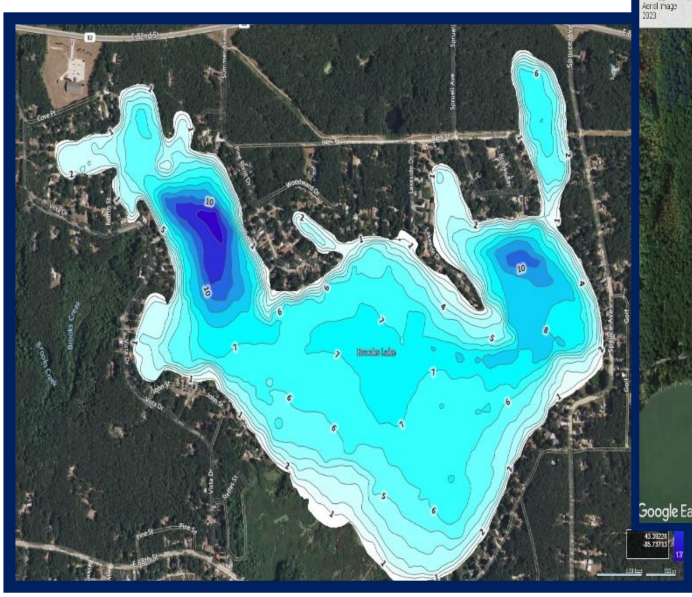
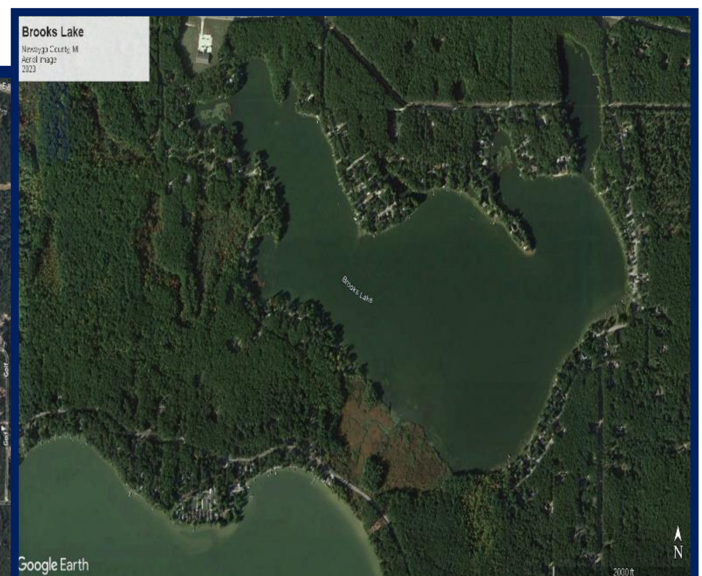
Brooks Lake 2024 Biochar Efficacy Evaluation, Baseline PrO2 Water Quality Data, and Future Restoration Recommendations Newaygo County, Michigan





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

TABLE OF CONTENTS

SECTION	PAGE

LIST OF FIGURES

LIST OF TABLES

Brooks Lake 2024 Biochar Efficacy Evaluation, Water Quality Data, and Future Restoration Recommendations Newaygo County, Michigan

November, 2024

1.0 EXECUTIVE SUMMARY

Brooks Lake has an approximate surface area of 279 acres (RLS, digitized, 2023) and shoreline length of approximately 5.4 miles (RLS, digitized, 2023). The maximum fetch of the lake is approximately 1.1 miles, which may result in sizeable waves during intense storm events. The maximum depth of the lake was 12.8 feet with a mean of 6.1 feet which represents a shallow lake. The water volume was estimated at 1,587.2 acre-feet (RLS, 2023 calculated based on lake scan data).

As in 2023, on May 3, 2024, July 10, 2024, September 10, 2024, two deep basins (east and west) were sampled for physical and chemical water quality parameters. The physical water quality parameters included water temperature, dissolved oxygen concentration, pH, conductivity, total dissolved solids, and Secchi transparency. These parameters were measured in 0.5-meter increments with a calibrated Eureka Manta II® multi-meter probe from the surface of the lake to the bottom. The chemical water quality parameters included total and ortho-phosphorus, total Kjeldahl and inorganic nitrogen, and total suspended solids. These parameters were measured at the top, middle, and bottom depths at the two deep basins. Chlorophyll-a was measured in situ with a calibrated Turner Designs® fluorimeter as a composite sample throughout the water column in both basins.

In addition to the basin sampling, the inlet from Hess Lake was sampled for the same water quality parameters as for the basins with the exception of chlorophyll-a and Secchi transparency which were not applicable for this evaluation in that location.

The baseline data showed pronounced dissolved oxygen depletion by late June in the West Basin with very low water clarity and very high chlorophyll-a (algal pigment) concentrations.

A total of 4 sediment samples were collected with an Ekman® hand dredge throughout the lake basin and analyzed for percentage of organic carbon and sediment particle size. The percentage of organic carbon was moderately high and thus significant quantities of "muck" are capable of biodegradation from possible future bioaugmentation (if needed).

On July 29, 2023, a total of 445 Biochar filters were attached to boatlifts and docks around Brooks Lake by Eden Lakes, Inc., to reduce nutrients within the lake basin. These filters are also needed at the inlet from Hess Lake in the future to reduce the nutrients entering Brooks Lake. Many of these filters were placed in the lake again in 2024.

This report compares the baseline condition of Brooks Lake in June, 2023 to post-Biochar conditions in 2023 and 2024 as well as presents baseline data needed to apply for a deep basin PrO2 hypolimnetic oxygenation system. Preliminary results indicate water quality improvements such as a reductions in specific conductivity, total dissolved solids, ammonia, total Kjeldahl and inorganic nitrogen, total phosphorus, and chlorophyll-a. Ammonia nitrogen in particular is a critical variable since it is associated with increased blue-green algal blooms which are prevalent in Brooks Lake. Much more data is needed in 2025 and future years to determine the true efficacy of the biochar on water quality improvements. The data emphasize the great need for the filters in the inlet since those nutrient loads are quite high and detrimental to Brooks Lake.

It must be emphasized that given the late installation of the filters in 2023, only one baseline data set was possible. The Brooks Lake Association decided to have these filters installed in July, 2023 and retained approval in 2025 to place them in the inlet and are also seeking to implement a PrO_2 aeration system to reduce the algae in the lake and increase water clarity and dissolved oxygen to improve the overall water quality of the lake.

RLS also recommends implementation of a proper septic system maintenance program and avoidance of all lawn fertilizers. Additionally, a PrO2 oxygenation system for the deepest basin is recommended to reduce the release of phosphorus from the bottom, which also exacerbates algal growth.

Surprisingly, Brooks Lake contains low submersed aquatic vegetation which is not favorable as they compete with blue-green algae for nutrients. The water clarity of Brooks Lake must improve before the appropriate quantity of submersed aquatic vegetation can successfully colonize due to light limitations. Brooks Lake currently exists in an alternate "stable" state where the low clarity selects for algae and the algae thrive on nutrients. In order to reduce algae, the nutrients and algae must be lowered. Only then can the lake revert back to a clear-water state with adequate submersed aquatic vegetation.

2.0 LAKE ECOLOGY BACKGROUND INFORMATION

2.1 Introductory Concepts

Limnology is a multi-disciplinary field which involves the study of the biological, chemical, and physical properties of freshwater ecosystems. A basic knowledge of these processes is necessary to understand the complexities involved and how management techniques are applicable to current lake issues. The following terms will provide the reader with a more thorough understanding of the forthcoming lake management recommendations for Brooks 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. 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. Brooks Lake may be categorized as a drainage lake since it has an inlet from Hess Lake and an outlet that drains into the Muskegon River.

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 influence from humans 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 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 storm water 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 (NPS) 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

The control of nutrients from a surrounding watershed or catchment to any lake is a proven necessity for long-term nutrient reduction. Although nutrients are a necessity for the primary production of algae and aquatic plants in a lake ecosystem, an overabundance of nutrients causes substantial problems as noted above. Lakes that lie within an agricultural watershed may experience acute and chronic influx of sediments, nutrients, and bacteria, among other pollutants. Those within urbanized watersheds face other stressors that include nutrient pollution but also influx of metals, dissolved solids, among other pollutants. In many areas, however, the watershed reduction approach is limited, and restorative measures must begin within the lake basin. Annadotter et *al*., (1999) noted that even years after a sewage treatment plant was built along the shores of Lake Finjasjön (Sweden), the lake trophic status continued to decline. This was due to the existence of sediments that continuously leaked phosphorus into the overlying waters. A combination of intensive lake restoration methods was needed to significantly improve the water quality and consisted of sediment removal, constructed wetlands for watershed nutrient removal, and food web manipulation to improve the fishery. Their study proved that in cases of extreme water quality degradation, multiple techniques are often needed to bring a marked balance back to the lake ecosystem. In other words, one solution may not be enough to accomplish adequate restoration that will result in improved water quality of a lake.

3.0 BROOKS LAKE BASIN & INLET 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 1). 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. Brooks Lake is classified as eutrophic (nutrient-enriched) due to the high nutrients and low Secchi transparency and marked dissolved oxygen depletion with depth (Figure 1).

Table 1. General Lake Trophic Status Classification Table.

Lake Trophic Status	*Total Phosphorus (mg L^{-1})*	*Chlorophyll-a (µg L^{-1})*	*Secchi Transparency (feet)*
Oligotrophic	< 0.010	< 2.2	> 15.0
Mesotrophic	0.010-0.025	2.2 – 6.0	7.5 – 15.0
Eutrophic	> 0.025	> 6.0	< 7.5

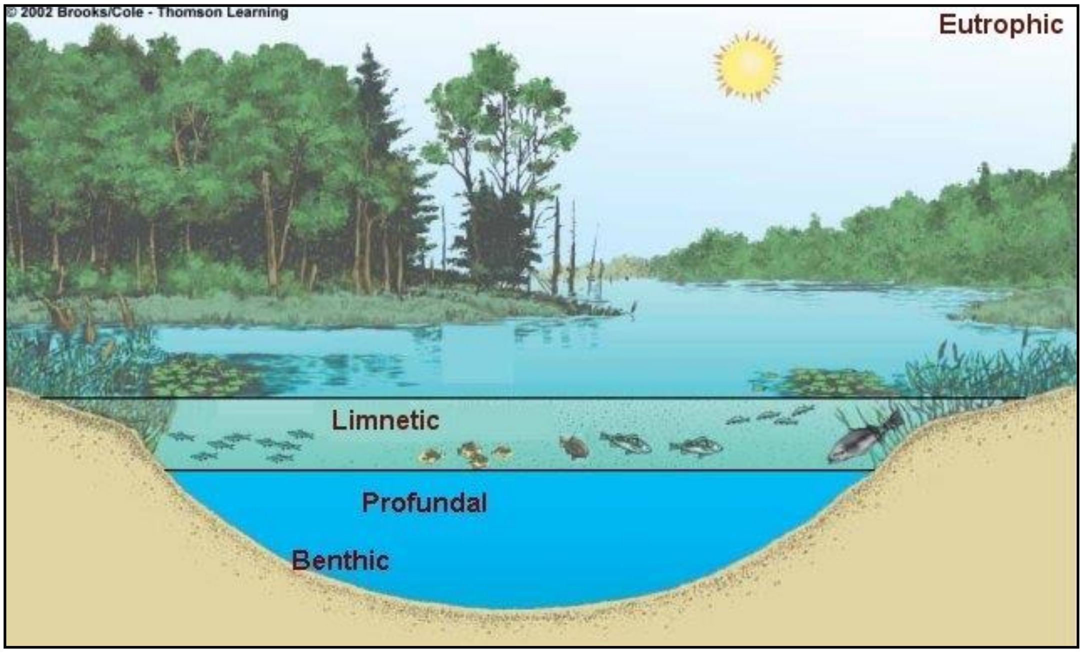


Figure 1. Diagram showing a eutrophic or nutrient-enriched lake ecosystem (photo adapted from Brooks/Cole Thomson learning online).

3.1 Water Quality Parameters

On May 3, 2024, July 10, 2024, September 23, 2024, the two deep basins (east and west) were sampled for physical and chemical water quality parameters. The physical water quality parameters included water temperature, dissolved oxygen concentration, pH, conductivity, total dissolved solids, and Secchi transparency. These parameters were measured in 0.5-meter increments with a calibrated Eureka Manta II® multi-meter probe. from the surface of the lake to the bottom. The chemical water quality parameters included total and ortho-phosphorus, total Kjeldahl and inorganic nitrogen, and total suspended solids. These parameters were measured at the top, middle, and bottom depths at the two deep basins with a 3.2-Liter Van Dorn horizontal water sampler. Chlorophyll-a was measured *in situ* with a calibrated Turner Designs® fluorimeter as a composite sample throughout the water column in both basins.

In addition to the basin sampling, the inlet from Hess Lake was sampled for the same water quality parameters as for the basins with the exception of chlorophyll-a and Secchi transparency which were not applicable for this evaluation at this location.

A total of 4 sediment samples were collected throughout the lake basin using an Ekman® hand dredge and analyzed for percentage of organic carbon.

All of these water quality parameters respond to changes in water quality and consequently serve as indicators of change over time. The deep basin results for all physical and chemical water quality parameters and sediment are discussed below and are presented in Tables 5-22. Tables 23 and 24 display the means for all parameters to date for 2023 and 2024, respectively. A map showing the sampling locations for all water quality samples is shown below in Figure 2. A map showing all sediment sampling locations is provided in Figure 3. All samples were taken to a NELAC-certified laboratory for analysis. Specific sampling methods for each parameter are discussed in each parameter section below.

Figure 2. Brooks Lake water quality sampling location map (RLS, 2023-2024).

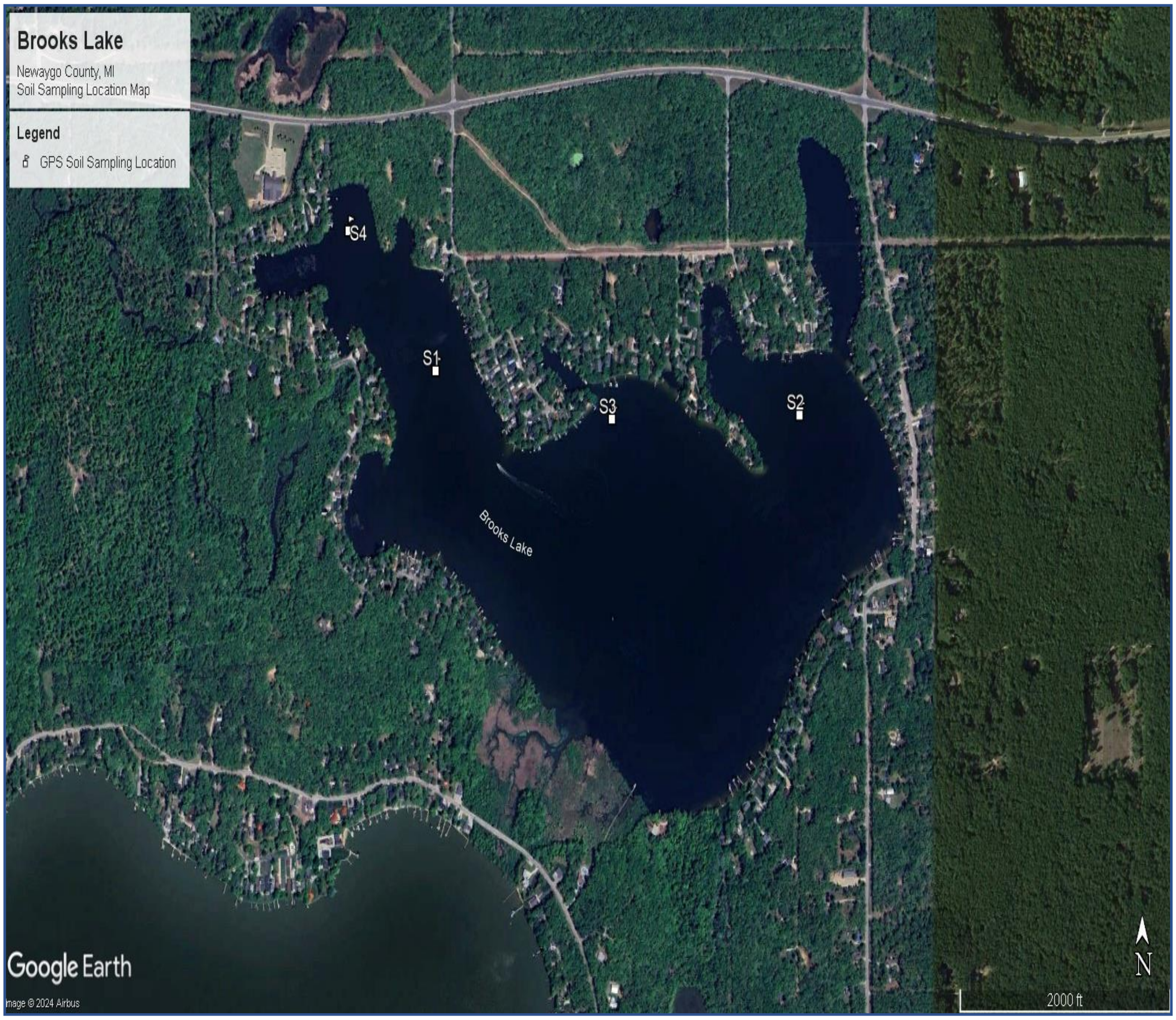
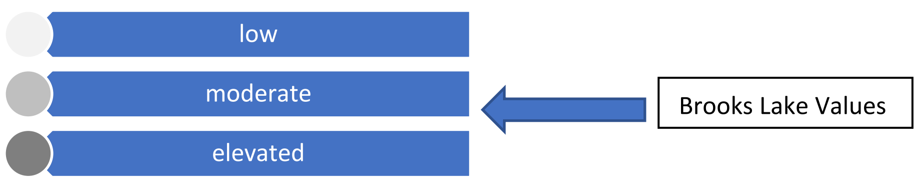


Figure 3. Brooks Lake sediment sampling location map (September 23, 2024).

3.1.1 Dissolved Oxygen

Dissolved oxygen is a measure of the amount of oxygen that exists in the water column. In general, dissolved oxygen levels should be greater than 5 mg/L to sustain a healthy warm-water fishery. Dissolved oxygen concentrations may decline if there is a high biochemical oxygen demand (BOD) where organismal consumption of oxygen is high due to respiration. Dissolved oxygen is generally higher in colder waters. Dissolved oxygen was measured in milligrams per liter (mg/L) with the use of a calibrated Eureka Manta II® dissolved oxygen meter.

The bottom of the lake produces a biochemical oxygen demand (BOD) due to microbial activity attempting to break down high quantities of organic plant matter, which reduces dissolved oxygen in the water column at depth. Furthermore, the lake bottom is distant from the atmosphere where the exchange of oxygen occurs. 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. The dissolved oxygen concentration in Brooks Lake ranged from 7.5-10.5 mg/L throughout the 2024 season. Both basins exhibited oxygen depletion with depth though during the summer months, but the West Basin has significantly more depletion with depth.



3.1.2 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" (Figure 4). 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 calibrated Eureka Manta II® submersible thermometer. The mean water temperature measurements in Brooks Lake ranged from 16.8-25.2°C throughout the 2024 season with the coolest temperatures in the spring.

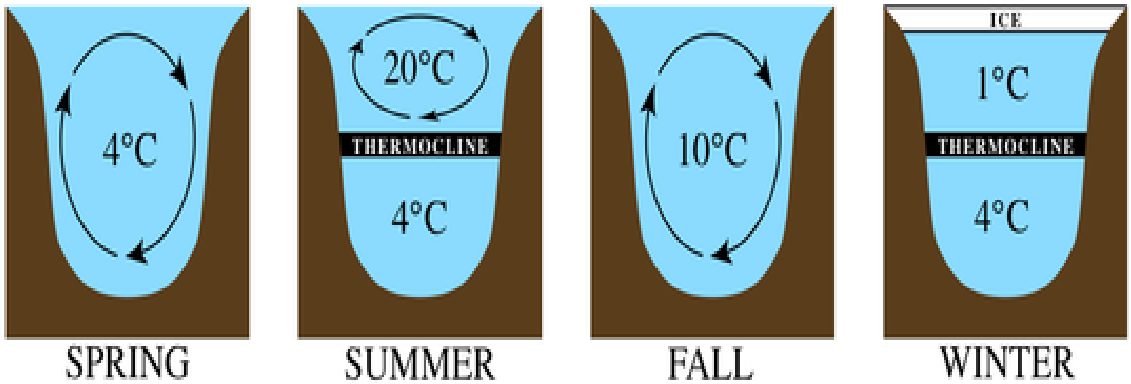
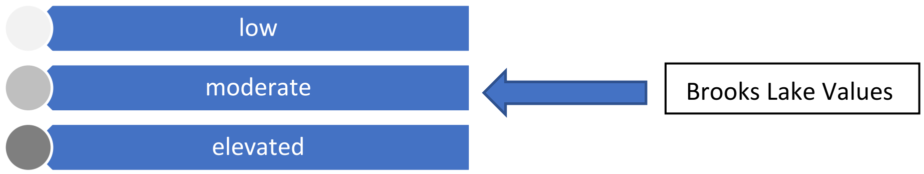


Figure 4. The lake thermal stratification process.

3.1.3 Specific Conductivity

Specific conductivity is a measure of the number 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. Specific conductivity was measured in micro Siemens per centimeter (µS/cm) with the use of a calibrated Eureka Manta II® conductivity probe and meter. The mean conductivity values in the

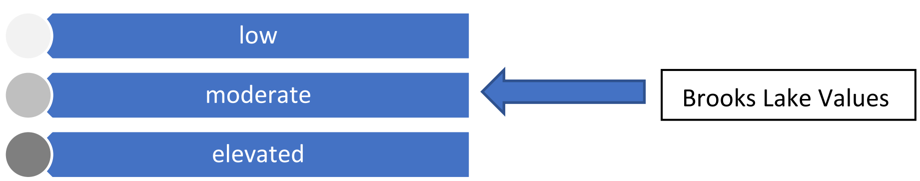
These values are moderate for an inland lake, which means the lake water contains moderate quantities of dissolved metals and ions such as calcium, potassium, sodium, chlorides, sulfates, and carbonates. Baseline parameter data such as conductivity are important to measure the possible influences of land use activities (i.e. road salt influences) on Brooks 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. Elevated conductivity values over 800 mS/cm can negatively impact aquatic life. The mean conductivity in Brooks Lake ranged from 332-351 mS/cm, which are moderate values. Pre biochar mean conductivity was 526±334 mS/cm More data is needed to determine if the biochar lowered the conductivity.



3.1.4 Total Dissolved Solids and Total Suspended Solids

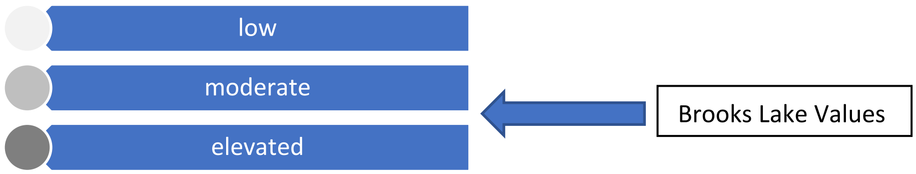
Total Dissolved Solids

Total dissolved solids (TDS) are 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 Eureka Manta II® meter in mg/L. Spring values are usually higher due to increased watershed inputs from spring runoff and/or increased planktonic algal communities. The mean TDS concentrations ranged from 189-638 mg/L which is moderately high. These values correlate with the measured moderate conductivity. The pre-biochar mean was 638±50 mg/L and the post-biochar means ranged from 213-225 mg/L. More data is needed to determine if the biochar was the main cause for this reduction.



Total Suspended Solids (TSS)

Total suspended solids are the measure of the number of suspended particles in the water column. Particles suspended in the water column absorb heat from the sun and raise the water temperature. Total suspended solids were measured in mg/L and analyzed in the laboratory with Method SM 2540 D-11. The lake bottom contains many fine sediment particles that are easily perturbed from winds and wave turbulence. Spring values would likely be higher due to increased watershed inputs from spring runoff and/or increased planktonic algal communities. The mean TSS concentrations in Brooks Lake ranged from 10.3-19.0 mg/L which is moderate. Ideally values should be < 10 mg/L. The TSS values from the inlet was much higher and indicate that most of the TSS that reaches the lake settles in the lake bottom. The pre-biochar TSS concentration mean was 18.7±3.5 mg/L.



3.1.5 pH

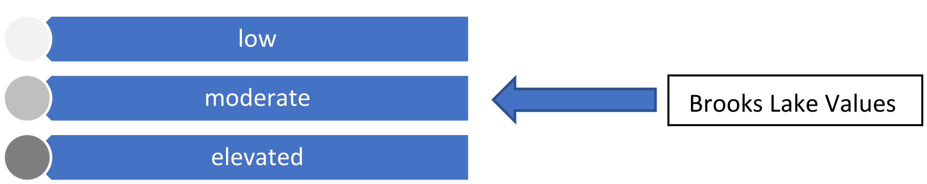
pH is the measure of acidity or basicity of water. pH was measured with a calibrated Eureka Manta II© pH electrode and pH-meter in Standard Units (S.U). The standard pH scale ranges from 0 (acidic) to 14 (alkaline), with neutral values around 7. Most Michigan lakes have pH values that range from 7.0 to 9.5 S.U. 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).

The mean pH values ranged from 8.4-8.9 S.U., which is normal for inland lakes. pH tends to rise when abundant aquatic plants or algae are actively growing through photosynthesis or when abundant marl deposits are present.

3.1.6 Total Phosphorus and Ortho-Phosphorus (SRP)

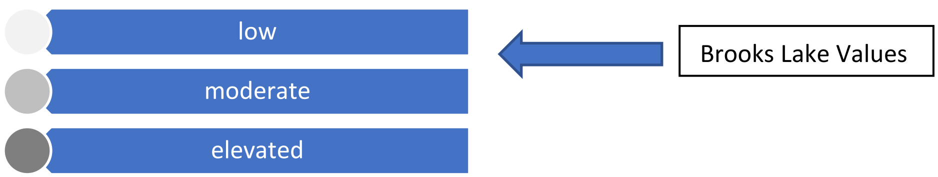
Total Phosphorus

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 0.020 mg/L of TP are defined as eutrophic or nutrient-enriched. TP concentrations are usually higher at increased depths due to the higher release rates of P from lake sediments under low oxygen (anoxic) conditions. Phosphorus may also be released from sediments as pH increases. Total phosphorus was measured in milligrams per liter (mg/L) with the use of Method EPA 200.7 (Rev. 4.4). The mean TP concentrations ranged from 0.011-0.030 mg/L which is moderate. The eutrophic threshold is 0.025 mg/L and thus most of the surface and mid-depth concentrations are below that threshold where the bottom concentrations are higher. These concentrations tend to be higher at the bottom depths and would be released under anoxic conditions such as the conditions present at the bottom of Brooks Lake.



Ortho-Phosphorus

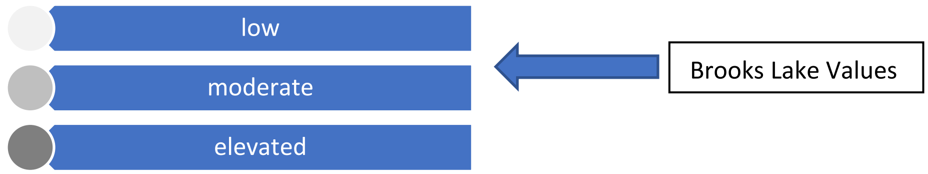
Ortho-Phosphorus (also known as soluble reactive phosphorus or SRP) was measured with Method SM 4500-P (E-11). SRP refers to the most bioavailable from of P used by all aquatic life. The mean SRP concentrations were all ≤0.010 mg/L which is favorable and moderately low.



3.1.7 Total Kjeldahl Nitrogen and Total Inorganic Nitrogen

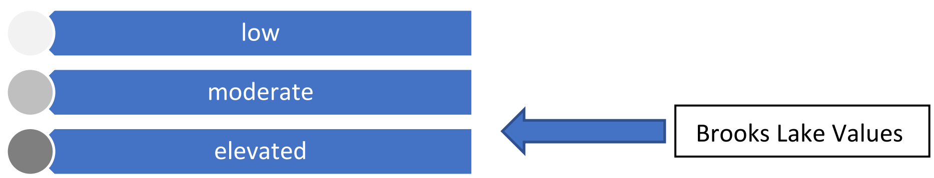
Total Kjeldahl Nitrogen (TKN) is the sum of nitrate (NO_3^-), nitrite (NO_2^-), ammonia (NH_4^+), and organic nitrogen forms in freshwater systems. TKN was measured with Method EPA 351.2 (Rev. 2.0) and Total Inorganic Nitrogen (TIN) was calculated based on the aforementioned three different forms of nitrogen at Trace Analytical Laboratories, Inc. (a NELAC-certified laboratory). 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 may be classified as oligotrophic, those with a mean TKN value of 0.75 mg /L may be classified as mesotrophic, and those with a mean TKN value greater than 1.88 mg/L may be classified as eutrophic. The mean TKN concentration ranged from 1.1-1.2 mg/L in 2024. More data is needed to determine if the Biochar is the reason for reduced TKN. In the absence of dissolved oxygen, nitrogen is usually in the ammonia form and will contribute to rigorous submersed aquatic plant growth if adequate water transparency is present.

The total inorganic nitrogen (TIN) consists of nitrate (NO3), nitrite (NO2), and ammonia (NH3) forms of nitrogen without the organic forms of nitrogen. The mean TIN concentrations in Brooks Lake during the sampling period were all ≤0.100 mg/L which is favorable. More data is needed to determine if the Biochar is the reason for reduced TIN. All of the inorganic nitrogen present in Brooks Lake was in the ammonia form.



3.1.8 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. Chlorophyll-a water samples were collected with an in situ Turner Designs® fluorimeter. High chlorophyll-a concentrations are indicative of nutrient-enriched lakes. Chlorophyll-*a* concentrations greater than 6 µg/L are found in eutrophic or nutrient-enriched aquatic systems, whereas chlorophyll-*a* concentrations less than 2.2 µg/L are found in nutrient-poor or oligotrophic lakes. The mean chlorophyll-*a* concentrations in Brooks Lake ranged from 0-6.0 µg/L which is moderate and problematic and results in reductions in water clarity. The mean chlorophyll-a pre-biochar was 25.0±1.4 µg/L. More data is needed to determine if the biochar effectively reduced the chlorophyll-a. The chlorophyll-a concentrations in Brooks Lake are high enough to prevent successful germination of submersed aquatic vegetation which is needed to make the waters in the basin clearer.

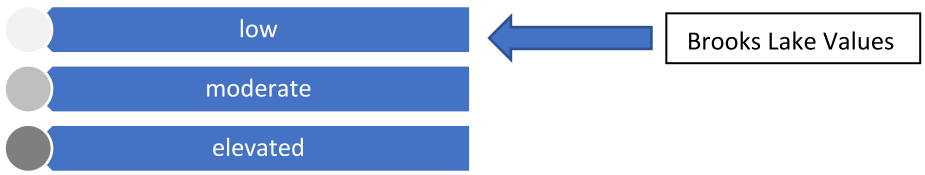


3.1.9 Secchi Transparency

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 during calm to light wind conditions. Secchi disk 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 (Figure 5). Elevated Secchi transparency readings allow for more aquatic plant and algae growth. Eutrophic systems generally have Secchi disk transparency measurements less than 7.5 feet due to turbidity caused by excessive planktonic algae growth.

The mean Secchi transparency in Brooks Lake ranged from 1.8-3.6 feet which is very low. This transparency indicates that an abundance of solids such as suspended particles and algae are present throughout the water column which increases turbidity and reduces water clarity.

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.



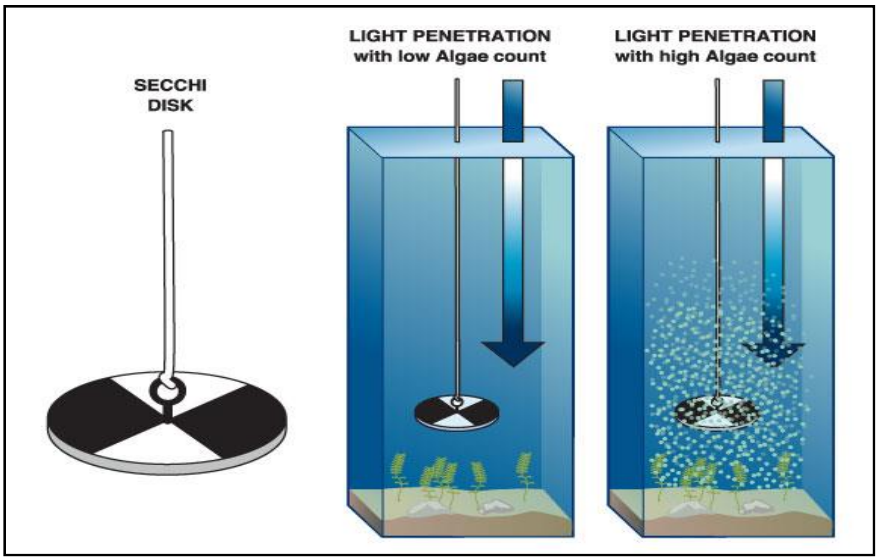


Figure 5. Measurement of water transparency with a Secchi disk.

3.1.10 Sediment Organic Matter

Organic matter (OM) contains a high amount of carbon which is derived from biota such as decayed plant and animal matter. Detritus is the term for all dead organic matter which is different than living organic and inorganic matter. OM may be autochthonous or allochthonous in nature where it originates from within the system or external to the system, respectively. Sediment samples were collected during the September 23, 2024 sampling event using an Ekman hand dredge (Figure 6) at each of the 4 sampling locations.

Sediment OM is measured with the ASTM D2974 Method and is usually expressed in a percentage (%) of total bulk volume. Many factors affect the degradation of organic matter including basin size, water temperature, thermal stratification, dissolved oxygen concentrations, particle size, and quantity and type of organic matter present.

There are two major biochemical pathways for the reduction of organic matter to forms which may be purged as waste. First, the conversion of carbohydrates and lipids via hydrolysis are converted to simple sugars or fatty acids and then fermented to alcohol, CO_2, or CH_4. Second, proteins may be proteolyzed to amino acids, deaminated to NH_3+, nitrified to NO_2- or NO_3-, and denitrified to N_2 gas. Bacteria are the major factor in the degradation of organic matter in sediments (Fenchel and Blackburn, 1979). The organic content ranged from 43-49% which is moderately high (Table 2). This is amenable to breakdown through the use of bioaugmentation with enzymes if needed in the future. The sediment particle size data indicated an abundance of sand substrate.

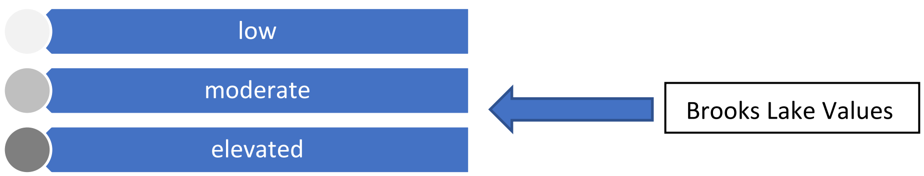


Figure 6. Ekman dredge used for sediment sampling.

Table 2. Brooks Lake sediment nutrient data collected at n= 4 locations (September 23, 2024).

Site	%OM	% Gravel	% Sand	% Fines
S1 (864)	49	0	95.1	4.9
S2 (865)	45	0	95.5	4.5
S3 (866)	43	0	70.8	29.2
S4 (867)	47	0	73.9	26.1

A bottom sediment hardness scan was conducted of the entire lake bottom on September 23, 2024. The bottom hardness map shows (Figure 7) that most of the lake bottom consists of fairly consolidated sediment throughout the lake with only a few small areas with soft organic bottom. This is not surprising given the amount of sandy loams in the region which contribute to lake geology. Table 3 below shows the categories of relative bottom hardness with 0.0-0.1 referring to the softest and least consolidated bottom and >0.4 referring to the hardest, most consolidated bottom for the two lake basins. This scale does not mean that any of the lake contains a truly “hard” bottom but rather a bottom that is more coherent and not flocculent.

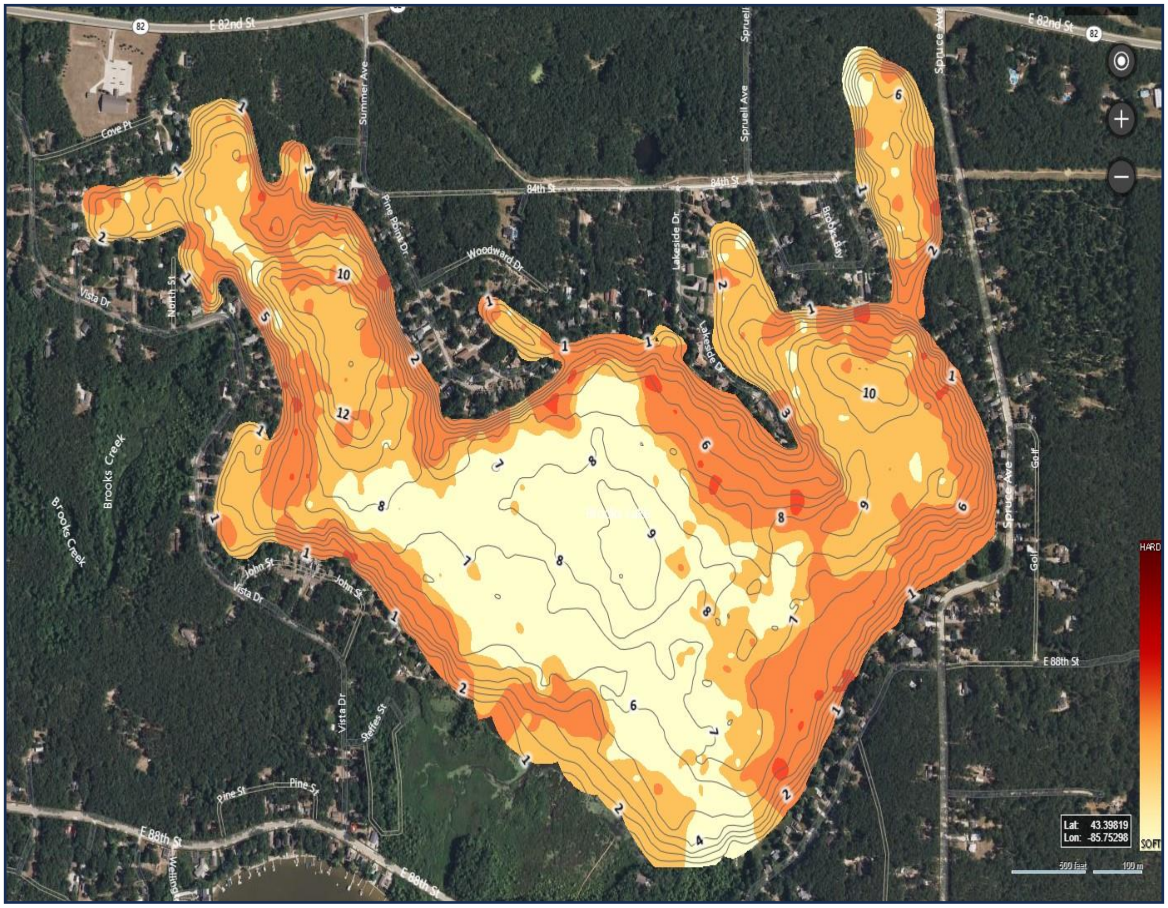


Figure 7. Brooks Lake sediment relative hardness scan map (September 23, 2024).

Table 3. Brooks Lake basin relative hardness of the lake bottom by category or hardness and percent cover of each category (relative cover).

Lake Bottom Relative Hardness Category	# GPS Points in Each Category (Total =9,526)	% Relative Cover of Bottom by Category
0.0-0.1	264	2.8
0.1-0.2	2457	25.8
0.2-0.3	4376	45.9
0.3-0.4	2429	25.5
>0.4	0	0.0

3.1.11 Aquatic Vegetation Biovolume

A whole-lake scan of the aquatic vegetation in Brooks Lake was conducted on September 23, 2024 with a WAAS-enabled Lowrance HDS 9 GPS with variable frequency transducer. Geo-referenced sounding points were then uploaded into a cloud software program to reveal maps that displayed depth contours, sediment hardness, and aquatic vegetation biovolume (Figure 8). On the biovolume maps, the color blue refers to areas that lack vegetation. The color green refers to low-lying vegetation. The colors red/orange refer to tall-growing vegetation. There are many areas around the littoral (shallow) zone of the lake that contain low-growing plants like Chara (Table 4). Overall, the lake lacks adequate cover of submersed aquatic vegetation, which is resulting in increased growth of algae, particularly blue-green algae.

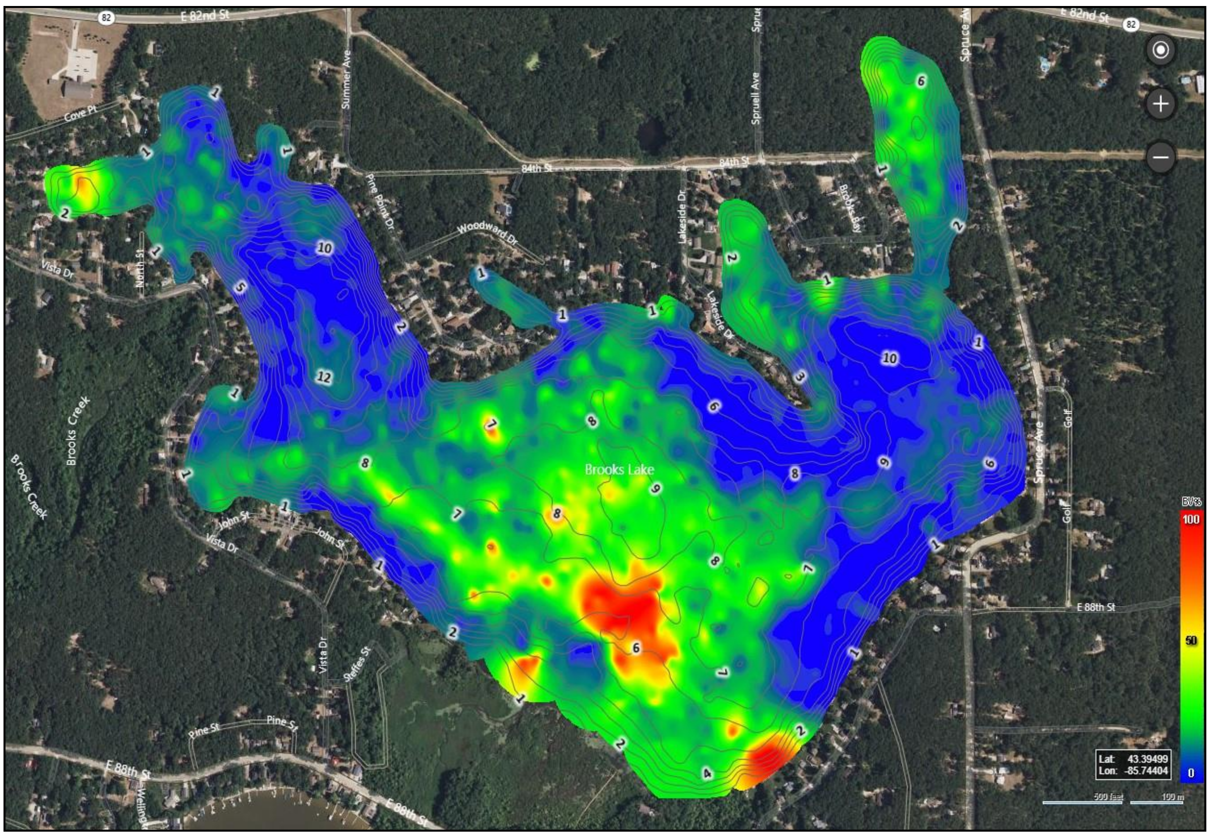


Figure 8. Aquatic plant biovolume of all aquatic plants in north Brooks Lake, Newaygo County, Michigan (September 23, 2024). Note: Red color denotes high-growing aquatic plants, green color denotes low-growing aquatic plants, and blue color represents a lack of aquatic vegetation.

Table 4. Brooks Lake basin aquatic vegetation biovolume by category percent cover of each category (relative cover on September 23, 2024).

Biovolume Cover Category	% Relative Cover of Bottom by Category
0-20%	73.7
20-40%	19.1
40-60%	4.5
60-80%	1.7
>80%	0.9

Table 5. Brooks Lake physical water quality parameter data collected at deep basin East (May 3, 2024).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)	Secchi Depth (ft)
0	18.5	10.0	9.1	327	210	3.5
0.5	18.0	11.0	9.2	327	210	
1.0	17.5	11.2	9.2	327	209	
1.5	17.4	11.3	9.2	327	209	
2.0	17.0	11.3	9.1	328	210	
2.5	16.5	11.2	9.1	331	212	
3.0	15.9	11.0	9.0	332	212	
3.5	15.4	10.2	8.5	342	219	
4.0	14.5	7.6	7.4	499	314	

Table 6. Brooks Lake chemical water quality parameter data collected at deep basin East (May 3, 2024).

Depth (m)	TKN (mg/L)	TIN (mg/L)	NH3 (mg/L)	NO3- (mg/L)	NO2- (mg/L)	TSS (mg/L)	TP (mg/L)	Ortho-P (mg/L)	Chl-a (µg/L)
0	1.0	<0.1	<0.010	<0.1	<0.10	<10	0.024	<0.010	0.00
2.0	1.2	<0.1	0.010	<0.1	<0.10	<10	0.022	<0.010	
4.0	1.7	<0.1	0.037	<0.1	<0.10	10	0.036	<0.010	

Table 7. Brooks Lake physical water quality parameter data collected at deep basin West (May 3, 2024).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)	Secchi Depth (ft)
0	18.2	9.6	9.1	328	210	3.6
0.5	18.1	10.1	9.1	328	210	
1.0	17.6	10.8	9.1	328	210	
1.5	17.5	11.0	9.1	328	210	
2.0	17.4	11.2	9.1	328	210	
2.5	17.3	11.3	9.1	329	211	
3.0	17.1	11.1	9.1	331	212	
3.5	16.1	11.1	8.9	335	214	
4.0	14.8	10.1	8.5	339	217	
4.5	14.3	8.7	8.2	364	245	

Table 8. Brooks Lake chemical water quality parameter data collected at deep basin West (May 3, 2024).

Depth (m)	TKN (mg/L)	TIN (mg/L)	NH3 (mg/L)	NO3- (mg/L)	NO2- (mg/L)	TSS (mg/L)	TP (mg/L)	Ortho-P (mg/L)	Chl-a (µg/L)
0	1.8	<0.1	<0.010	<0.1	<0.10	<10	0.028	<0.010	0.00
2.5	2.4	<0.1	0.012	<0.1	<0.10	<10	0.032	<0.010	
4.5	1.7	<0.1	0.057	<0.1	<0.10	12	0.032	<0.010	

Table 9. Brooks Lake physical water quality parameter data collected at in the inlet (May 3, 2024).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)
0	18.7	9.1	8.8	362	232

Table 10. Brooks Lake chemical water quality parameter data collected at the inlet (May 3, 2024).

TKN (mg/L)	TIN (mg/L)	NH3 (mg/L)	NO3- (mg/L)	NO2- (mg/L)	TSS (mg/L)	TP (mg/L)	Ortho-P (mg/L)
1.5	0.300	0.140	0.160	<0.10	26	0.052	0.010

Table 11. Brooks Lake physical water quality parameter data collected at deep basin East (July 10, 2024).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)	Secchi Depth (ft)
0	26.1	9.0	8.8	344	220	3.3
0.5	26.1	8.7	8.8	344	220	
1.0	26.1	8.7	8.9	345	220	
1.5	25.9	8.6	8.7	347	222	
2.0	25.6	8.2	8.6	349	223	
2.5	25.2	6.4	8.1	353	226	
3.0	24.2	5.7	7.7	357	229	
3.5	23.4	3.1	7.2	371	237	

Table 12. Brooks Lake chemical water quality parameter data collected at deep basin East (July 10, 2024).

Depth (m)	TKN (mg/L)	TIN (mg/L)	NH3 (mg/L)	NO3- (mg/L)	NO2- (mg/L)	TSS (mg/L)	TP (mg/L)	Ortho-P (mg/L)	Chl-a (µg/L)
0	0.9	<0.1	<0.010	<0.1	<0.10	10	0.022	<0.010	4.81
1.5	1.7	<0.2	0.017	<0.2	<0.10	10	0.036	<0.010	
3.5	0.7	<0.2	0.011	<0.2	<0.10	16	0.038	<0.010	

Table 13. Brooks Lake physical water quality parameter data collected at deep basin West (July 10, 2024).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)	Secchi Depth (ft)
0	25.7	8.9	8.8	345	221	3.4
0.5	25.7	8.9	8.9	345	221	
1.0	25.7	8.9	8.9	345	221	
1.5	25.7	8.9	8.9	345	221	
2.0	25.7	8.9	8.8	346	221	
2.5	25.3	8.3	8.4	351	225	
3.0	24.7	7.5	8.0	354	226	
3.5	24.0	5.5	7.6	356	228	
4.0	23.2	2.9	7.3	368	236	

Table 14. Brooks Lake chemical water quality parameter data collected at deep basin West (July 10, 2024).

Depth (m)	TKN (mg/L)	TIN (mg/L)	NH3 (mg/L)	NO3- (mg/L)	NO2- (mg/L)	TSS (mg/L)	TP (mg/L)	Ortho-P (mg/L)	Chl-a (µg/L)
0	1.1	<0.2	<0.010	<0.2	<0.10	12	0.024	<0.010	7.12
2.0	1.1	<0.2	<0.010	<0.2	<0.10	13	0.024	<0.010	
4.0	1.4	<0.2	0.014	<0.2	<0.10	13	0.036	<0.010	

Table 15. Brooks Lake physical water quality parameter data collected at in the inlet (July 10, 2024).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)
0	25.0	8.6	8.7	322	206

Table 16. Brooks Lake chemical water quality parameter data collected at the inlet (July 10, 2024).

TKN (mg/L)	TIN (mg/L)	NH3 (mg/L)	NO3- (mg/L)	NO2- (mg/L)	TSS (mg/L)	TP (mg/L)	Ortho-P (mg/L)
1.0	<0.2	<0.010	<0.2	<0.10	14	0.028	<0.010

Table 17. Brooks Lake physical water quality parameter data collected at deep basin East (September 23, 2024).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)	Secchi Depth (ft)
0	23.8	8.5	9.1	314	201	1.3
0.5	23.6	9.3	9.1	314	201	
1.0	23.3	9.4	9.1	314	201	
1.5	23.2	9.4	9.1	314	201	
2.0	22.9	9.3	9.1	315	202	
2.5	22.7	9.1	9.1	315	201	
3.0	22.3	9.0	9.0	315	202	
3.5	22.3	8.9	7.9	386	261	

Table 18. Brooks Lake chemical water quality parameter data collected at deep basin East (September 23, 2024).

Depth (m)	TKN (mg/L)	TIN (mg/L)	NH3 (mg/L)	NO3- (mg/L)	NO2- (mg/L)	TSS (mg/L)	TP (mg/L)	Ortho-P (mg/L)	Chl-a (µg/L)
0	1.0	<0.1	<0.010	<0.1	<0.10	16	<0.010	<0.010	0.00
1.5	1.0	<0.1	<0.010	<0.1	<0.10	18	<0.010	<0.010	
3.5	0.8	<0.1	<0.010	<0.1	<0.10	19	<0.010	<0.010	

Table 19. Brooks Lake physical water quality parameter data collected at deep basin West (September 23, 2024).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)	Secchi Depth (ft)
0	24.0	9.0	8.9	317	203	1.3
0.5	23.8	9.0	9.0	316	202	
1.0	23.6	9.0	9.0	316	202	
1.5	23.5	8.9	9.0	316	202	
2.0	23.4	8.8	8.9	317	203	
2.5	23.1	8.7	8.9	317	203	
3.0	23.1	8.5	8.9	317	203	
3.5	22.8	8.5	8.9	316	202	
4.0	22.6	4.3	6.7	532	338	

Table 20. Brooks Lake chemical water quality parameter data collected at deep basin West (September 23, 2024).

Depth (m)	TKN (mg/L)	TIN (mg/L)	NH3 (mg/L)	NO3- (mg/L)	NO2- (mg/L)	TSS (mg/L)	TP (mg/L)	Ortho-P (mg/L)	Chl-a (µg/L)
0	1.2	<0.1	0.015	<0.1	<0.10	17	0.018	<0.010	3.56
2.0	1.1	<0.1	<0.010	<0.1	<0.10	20	0.010	<0.010	
4.0	1.4	<0.1	0.210	<0.1	<0.10	24	<0.010	<0.010	

Table 21. Brooks Lake physical water quality parameter data collected at in the inlet (September 23, 2024).

Depth (m)	Water Temp (°C)	DO (mg/L)	pH (S.U.)	Conduc. (mS/cm)	TDS (mg/L)
0	25.7	5.7	9.4	287	183

Table 22. Brooks Lake chemical water quality parameter data collected at the inlet (September 23, 2024).

TKN (mg/L)	TIN (mg/L)	NH3 (mg/L)	NO3- (mg/L)	NO2- (mg/L)	TSS (mg/L)	TP (mg/L)	Ortho-P (mg/L)
1.1	<0.100	0.013	<0.100	<0.10	22	<0.010	<0.010

Table 23. Descriptive statistics of all water quality parameters in the deepest basin of Brooks Lake for biochar baseline parameters collected on June 23, 2023, July 28, 2023, September 20, 2023, and November 7, 2024.

Water Quality Parameter	Baseline Pre Biochar June 23 Means ± SD	Post Biochar July 28 Means ± SD	Post Biochar Sept 20 Means ± SD	Post Biochar November 7 Means ± SD
Water temp (°C)	22.9±2.6	26.1±1.1	18.9±0.5	8.4±0.0
pH (S.U.)	8.4±0.6	8.6±0.1	9.1±0.3	8.9±0.1
Dissolved oxygen (mg/L)	7.4±4.8	7.4±2.3	10.6±0.4	11.7±0.4
Conductivity (mS/cm)	526±334	344±75	326±92	297±4.0
Total dissolved solids (mg/L)	638±50	190±0.5	208±58	189±1.5
Secchi transparency (ft)	2.0±0.1	3.4±0.1	1.7±0.1	2.4±0.2
Chlorophyll-a (µg/L)	25.0±1.4	6.5±0.7	4.5±0.7	14.0±0.0
Total Kjeldahl nitrogen (mg/L)	1.5±061	1.2±0.3	1.0±0.1	1.3±0.2
Total inorganic nitrogen (mg/L)	0.279±0.6	0.026±0.015	0.010±0.0	0.010±0.0
Ammonia nitrogen (mg/L)	0.279±0.6	0.026±0.015	0.010±0.0	0.010±0.0
Nitrate nitrogen (mg/L)	0.100±0.0	0.100±0.0	0.100±0.0	0.100±0.0
Nitrite nitrogen (mg/L)	0.100±0.0	0.100±0.0	0.100±0.0	0.100±0.0
Total phosphorus (mg/L)	0.029±0.0	0.016±0.0	0.023±0.0	0.034±0.014
Ortho-Phosphorus (mg/L)	0.010±0.0	0.010±0.0	0.010±0.0	0.016±0.002
Total suspended solids (mg/L)	18.7±3.5	23.0±8.0	16.0±3.8	10.0±0.0

Table 24. Descriptive statistics of all water quality parameters in the east and west basins of Brooks Lake for PrO2 baseline parameters and post biochar evaluation collected on May 3, July 10, and September 23, 2024. Note: June 2023 pre-biochar data was left in the table for ease of data comparison.

Water Quality Parameter	Baseline Pre Biochar June 23 Means ± SD	Post Biochar May 3, 2024 Means ± SD	Post Biochar July 10, 2024 Means ± SD	Post Biochar Sept 23, 2024 Means ± SD
Water temp (°C)	22.9±2.6	16.8±1.3	25.2±0.9	23.2±0.5
pH (S.U.)	8.4±0.6	8.9±0.5	8.4±0.6	8.8±0.6
Dissolved oxygen (mg/L)	7.4±4.8	10.5±1.0	7.5±2.0	8.7±1.2
Conductivity (mS/cm)	526±334	341±39	351±8.2	332±54
Total dissolved solids (mg/L)	638±50	219±24	225±5.0	213±35
Secchi transparency (ft)	2.0±0.1	3.6±0.1	3.4±0.1	1.3±0.0
Chlorophyll-a (µg/L)	25.0±1.4	0.0±0.0	6.0±1.6	1.8±2.5
Total Kjeldahl nitrogen (mg/L)	1.5±061	1.6±0.5	1.2±0.4	1.1±0.2
Total inorganic nitrogen (mg/L)	0.279±0.6	0.1±0.0	0.1±0.0	0.1±0.0
Ammonia nitrogen (mg/L)	0.279±0.6	0.023±0.0	0.012±0.0	0.044±0.1
Nitrate nitrogen (mg/L)	0.100±0.0	0.100±0.0	0.100±0.0	0.100±0.0
Nitrite nitrogen (mg/L)	0.100±0.0	0.100±0.0	0.100±0.0	0.100±0.0
Total phosphorus (mg/L)	0.029±0.0	0.029±0.0	0.030±0.0	0.011±0.0
Ortho-Phosphorus (mg/L)	0.010±0.0	0.010±0.0	0.010±0.0	0.010±0.0
Total suspended solids (mg/L)	18.7±3.5	10.3±0.8	12.3±2.3	19.0±2.8

4.0 BROOKS LAKE FUTURE RESOTORATION RECOMMENDATIONS

4.1 Brooks Lake Water Quality Improvement

In addition to commonly known best management practices (BMP's) such as the avoidance of lawn fertilizer use and proper maintenance of septic systems, there are some methods available to improve the water quality within the lake basin. These methods are often large in scale and costly but are highly effective at increasing water clarity, reducing algae, increasing dissolved oxygen, reducing muck, and allowing for enhanced recreational activities.

4.1.1 Biochar

A natural charcoal technology called EarthFood Biochar US® (Figure 9) is available for filtration of nutrients and pollutants that may enter inland waters such as Brooks Lake. The Biochar is comprised of 87.4% organic carbon based on percentage of total dry mass. Particles range in size from 8-25 mm so there is inherent variability in particle size. This variability allows for the adsorption of nutrients and pollutants due to increased adsorptive surface area. Biochar may be placed in a multi-filament polypropylene sock (such as Silt Sock®; Figure 10) which has a life expectancy of up to 2 years. It is considered an inert product with no chemical effect on the environment. This product allows for the Biochar to be contained in an area and serves to consolidate the particles for optimum filtration efficiency. It has recently demonstrated excellent results on reducing total phosphorus, ammonia nitrogen, and total suspended solids in Silver Lake in Oceana County. Preliminary results in Brooks Lake are also encouraging but much more data is needed.

Figure 9. TimberChar® Aqua biochar.

Figure 10. Biochar filters mounted on a dock in Silver Lake.

4.1.2 Hypolimnetic Oxygenation

There are many forms of aeration in inland lakes, but all include the movement of water or oxygenated water throughout the water column (Figure 11). Fountain aeration can be used in ponds and canals and only increases dissolved oxygen within a small radius of influence from the fountain. Laminar flow aeration consists of placement of diffusers along the lake bottom but has been demonstrated to transport higher phosphorus from the lake bottom to the surface layers, resulting in increased algae and turbidity. Hypolimnetic aeration such as PrO2 aims to aerate only the hypoxic (low-oxygen) layer at the lake bottom to reduce phosphorus release without disrupting the middle and upper layers via destratification.

May benefits of aeration systems in general have demonstrated significant and positive results. 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. 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 in reservoirs. 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.

Benefits and Limitations of Aeration

In addition to the reduction in toxic blue-green algae (such as *Microcystis* sp.) as described by Toetz (1981), aeration and bioaugmentation 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 bioaugmentation. 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 study by Turcotte et *al*. (1988) analyzed the impacts of bioaugmentation on the growth of Eurasian Watermilfoil 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.

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 Eurasian Watermilfoil 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.

All aeration systems have some limitations including the inability to break down mineral sediments and the requirement of a constant Phase I electrical energy source to power the units. The largest benefit of oxygenation for Brooks Lake would be the increase in water column dissolved oxygen which would reduce the release of phosphorus and also the reduction in blue-green algae which is critical. Hypolimnetic oxygenation via a PrO2 unit (Figure 11) made by Greener Planet Systems® (Iowa, USA), is a technology that has been previously used in wastewater treatment. The treatment of wastewater to reduce nutrients and pollutants is required for state-issued discharge permits. This technology is a patented technology that utilizes pure oxygen that is pumped into the bottom of a lake through direct hoses that deliver the oxygen to the hypolimnion to avoid destratification of the water column.

This reduces the release of phosphorus from lake sediments which reduces the nutrients in the upper water layers and thus reduces the presence of blue-green algae blooms. Numerous peer-reviewed studies support this method (Bormans et *al*., 2015 and Wagner, 2015, among others).

Dissolved oxygen from the PrO2 series is not limited by ambient saturation levels because the delivered oxygen is already dissolved and will experience no effects of buoyancy because it is not a bubble. The PrO2 Series efficiently delivers extremely large amounts of dissolved oxygen into waste matter with up to 96% oxygen transfer efficiency. As a result, the oxygen rich environment will accelerate the natural breakdown of organic matter while creating and preserving an odor free environment.

The major deliverables offered by the PrO2 unit are as follows:

- Empowers microbes to consume 95% of organic waste
- 96% Oxygen transfer efficiency
- 75% Reduction in conventional aeration costs
- Targeted application control (oxygenates the deep basin(s) only if desired)
- Remote and onsite control options (can maintain constant stable dissolved oxygen concentrations)
- Scalable to every lake size (includes a secure shed or trailer for large units)

Figure 11. Diagram of PrO2 Hypolimnetic Oxygenation System.

4.1.3 Proper Septic System Maintenance

Nutrient pollution of inland lakes from septic systems and other land use activities is not a modern realization and has been known for multiple decades. The problem is also not unique to Michigan Lakes and was first described in Montreal Canada by Lesauteur (1968) who noticed that summer cottages were having negative impacts on many water bodies. He further noted that a broader policy was needed to garner control of these systems because they were becoming more common over time. Many of our inland lakes are in rural areas and thus sewer systems or other centralized wastewater collection methods are not practical. Thus, septic systems have been common in those areas since development on inland lakes began. Septic systems have four main components consisting of a pipe from the residence, a septic tank or reservoir, a drainage field, and the surrounding soils Figure 12).

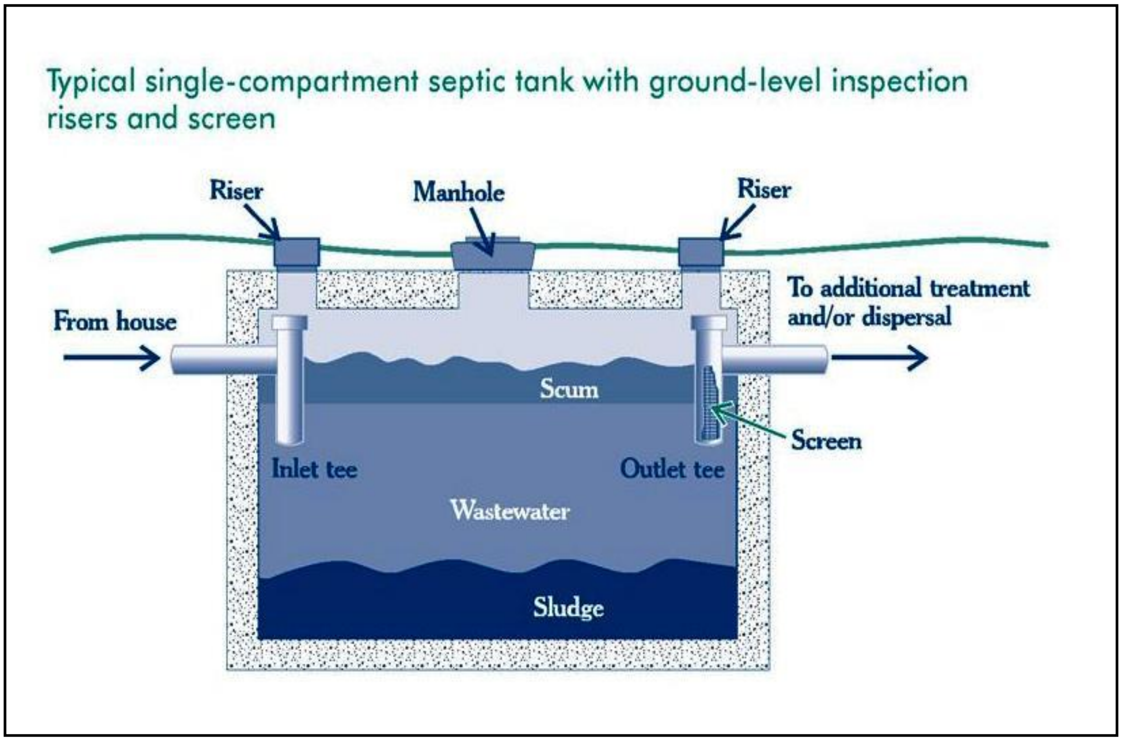


Figure 12. Diagram of essential septic tank components (US EPA).

On ideal soil types, microbes in the soil are able to decompose nutrients and reduce the probability of groundwater contamination. However, many lakes in Michigan contain soils that are not suitable for septic systems. Soils that are not very permeable, prone to saturation or ponding, and have mucks exist around many lakes and currently have properties with septic systems.

In fact, soils that are saturated may be associated with a marked reduction in phosphorus assimilation and adsorption (Gilliom and Patmont, 1983; Shawney and Starr, 1977) which leads to the discharge of phosphorus into the groundwater, especially in areas with a high water table. In the study by Gilliom and Patmont (1983) on Pine Lake in the Puget Sound of the western U.S., they found that it may take 20-30 years for the phosphorus to make its way to the lake and cause negative impacts on water quality.

Typical septic tank effluents are rich in nutrients such as phosphorus and nitrogen, chlorides, fecal coliform, sulfates, and carbon (Cantor and Knox, 1985). Phosphorus and nitrogen have long been identified as the key causes of nuisance aquatic plant and algae growth in inland lakes. Although phosphorus is often the limiting growth factor for aquatic plant growth, nitrogen is often more mobile in the groundwater and thus is found in abundance in groundwater contributions to lakes.

A groundwater seepage study on submersed aquatic plant growth in White Lake, Muskegon County, Michigan, was conducted in 2005 by Jermalowicz-Jones (MS thesis, Grand Valley State University) and found that both phosphorus and nitrogen concentrations were higher in developed areas than in undeveloped areas. This helped to explain why the relatively undeveloped northern shore of White Lake contained significantly less submersed aquatic plant growth than the developed southern shoreline. The research also showed that more nutrients were entering the lake from groundwater than in some of the major tributaries.

Spence-Cheruvelil and Soranno (2008) studied 54 inland lakes in Michigan and found that total aquatic plant cover (including submersed plants) was most related to secchi depth and mean depth. However, they also determined that man-made land use activities are also predictors of aquatic plant cover since such variables can also influence these patterns of growth. Prior to changes in offshore aquatic plant communities, an additional indicator of land use impacts on lake water quality in oligotrophic lakes (lakes that are low in nutrients) includes changes in periphytic algae associated with development nearshore. Such algae can determine impacts of septic leachate before other more noticeable changes offshore are found (Rosenberger et *al*., 2008). Development in the watershed also may influence the relative species abundance of individual aquatic plant species. Sass et *al*. (2010) found that lakes associated with rigorous development in surrounding watersheds had more invasive species and less native aquatic plant diversity than less developed lakes. Thus, land use activities such as failing septic systems may not only affect aquatic plant biomass and algal biomass, but also the composition and species richness of aquatic plant communities.

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

It is estimated that Michigan has over 1.2 million septic systems currently installed with many of them occurring in rural areas around inland lakes. Currently only seven counties in Michigan (Benzie, Grand Traverse, Macomb, Ottawa, Shiawassee, Washtenaw, and Wayne) require a septic system inspection prior to a property being sold. The number of septic systems that are a risk to the aquatic environment is unknown which makes riparian awareness of these systems critical for protection of lake water. Construction of new septic tanks require notification and application by the homeowner to the county Department of Public Health and also that soils must be tested to determine suitability of the system for human health and the environment. It is recommended that each septic tank be inspected every 2-3 years and pumped every 3-5 years depending upon usage. The drain field should be inspected as well and only grasses should be planted in the vicinity of the system since tree roots can cause the drain field to malfunction. Additionally, toxins should not be added to the tank since this would kill beneficial microbes needed to digest septic waste.

Areas that contain large amounts of peat or muck soils may not be conducive to septic tank placement due to the ability of these soils to retain septic material and cause ponding in the drain field. Other soils that contain excessive sands or gravels may also not be favorable due to excessive transfer of septage into underlying groundwater. Many sandy soils do not have a strong adsorption capacity for phosphorus and thus the nutrient is easily transported to groundwater. Nitrates, however, are even more mobile and travel quickly with the groundwater and thus are also a threat to water quality.

The utilization of septic systems by riparians is still quite common around inland lake shorelines. A basic septic system typically consists of a pipe leading from the home to the septic tank, the septic tank itself, the drain field, and the soil. The tank is usually an impermeable substance such as concrete or polyethylene and delivers the waste from the home to the drain field. The sludge settles out at the tank bottom and the oils and buoyant materials float to the surface. Ultimately the drain field receives the contents of the septic tank and disperses the materials into the surrounding soils. The problem arises when this material enters the zone of water near the water table and gradually seeps into the lake bottom. This phenomenon has been noted by many scholars on inland waterways as it contributes sizeable loads of nutrients and pathogens to lake water. Lakebed seepage is highly dependent upon water table characteristics such as slope (Winter 1981). The higher the rainfall, the more likely seepage will occur and allow groundwater nutrients to enter waterways. Seepage velocities will differ greatly among sites and thus failing septic systems will have varying impacts on the water quality of specific lakes. Lee (1977) studied seepage in lake systems and found that seepage occurs as far as 80 meters from the shore. This finding may help explain the observed increases in submersed aquatic plant growth near areas with abundant septic tank systems that may not be adequately maintained. Loeb and Goldman (1978) found that groundwater contributes approximately 44% of the total soluble reactive phosphorus (SRP) and 49% of total nitrates to Lake Tahoe from the Ward Valley watershed.

Additionally, Canter (1981) determined that man-made (anthropogenic) activities such as the use of septic systems can greatly contribute nutrients to groundwater. Poorly maintained septic systems may also lead to increases in toxin-producing blue-green algae such as *Microcystis.* This alga is indicative of highly nutrient-rich waters and forms an unsightly green scum on the surface of a water body. Toxins are released from the algal cells and may be dangerous to animals and humans in elevated concentrations. Furthermore, the alga may shade light from underlying native aquatic plants and create a sharp decline in biomass which leads to lower dissolved oxygen levels in the water column. Repeated algae treatments are often not enough to compensate for this algal growth and the problem persists. There are on-site technologies such as the SludgeHammer® that aerate the effluent prior to entering the drain field to reduce nutrients to inland lakes.

4.1.4 Erosion and Shoreline Stabilization

In addition to the proposed protection of native aquatic plants and control of invasives in Brooks Lake, it is recommended that BMPs 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%)
2) Development of an emergent vegetation buffer zone 25-30 feet from the land-water interface with approximately 60-80% of the shoreline bordered with vegetation
3) Limiting boat traffic and boat size to reduce wave energy and thus erosion potential
4) Encouraging the growth of dense shrubs or emergent shoreline vegetation to control erosion
5) Using only <u>native</u> genotype plants (those native to Brooks Lake or the region) around the lake since they are most likely to establish and thrive than those not acclimated to growing in the area soils. A local horticultural supply center would likely have a list of these species.
6) 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.
7) All wetland areas around Brooks Lake should be preserved to act as a filter of nutrients from the land and to provide valuable wildlife habitat.
8) Erosion of soils into the water may lead to increased turbidity and nutrient loading to the lake. Seawalls should consist of riprap (stone, rock), rather than metal or concrete, since riprap offers a more favorable habitat for lakeshore organisms, which are critical to the ecological balance of the lake ecosystem (Figure 13). Rip-rap should be installed in front of areas where metal seawalls are currently in use. The riprap should extend into the water to create a presence of microhabitats for enhanced biodiversity of the aquatic organisms within Brooks Lake.

9) Planting of emergent aquatic plants around Brooks Lake may offer stabilization of shoreline sediments and assist in protection of areas prone to erosion.

Figure 13. An example of a lake shoreline home with riprap to reduce erosion (2024).

Erosion Control/Shoreline Survey:

RLS noted areas of shoreline erosion around Brooks Lake during the September 23, 2024 evaluation. Multiple areas with impaired erosion conditions were observed along Brooks Lake's shoreline that are typical of recreational lakes (Figures 14-16). Erosion was overall moderate to slightly severe. This erosion negatively impacts numerous resources such as public use areas through water quality degradation from the soils eroding into the lake, fisheries and wildlife habitat being diminished from turbidity, and a lack of suitable vegetative cover.

The fetch in Brooks Lake, which is the distance across the greatest length of the lake to produce a wind-driven wave, is approximately 1.1 miles which can lead to waves with heights exceeding 2.0 feet. Shoreline bathymetry also plays a big part in determining the degree of erosion at a particular shoreline site. Sites with straight shorelines and points that are exposed to long wind fetches from prevailing wind directions, are vulnerable to more frequent and higher waves. Additionally, where the water deepens abruptly and there is less resistance or bottom roughness to influence the wave, exposed shorelines are susceptible to larger waves.

Lastly, heavy human foot traffic and mowed areas all contribute to substantial shoreline erosion in certain reaches of the lake. A loss of vegetative cover in these locations accelerates erosion and sedimentation. Additional steps for evaluating all areas around the lake with erosion could include a detailed assessment to prioritize sites based on severity, feasibility, costs, landowner willingness, and other factors. There is a wide range of erosion control methods that can be used in a cost-effective manner to address the shoreline erosion problems. Higher priority should go to sites where structures or amenities are threatened.

Figure 14. Shoreline erosion on the Brooks Lake shoreline (May, 2024).

Figure 15. Shoreline erosion on the Brooks Lake shoreline (May, 2024).

Figure 16. Shoreline erosion on the Brooks Lake shoreline (May, 2024).

4.1 Brooks Lake Aquatic Vegetation Community Improvement

A critical component of a healthy lake ecosystem is a balance of native aquatic vegetation with adequate cover of biovolume. The presence of invasive species should be reduced as they are a threat to the biodiversity of the aquatic vegetation community.

An initial aquatic vegetation survey was conducted by RLS scientists on May 3, 2024 and determined the presence of 22 acres of invasive Eurasian Watermilfoil (EWM), 88 acres of invasive curly-leaf Pondweed (CLP) that were recommended for treatment (Figure 17). Nuisance growth was treated where dense to spare the lake some submersed aquatic vegetation (SAV) since many native aquatic plants did not colonize until later in the season. It is critical to retain adequate SAV cover to reduce the nutrients that cyanobacteria use for enhanced growth. Some locations around the lake also contained the emergent invasive Purple Loosestrife and these will be carefully inventoried during the spring, 2025 survey and treatment will be recommended to reduce its presence (Figure 18).

Lastly, Figures 19 and 20 show the aquatic vegetation biovolume in 2023 and 2024 with a marked increase in 2024 which is favorable for preserving native SAV and reducing nutrients in the water column.

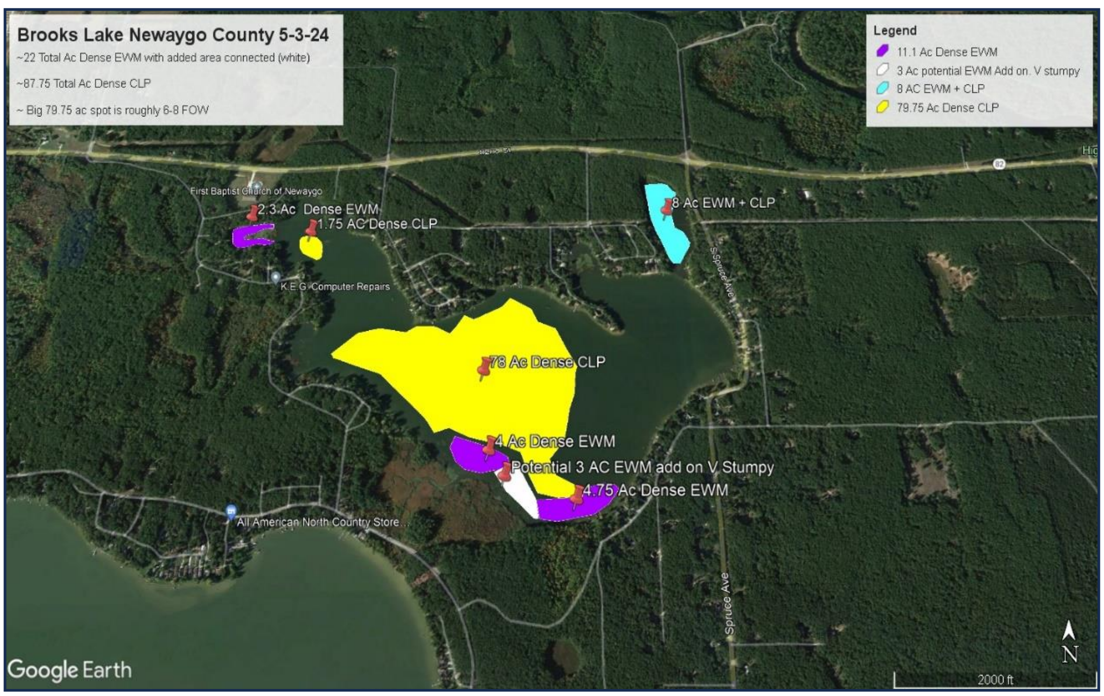


Figure 17. Invasive aquatic plant growth in Brooks lake (May 3, 2024).

Figure 18. Invasive emergent Purple Loosestrife on the Brooks Lake shoreline (May, 2024).

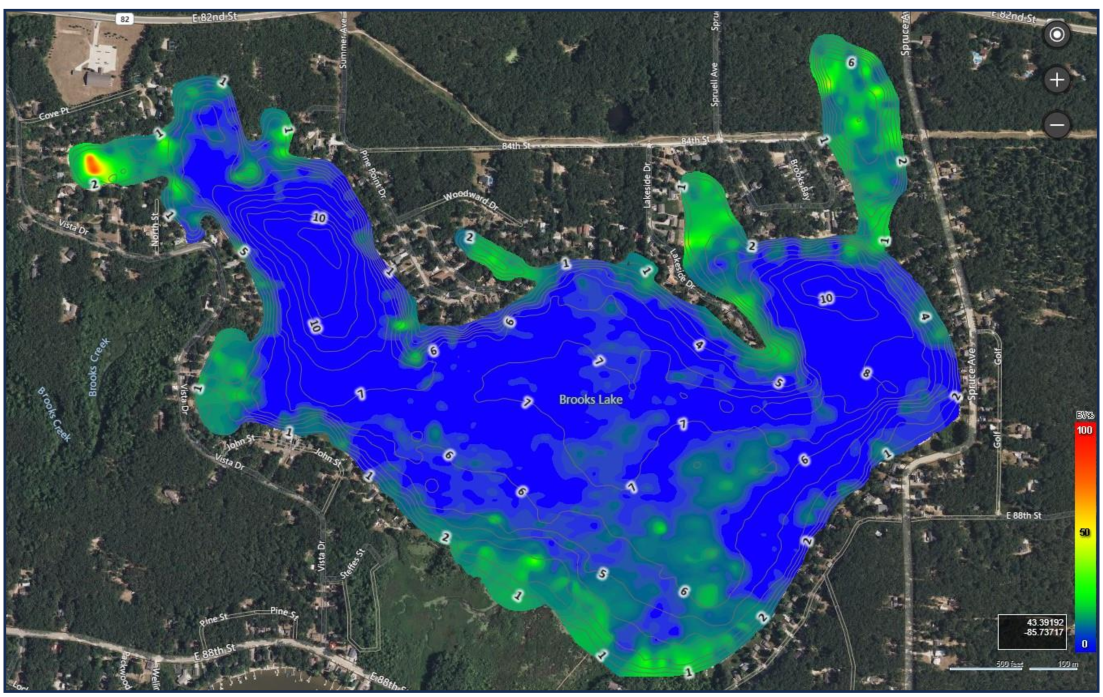


Figure 19. Brooks Lake September 24, 2023 aquatic vegetation biovolume map.

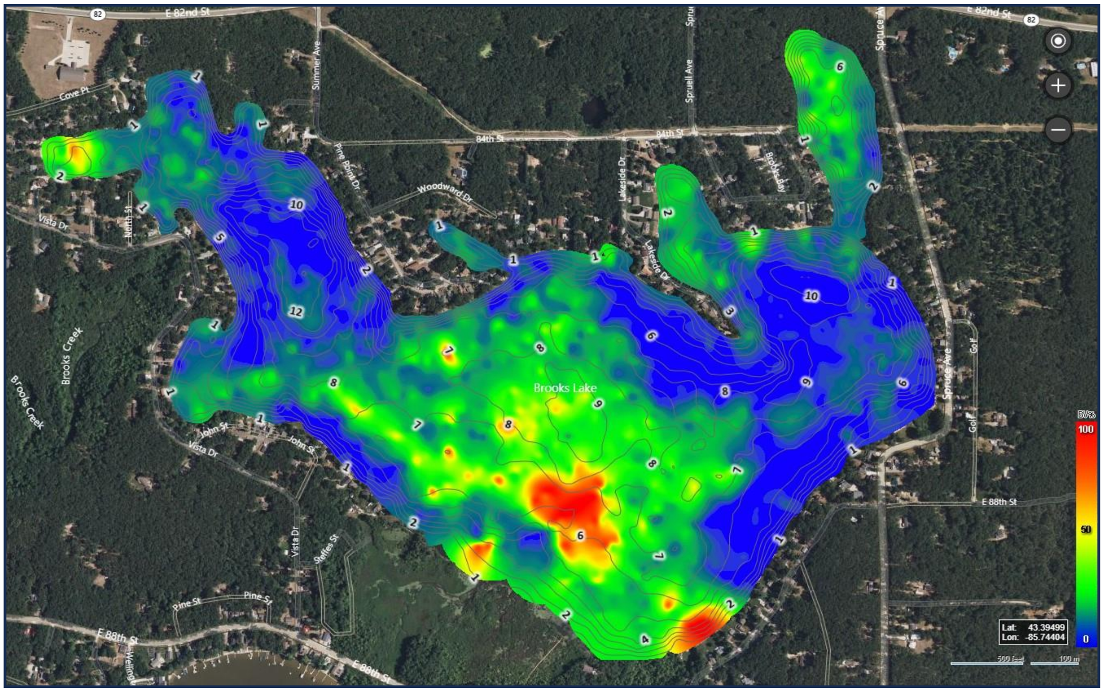


Figure 20. Brooks Lake September 23, 2024 aquatic vegetation biovolume map.

5.0 BROOKS LAKE POST-BIOCHAR CONCLUSIONS

RLS recommends continuation of the biochar in the lake basin as well as installation of biochar filters in the Hess Lake outlet/Brooks Lake inlet. The overall evaluation of the biochar supports the following conclusions:

1. Water temperatures are not affected by biochar and show seasonal variation.
2. The mean pH has slightly increased post-biochar but may also increase with increased cyanobacteria, which has been problematic on Brooks Lake.
3. The mean dissolved oxygen concentrations have increased post-biochar. This may be related to reduce biochemical oxygen demand (BOD) from reduced cyanobacterial growth and decay.
4. The mean conductivity has declined post-biochar.
5. The mean total dissolved solids has declined post-biochar.
6. The secchi transparency increased post-biochar, with the exception of September, 2024 which was still very warm due to unprecedented late summer conditions.
7. The mean chlorophyll-a concentrations have substantially decreased post-biochar.
8. The mean total Kjeldahl nitrogen (TKN) was reduced significantly post-biochar.
9. The mean total inorganic nitrogen (TIN) was reduced significantly post-biochar.
10. The mean ammonia nitrogen (NH_3) was reduced significantly post-biochar.
11. The mean total phosphorus (TP) was reduced significantly post-biochar.
12. The mean ortho-phosphorus (SRP) remained below detection post-biochar.
13. The mean total suspended solids (TSS) declined with the exception of September, 2024 and may be attributed to continued inputs from the inlet.

Dissolved oxygen depletion only occurred in the West Basin and thus RLS recommends a PrO2 unit in that basin. However, if biochar filters are installed in the Brooks Lake inlet, this could reduce total nutrient loads in the lake basin over time and along with continued use of biochar in the lake basin itself possibly reduce the need for PrO2 in the future. The TP concentrations in the lake are approaching mesotrophic values and thus continued reduction is necessary to reduce the presence of cyanobacteria blooms.

RLS also recommends immediate mitigation of the erosion sites around the lake as these will continue to contribute sediment and nutrient loads to the lake. All areas with exposed soil and lack of vegetation, especially on steep slopes, are most critical for improvements.

Lastly, continued intense aquatic vegetation surveys are needed to reduce the presence of invasive species such as CLP and EWM. Caution must be taken to allow more native submersed aquatic vegetation to germinate and colonize the lake bottom. This is critical since a lake dominated by aquatic vegetation is much less susceptible to cyanobacteria blooms that reduce water clarity and may pose public health risks with the presence and release of toxins.

6.0 SCIENTIFIC REFERENCES

Allen, J. 2009. Ammonia oxidation potential and microbial diversity in sediments from experimental bench-scale oxygen-activated nitrification wetlands. MS thesis, Washington State University, Department of civil and Environmental Engineering.

Annadotter, H., G. Cronberg, R. Aagren, B. Lundstedt, P. Nilsson, and S. Ströbeck., 1999. Multiple techniques for lake restoration. Hydrobiologia 395/396:77-85.

Bormans, Myriam, Blahoslav Marsalek, and Daniel Jancula, 2015. Controlling internal phosphorus loading in lakes by physical methods to reduce cyanobacterial blooms: a review. Aquatic Ecology 50. DOI.

Canter, L.W., and R.C. Knox. Septic tank system effluents on groundwater quality. Chelsea, Michigan, Lewis Publications, Inc. 336 p.

Engstrom, D.R., and D.I. Wright. 2002. Sedimentological effects of aeration-induced lake circulation. *Lake and Reservoir Management* 18(3):201-214.

Fenchel, T., and T.H. Blackburn. 1979. Bacteria and mineral cycling. Academic.

Gilliom, R.J., and Patmont, C.R. 1983. Lake phosphorus loading from septic systems by seasonally perched groundwater. Journal of the Water Pollution Control Federation. 55(10):1297-1305.

Laing, R.L. 1978. Pond/Lake Management organic waste removal through multiple inversion. In house report. Clean-Flo Lab, Inc.

Lee, D.R. 1977. A device for measuring seepage flux in lakes and estuaries. Limnology and Oceanography 22(1):140-147.

Lesauteur, T. 1968. Water pollution in summer cottage areas. Canadian Journal of Public Health 59(7):276-277.

Malueg, K., J. Tilstra, D. Schults, and C. Powers. 1973. Effect of induced aeration upon stratification and eutrophication processes in an Oregon farm pond. *Geophysical Monograph Series* 17: 578-587. American Geophysical Union. Washington DC.

Rosenberger, E.E., Hampton, S.E., Fradkin, S.C., and Kennedy, B.P. 2008. Effects of shoreline development on the nearshore environment in large, deep, oligotrophic lakes. Freshwater Biology 53:1673-1691.

Sass. L.L., Bozek, M.A., Hauxwell, J.A., Wagner, K., and Knights, S. 2010. Response of aquatic macrophytes to human land use perturbations in the watersheds of Wisconsin lakes, USA. Aquatic Botany 93:1-8.

Shawney, B.L., and J.L. Starr. 1977. Movement of phosphorus from a septic system drain field 9(11):2238-2242.

Toetz, D.W., 1981. Effects of whole lake mixing on water quality and phytoplankton. *Water Research* 15: 1205-1210.

Turcotte, A.C., C.V. Déry, and K.F. Ehrlich. 1988. Manipulation of microbial ecosystems to control the aquatic plant Eurasian Watermilfoil. Preprint paper. Département de Biologie, Université de Sherbrooke, Sherbrooke, Québec, CANADA J1K 2R1.

Verma, N. and S. Dixit. 2006. Effectiveness of aeration units in improving water quality of Lower Lake, Bhopal, India. *Asian Journal of Experimental Science* 20(1): 87-95.

Weiss, C., and B. Breedlove. 1973. Water quality changes in an impoundment as a consequence of artificial destratification. 216 pp. Water Resources Research Institute. University of North Carolina. Raleigh.

Wetzel, R. G. 2001. Limnology: Lake and River Ecosystems. Third Edition. Academic Press, 1006 pgs.

Winter, T.C. 1981. Effects of water-table configuration on seepage through lake beds. Limnology and Oceanography 26(5):925-934.