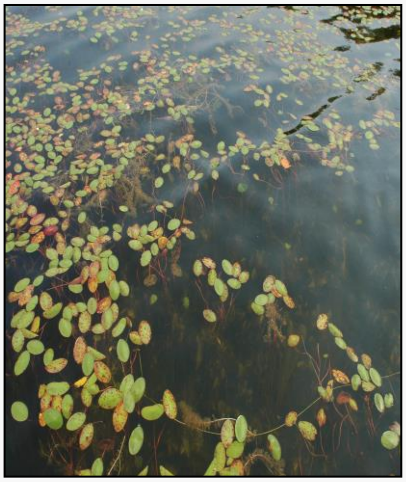

Figure 40. Watershield ©RLS

Figure 41. Arrowhead ©RLS

4.3 Gourdneck/Hogsett Lakes 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 processing of energy. Others are important predators, graze alga on rocks and logs, and are important food sources (biomass) for fish. The removal of macroinvertebrates has been shown to impact fish populations and total species richness of an entire lake or stream food web (Lenat and Barbour 1994). In the food webs of lakes, benthic macroinvertebrates have an intermediate position between primary producers and higher trophic levels (as fish) on the other side. Hence, they play an essential role in key ecosystem processes (food chain dynamics, productivity, nutrient cycling and decomposition). These may also include many rare species.

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

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

RLS collected aquatic macroinvertebrates in three separate locations (at the bottom of each of the three deep basins in both lakes) on November 4, 2016 (Table 11). The study found midge larvae (Chironomindae), fingernail clams, glassworms, and zebra mussels (Dreisseniidae). 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 10-year study, although some species were considered more pollution-tolerant than others. This increase was thought to have been due to an increase in *Dreissena* colonies increasing additional habitat for other macroinvertebrates.

Eurasian water-milfoil (*Myriophyllum spicatum*) has also been shown to negatively influence both fish and macroinvertebrate communities (Lillie and Budd 1992).

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.

Table 11. Sediment macroinvertebrates in Gourdneck Lake and Hogsett Lakes (November, 2016).

***Sample 1* Gourdneck East Basin**	**Sample Type - Sediment Grab**				
		Diptera	Chaoboridae	8	Glassworms
		Diptera	Chironomidae	4	Midge larvae
			Total	**12**	
***Sample 2* Gourdneck West Basin**	**Sample Type - Sediment Grab**				
		Diptera	Chaoboridae	15	Glassworms
		Bivalvia	Sphaeriidae	9	Fingernail clams
			Total	**24**	
***Sample 3* Hogsett Lake Deep Basin**	**Sample Type – Sediment Grab**				
		Bivalvia	Sphaeriidae	2	Fingernail clams
		Diptera	Chaoboridae	21	Glassworms
			Total	**23**	

4.4 Gourdneck/Hogsett Lakes Zooplankton Communities

Zooplankton are microscopic organisms that cannot produce their own food and thus feed on algae (phytoplankton) in the water column. They are thus responsible for keeping algae populations balanced and are the reason that many lakes are not completely covered with algae. Zooplankton are selective feeders, only ingesting green algae and diatoms. They will not consume blue-green algae due to the compounds and toxins often present in that type of algae. Zooplankton includes the rotifers which have over 2,000 freshwater species and cladocerans which are small crustaceans that have a carapace that covers much of their body. Another group, the copepods are active and powerful swimmers and are an excellent fish food source. The last group consists of protozoans which are the smallest and least motile.

They tend to reside in lake sediments unless they are planktonic which then they are common in the water column during summer.

Two zooplankton tows (one over the deepest basins of both lakes) using a pelagic plankton net with collection jar were conducted by RLS scientists on November 4, 2016. Plankton sub-samples (in 10 ml aliquots) were analyzed under a Meiji dissection scope with the use of a Bogorov counting chamber. The most abundant zooplankton genera included copepods such as *Diaptomus* sp. and *Diaphanasoma* sp. (approximately 31 organisms per 10 ml aliquot), *Mesocyclops* (approximately 24 organisms per 10 ml aliquot). Also present were the cladocerans *Daphnia* (approximately 29 organisms per 10 ml aliquot). The rotifer *Keratella* sp. was also present (approximately 7 organisms per 10 ml aliquot).

5.0 GOURDNECK/HOGSETT LAKES MANAGEMENT IMPROVEMENT METHODS

Improvement strategies, including the management of exotic aquatic plants, control of beach and shoreline erosion, and protection from nutrient loading from external sources, are available for the various problematic issues facing Gourdneck Lake. The increase in developmental pressures and use of the aquatic ecosystem necessitates the implementation of inland lake management practices to preserve and maintain balance within the Gourdneck Lake watershed. The lake management components involve both within-lake (basin) and around-lake (watershed) solutions to protect and restore complex aquatic ecosystems. The goals of a Lake Management Plan (LMP) are to increase water quality, favorable wildlife habitat, aquatic plant and animal biodiversity, recreational use, and lakefront 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 LMP (Madsen 1997).

5.1 Chemical 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.

Contact herbicides 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.

Systemic herbicides such as 2, 4-D and Triclopyr are the two primary systemic herbicides used to treat milfoil that grows in less than 35% of a lake. In November, 2016 Gourdneck Lake was found to have approximately 17.4 acres of EWM and Hogsett Lake was found to have approximately 11.9 acres of EWM. Thus, the use of either of these systemic herbicides is recommended for the control of milfoil in Gourdneck Lake. 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. The objective of a fluridone treatment is to selectively control the growth of milfoil in order to allow other native aquatic plants to germinate and create a more diverse aquatic plant community. A whole-lake treatment of fluridone is not recommended for Gourdneck Lake since it contains a low amount of native vegetation and milfoil relative to its size and may be better controlled with spot-treatments using Triclopyr near shore and 2,4-D offshore. Additionally, fluridone can be lost to the deeper areas of the lake and not stay in confined shallow areas where the milfoil is dominant.

Algae treatments with the use of algaecides should be limited to filamentous algal blooms and efforts should be taken to reduce the nutrient loads that encourage algal blooms that may require treatments. The current low abundance of green algae in the water of Gourdneck Lake denotes that algal treatments may not be needed. The canals, however, may benefit from periodic algal treatments. All products are applied to the lake in a specialized treatment boat similar to the one in Figure 42.

Figure 42. An airboat used to apply aquatic herbicides.

5.2 Mechanical Harvesting

Mechanical harvesting involves the physical removal of nuisance aquatic vegetation with the use of a mechanical harvesting machine (Figure 43). 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 Eurasian Watermilfoil since the plant may fragment when cut and re-grow on the lake bottom. Due to the threat of milfoil fragmentation, the use of mechanical harvesting for the removal of the milfoil in Gourdneck and Hogsett Lakes is not recommended. It may be used in future years if the milfoil is eradicated and natural removal of nuisance native aquatic vegetation is desired.

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.

Figure 43. A mechanical harvester.

5.3 Diver Assisted Suction Harvesting (DASH)

Suction harvesting via a Diver Assisted Suction Harvesting (DASH) boat (Figure 44) involves hand removal of individual plants by a SCUBA diver in selected areas of lake bottom with the use of a hand-operated suction hose. Samples are dewatered on land or removed via fabric bags to an offsite location. This method is generally recommended for small (less than 1 acre) spot removal of vegetation since it is costly on a large scale. It may be used in the future to remove small remaining areas of milfoil after large-scale initial treatments. Costs typically range from $1,000-$5,000 per acre. It may be used in the future to remove small remaining areas of milfoil after large-scale initial treatments have been successful or is useful on dense lily pad growth or for stubborn areas that do not respond well to aquatic herbicides. If the DASH method is used on aquatic plants that fragment, then the use of a barrier to prevent movement of the fragments is recommended.

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. This is especially the case when this method is conducted in soft, flocculent sediments. This method is a sustainable option for removal of plant beds in beach areas and areas where herbicide treatments may be restricted. The process requires a permit from the MDEQ. This activity may cause re-suspension of sediments (Nayar et *al*., 2007) which may lead to increased turbidity and reduced clarity of the water. This method is a sustainable option for removal of plant beds in beach areas and areas where herbicide treatments may be restricted. The process requires a permit from the MDEQ.

Figure 44. A DASH boat for hand-removal of milfoil or other nuisance vegetation. ©RLS

5.4 Biological Control

The aquatic weevil, *Euhrychiopsis lecontei* (Figure 45) was once used to control Eurasian Watermilfoil but is no longer commercially available. Much of this is because the science of the required stocking densities for effective treatment was not well understood which led to variable results among lakes which were often negligible (except for some unique sites).

Figure 45. The milfoil weevil (*Euhrychiopsis lecontei*). Photo from R. Newman used with permission.

5.5 Benthic Barriers and Nearshore Management Methods

The use of benthic barrier mats (Figure 46) or Weed Rollers (Figure 47) have been used to reduce rooted aquatic weed growth in small areas such as in beach areas and around docks. The mats are not effective on non-rooted aquatic plants since they can rest on top of the mats and move freely throughout the water column. 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 could be useful in recreational lakes such as Gourdneck and Hogsett Lakes and work best in beach areas and near docks to reduce nuisance rooted aquatic vegetation growth.

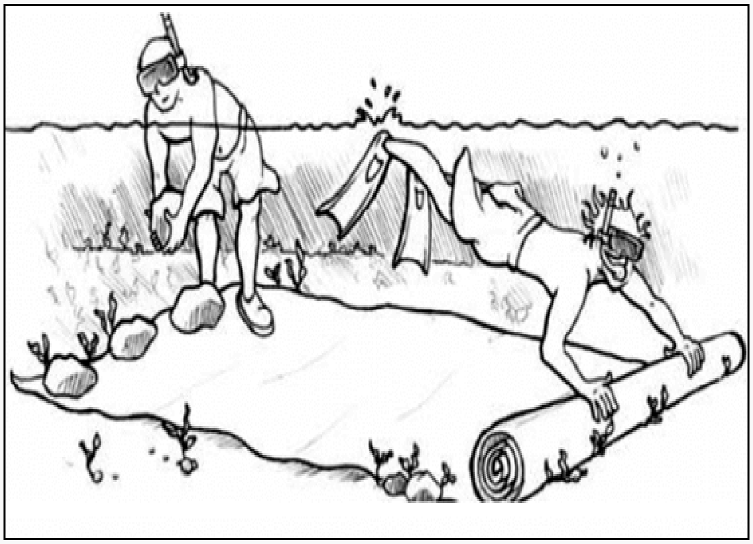

Figure 46. A Benthic Barrier. Photo courtesy of Cornell Cooperative Extension

Figure 47. A Weed Roller

5.6 Laminar Flow Aeration and Bioaugmentation

Laminar flow aeration systems (Figure 48) are retrofitted to a particular site and account for variables such as water depth and volume, contours, water flow rates, and thickness and composition of lake sediment. The systems are designed to completely mix the surrounding waters and evenly distribute dissolved oxygen throughout the lake sediments for efficient microbial utilization.

A laminar flow aeration system utilizes diffusers which are powered by onshore air compressors. The diffusers are connected via extensive self-sinking airlines which help to purge the lake sediment pore water of gases such as benthic carbon dioxide (CO_2) and hydrogen sulfide (H_2S), which is a primary nutrient necessary aquatic plant photosynthetic growth and productivity and is also a byproduct of microbial metabolism.

In addition to the placement of the diffuser units, the concomitant use of bacteria and enzymatic treatments to facilitate the microbial breakdown of organic sedimentary constituents is also used as a component of the treatment. 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 ± 0.80 mg N g dry wt day^{-1} for aerated mesocosms and 0.48 ± 0.20 mg N g dry wt day^{-1} in controls. Although this is a relatively new area of research, several recent case studies have shown promise on the positive impacts of laminar flow aeration systems on aquatic ecosystem management with respect to organic matter degradation and resultant increase in water depth, and rooted aquatic plant and algae management in eutrophic ecosystems (Restorative Lake Sciences, LLC 2009-present). 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.

Conversely, a study by Engstrom and Wright (2002) found no significant differences between aerated and non-aerated lakes with respect to reduction in organic sediments. This study was however limited to one sediment core per lake and given the high degree of heterogeneous sediments in inland lakes may not have accurately represented the conditions present throughout much of the lake bottom. The philosophy and science behind the laminar flow aeration system is to reduce the organic matter layer in the sediment so that a significant amount of nutrient is removed from the sediments and excessive sediments are reduced to yield a greater water depth.

Benefits and Limitations of Laminar Flow Aeration

In addition to the reduction in toxic blue-green algae (such as *Microcystis* sp.) as described by Toetz (1981), aeration and bio augmentation in combination have been shown to exhibit other benefits for the improvements of water bodies. Laing (1978) showed that a range of 49-82 cm of organic sediment was removed annually in a study of nine lakes which received aeration and bio augmentation. It was further concluded that this sediment reduction was not due to re-distribution of sediments since samples were collected outside of the aeration "crater" that is usually formed. A detailed study by Restorative Lake Sciences (2009-present) of Indian Lake (Van Buren County, Michigan) during 2010 also indicated a significant reduction of organic sediments in bioaugmented/aerated regions, as well as a decline in the relative proportion of blue-green algae and the presence of the rooted, submersed, exotic aquatic plant, Eurasian Watermilfoil (*Myriophyllum spicatum*). A study by Turcotte et *al*. (1988) analyzed the impacts of bio augmentation on the growth of EWM and found that during two four-month studies, the growth and re-generation of this plant was reduced significantly with little change in external nutrient loading. Currently, it is unknown whether the reduction of organic matter for rooting medium or the availability of nutrients for sustained growth is the critical growth limitation factor and these possibilities are being researched. A reduction of EWM is desirable for protection of native plant biodiversity, recreation, water quality, and reduction of nutrients such as nitrogen and phosphorus upon decay (Ogwada et *al*., 1984).

Furthermore, bacteria are the major factor in the degradation of organic matter in sediments (Fenchel and Blackburn, 1979) so the concomitant addition of microbes to lake sediments will accelerate that process. A reduction in sediment organic matter would likely decrease EWM growth as well as increase water depth and reduce the toxicity of ammonia nitrogen to overlying waters. A study by Verma and Dixit (2006) evaluated aeration systems in Lower Lake, Bhopal, India, and found that the aeration increased overall dissolved oxygen, and reduced biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total coliform counts.

The laminar flow aeration system has some limitations including the inability to break down mineral sediments, the requirement of a constant Phase I electrical energy source to power the units and possible unpredictable response by various species of rooted aquatic plants (currently being researched by Restorative Lake Sciences). Deep basin diffusers can be placed in Gourdneck Lake and could be implemented with the existing program or in future years once the invasive watermilfoil problem is under control (due to budget constraints).

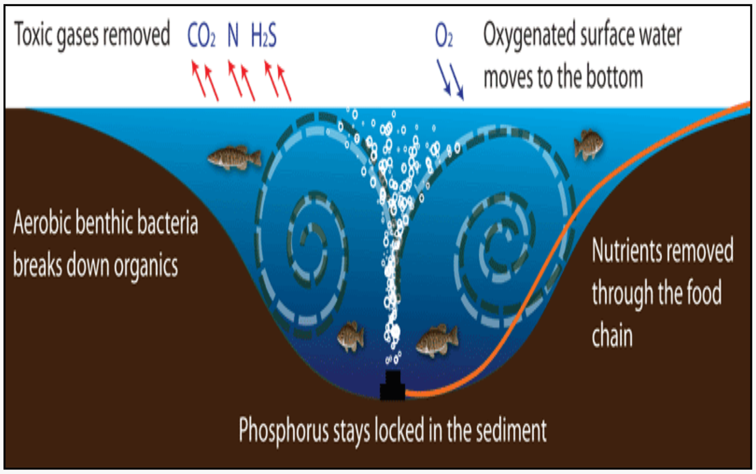

Figure 48. A diagram showing the laminar flow aeration mechanisms. ©Restorative Lake Sciences

6.0 GOURDNECK/HOGSETT LAKES CONCLUSIONS & RECOMMENDATIONS

The urgent control of the Eurasian Watermilfoil infestations throughout both Gourdneck and Hogsett Lakes is essential for the long-term preservation of the native aquatic plant communities. Furthermore, the selected methods for the control of it should also protect native aquatic plant species through targeted control. Gourdneck Lake possesses a very robust fishery, with many species of native aquatic plants that help to support the associated fishery through housing macro invertebrates (fish food) and providing habitat and shelter in the lake. The preferred aquatic plant management method(s) must also satisfy the needs of lake residents, by enhancing recreational activities such as boating (navigation) and fishing, increasing the safety of swimming, and protecting the property values of surrounding homes. Thus, management options must complement the socio-economic climate that influences both riparians and individual components of the Gourdneck Lake ecosystem. Every lake management plan should offer solutions that are ecologically sound, practical, and economically feasible. Improvements can be implemented though an SAD established through Schoolcraft Township and the City of Portage pursuant to provisions of P.A. 451 of 1994, as amended. The objective of an SAD is to provide an equitable way to disperse costs for lake-wide improvement project(s). The SAD is typically chosen based on established criteria that define “units of benefit” that each individual property derives from the proposed improvements.

6.1 Further Recommendations: Integrated Management

Integrated management combines the use of chemical, biological, mechanical, aeration, or other methods to control aquatic plant growth and protect the lake health. Integrated management is becoming increasingly common since aquatic ecosystems are multi-dimensional and have different vegetation communities in certain lake areas and thus may show variable responses to specific treatments. The recommended use of systemic chemical herbicides for the EWM and contact herbicides for nuisance native aquatic plant growth present within the lake and the recommended use of aeration for reduction of sediment organic muck and oxygenation of the Gourdneck Lake deep basin and the use of other watershed management methods (i.e., BMP's for the reduction of external nutrient inputs to the lake), are all indicative of an integrated management plan.

Furthermore, a professional limnologist/aquatic botanist from RLS should perform regular GPS-guided whole-lake surveys each spring and fall to monitor the growth and distribution of EWM, and continuously monitor the lake for potential influxes of other exotic aquatic plant genera (i.e. *Hydrilla*) that could also significantly disrupt the ecological stability of Gourdneck and Hogsett Lakes. The lake manager should oversee all management activities and would be responsible for the creation of aquatic plant management survey maps, direction of the herbicide applicator or other lake contractors to target-specific areas of aquatic vegetation for removal, implementation of watershed best management practices, administrative duties such as the processing of contractor invoices, and the education of lakefront owners through an educational newsletter and through attending meetings with the Gourdneck Lake riparians. An educational newsletter should be devised and circulated to riparians that contains educational tips for residents to recognize and prevent the transfer of invasive species to the lake and watershed management methods.

6.2 Gourdneck/Hogsett Lakes Watershed Management

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

1) Maintenance of brush cover on lands with steep slopes (those > 6%--see soils map for each lake),
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 size to reduce wave energy and thus erosion potential,
4) Avoiding the use of retaining walls and encouraging the growth of dense shrubs or rip-rap to control erosion,
5) Maintenance of drainfields and/or sewers and runoff is critical in areas with Houghton Muck soils which are prone to ponding during heavy rain events,
6) Using only native genotype plants (those native to Gourdneck and Hogsett Lakes or the region) around the lakes since they are most likely to establish and thrive than those not acclimated to growing in the area soils, and

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

6.2.1 Gourdneck/Hogsett Lakes 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 Gourdneck and Hogsett Lakes should be preserved to act as a filter of nutrients from the land and to provide valuable wildlife habitat. Construction practices near the lakeshores should minimize the chances for erosion and sedimentation by keeping land areas adjacent to the water stabilized with rock, vegetation, or wood retaining walls. The November survey noted that the majority of the riparian shorelines contained natural vegetation, or were currently being mowed and sanded. Erosion of sand 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 those residences 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 Gourdneck and Hogsett Lakes. The emergent aquatic plant, *Scirpus* sp. (Bulrushes) or Cattails offer satisfactory stabilization of shoreline sediments and assists in the minimization of sediment release into the lakes.

6.2.2 Gourdneck/Hogsett Lakes Nutrient Source Control

Additional inputs of phosphorus or nitrogen to the lake are likely to create additional algal and aquatic plant growth. Accordingly, it is recommended that the following procedures to protect the water quality of Gourdneck and Hogsett Lakes:

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.

2) Preserve riparian vegetation buffers around lakes (such as those that consist of Cattails, Bulrushes, and Swamp Loosestrife which are present around both lakes), since they act as a filter to catch nutrients and pollutants that occur on land and may run off into the lake. As an additional bonus, Canada geese (*Branta canadensis*) usually do not prefer lakefront lawns with dense riparian vegetation because they are concerned about the potential of hidden predators within the vegetation.

3) Do not burn leaves near the lake shorelines 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) Annually inspect septic tank systems and be sure to clean as needed and maintain the viability of the drain field since this area drains into the groundwater which enters the lake.

6.3 Invasive Aquatic 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 transfer of exotic species to Gourdneck and Hogsett Lakes is awareness and education.

6.3.1 Zebra Mussels

Zebra mussels (*Dreissena polymorpha*; Figure 49) 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 have a nearly microscopic larval stage where they can easily avoid detection. The mussels then grow into the adult (shelled) form and attach to substrates (i.e. boats, rafts, docks, pipes, aquatic plants, and lake bottom sediments) with the use of byssal threads. The fecundity (reproductive rate) of female zebra mussels is high, with as many as 40,000 eggs laid per reproductive cycle and up to 1,000,000 in a single spawning season (Mackie and Schlosser 1996). Although the mussels only live 2-3 years, they are capable of great harm to aquatic environments. In particular, they have shown selective grazing capabilities by feeding on the preferred zooplankton food source (green algae) and expulsion of the non-preferred blue green algae (cyanobacteria). Additionally, they may decrease the abundance of beneficial diatoms in aquatic ecosystems (Holland 1993). Such declines in favorable algae can decrease zooplankton populations and ultimately the biomass of planktivorous fish populations. Zebra mussels are viewed by some as beneficial to lakes due to their filtration capabilities and subsequent contributions to increased water clarity. However, such water clarity may allow other photosynthetic aquatic plants to grow to nuisance levels (Skubinna et *al*. 1995).

The recommended prevention protocols for introduction of zebra mussels includes steam-washing all boats, boat trailers, jet-skis, and floaters prior to placing them into Gourdneck and Hogsett Lakes. Boat transom wells must always be steam-washed and emptied prior to entry into the lakes. Excessive waterfowl should also be discouraged from the lakes since they are a natural transportation vector of the microscopic zebra mussel larvae or mature adults. Fishing poles, lures, and other equipment used in other lakes (and especially the Great Lakes) should also be thoroughly steam-washed before use in Gourdneck and Hogsett Lakes. Additionally, all solid construction materials (if recycled from other lakes) must also be steam-washed. There were a few areas in the lake where Zebra Mussels were found during the November, 2016 study.

Figure 49. Photo of a zebra mussel colony, USGS.

6.3.2 Invasive Aquatic Plants

In addition to Eurasian watermilfoil, 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* (Figure 50) and *Trapa natans* (Water Chestnut; Figure 51). *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. Recently, *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 May and are extremely thick and hardy and may last for up to 12 years in the lake sediment. If stepped on, the seed pods may even cause deep puncture wounds to those 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.

Figure 50. Hydrilla, a highly invasive tropical aquatic plant (©RLS).

Figure 51. Water Chestnut, a highly invasive aquatic plant.

7.0 GOURDNECK/HOGSETT LAKES PROPOSED IMPROVEMENT COSTS

It is highly recommended that the residents around Gourdneck and Hogsett Lakes adopt the lake water quality and aquatic vegetation guidelines suggested in this management plan. To protect the biodiversity of native aquatic plants within Gourdneck and Hogsett Lakes, aquatic herbicides should be minimized and used primarily for exotic species or on nuisance native aquatic plants in target areas. Additionally, an integrated management approach involving the use of other lake improvement strategies (i.e. nutrient-reducing BMP's and shoreline erosion reduction methods and possibly aeration for the Gourdneck Lake deep basins) for water quality improvement is recommended for the management of nuisance rooted aquatic plant growth and improvement of water quality in Gourdneck and Hogsett Lakes.

7.1 Cost Estimates for Gourdneck/Hogsett Lake Improvements

The proposed integrated management program for the control of EWM and lake improvement of Gourdneck Lake would begin during the 2017 season. A separate SAD may be needed to implement a laminar flow aeration system if a whole-lake system is desired due to a measureable increase in cost in addition to the weed control program. A breakdown of costs associated with Gourdneck Lake improvements is presented in Table 12. It should be noted that proposed costs are estimates and may change in response to changes in environmental conditions (i.e. increases in aquatic plant growth or distribution, or changes in herbicide costs).

Table 12. Gourdneck and Hogsett Lakes proposed lake improvement program costs (2017-2020).

Proposed Lake Improvement Item	Estimated 2017 Cost	Estimated 2018 Cost[4]	Estimated 2019-2020 Cost[5]
Herbicides for *EWM*[1] for 30 acres@ $750 per acre; $800 MDEQ permit fee; Control of nuisance natives with contact herbicides/algaecides @$400 per acre for 50 acres (includes canals); also include emergent invasives	$23,300 $20,000	$17,475 $20,000	$13,106 $20,000
Professional Services (limnologist surveys, oversight, processing, education, newsletter)[2]	$6,800	$6,800	$6,800
Contingency[3]	$5,010	$4,428	$3,991
Total Annual Estimated Cost	$55,110	$48,703	$43,897
Approx. Riparian Cost[6]	$421	$372	$335

[1] Herbicide treatment scope may change annually due to changes in the distribution and/or abundance of aquatic plants.
[2] Professional services includes two 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, processing of all invoices from contractors and others billing for services related to the improvement program, education of local riparians through the development of a high-quality, scientific newsletter, and attendance at up to 4 Gourdneck Lake Improvement Board meetings.
[3] Contingency is 10% of the total project cost, to assure that extra funds are available for unexpected expenses. Note: Contingency may be advised and/or needed for future treatment years. Contingency funds may also be used for other water quality improvements and watershed management.

[4] Cost estimates for 2018 based on 75% of the herbicide treatment costs for 2017. Note: Herbicide unit costs may change due to cost of living adjustments for the contractor services and/or products.
[5] Costs of the proposed program for years 2019-2020 are estimates only and may change based on the distribution and/or abundance of EWM and costs of products and contractor services.
[6]Cost estimates per riparian based on 131 lakefront properties.

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APPENDIX A

GOURDNECK AND HOGSETT LAKES CURRENT AND HISTORICAL DATA

I, James E. Tiffany, a licensed Professional Engineer in the State of Michigan (PE# 43942) have reviewed the December, 2016 *Lakes Improvement Feasibility Study and Management Plan* prepared by Restorative Lake Sciences for the Gourdneck/Hogsett Lakes, Kalamazoo County, Michigan as pertains to the engineering requirements of Section 30909 of Part 309 of P.A. 451 of 1994, as amended.

Signature & Seal: