Lake Oglethorpe
Water Quality Report

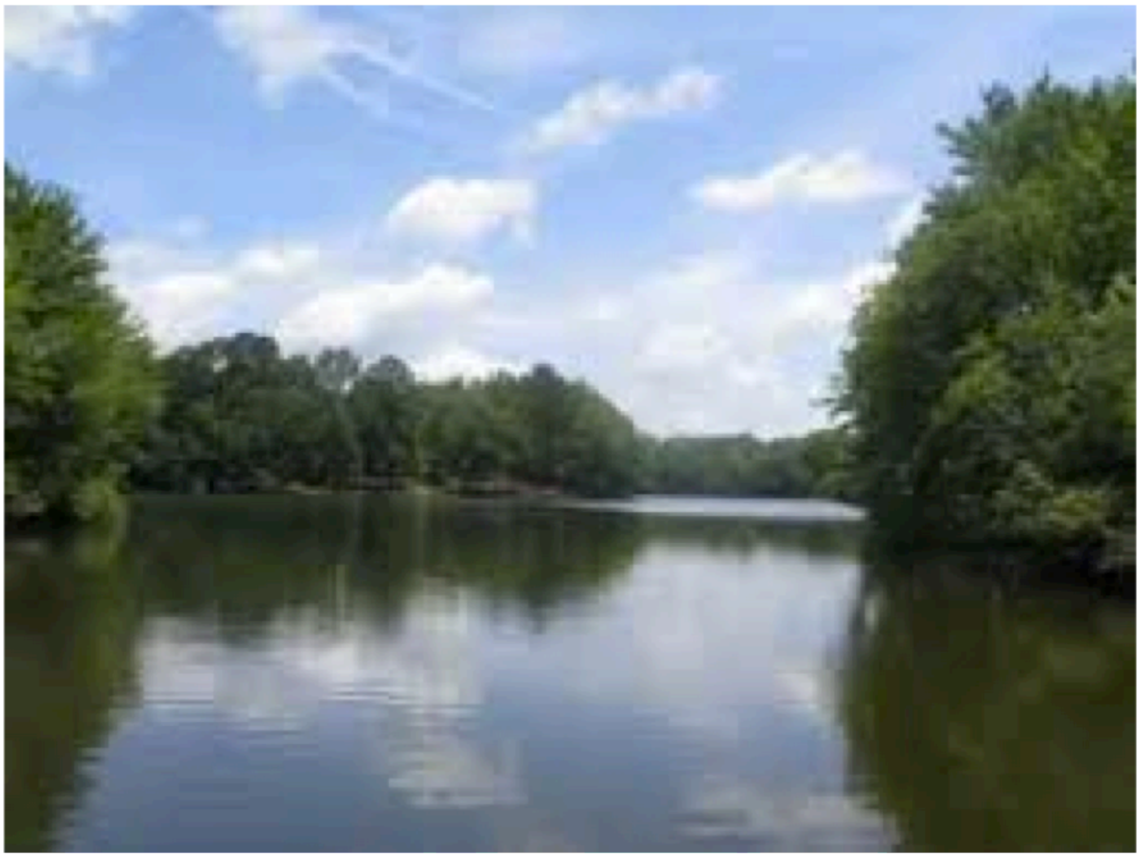

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Table of Contents

Introduction

Lake Oglethorpe is a ~65-acre man-made piedmont lake located in Arnoldsville, Georgia. The lake dam was designed by the Soil Conservation Service (known today as the Natural Resources Conservation Service) in 1970 and construction was completed in 1972. The lake was constructed to provide ample recreation opportunities on Goulding Creek for nearby residents, while also providing flood protection for downstream communities. The lake is currently operated by the Lake Oglethorpe Association including ~80 members.

Lake Oglethorpe has been studied somewhat closely over the past two decades due, in part, to its close proximity to the University of Georgia. In comparison to its status in 1996, the lake has become increasingly eutrophic and recently, large cyanobacteria algal blooms have been observed. Higher concentrations of ammonia and phosphorus have been measured while dissolved oxygen levels have decreased indicating a high biological oxygen demand (BOD) in the lake. In an effort to spearhead mitigation efforts and restore the lake's designated use of recreation and fishing, data has been collected since November 2014 to help identify the causes of hypereutrophication and draft a comprehensive solution for moving forward with restoration. Based on the scientific findings, the assessment of different engineering technologies helped to guide the decision-making process and create a proposed solution to address the issues of eutrophication and nutrient loading within the lake.

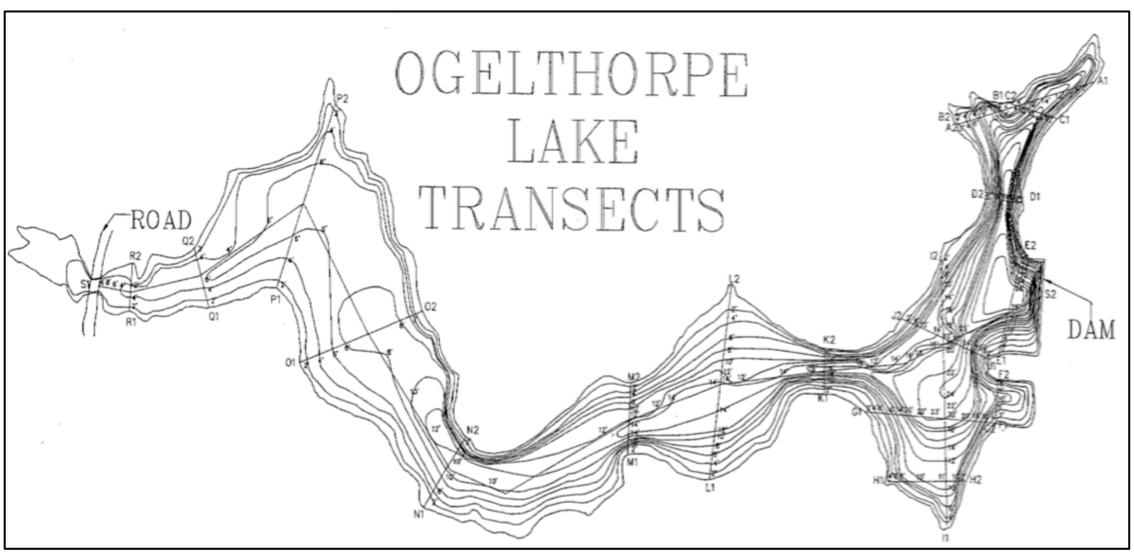
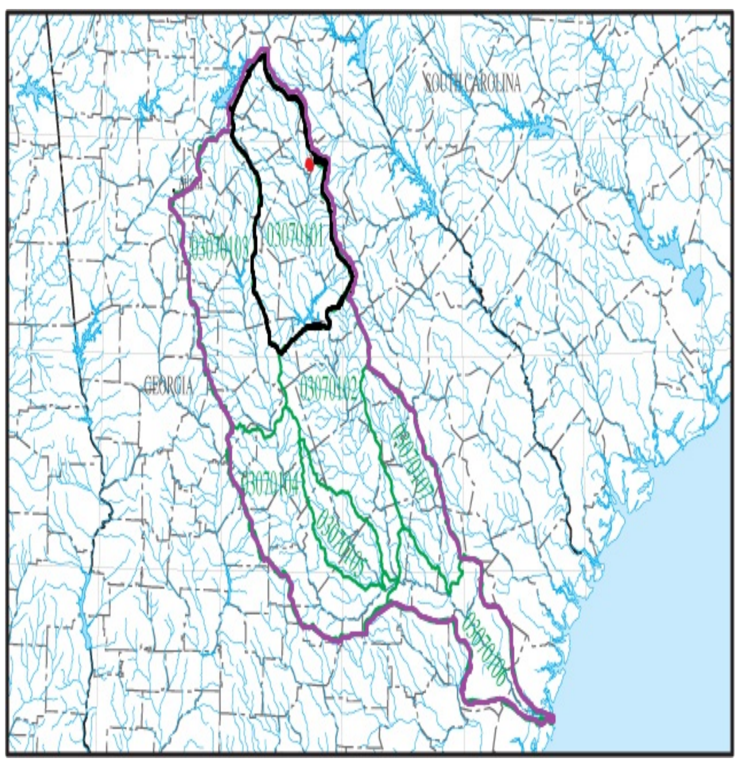


Figure 1.1 1989 Lake Oglethorpe Transects

1.0 Location

Lake Oglethorpe is located about 15 miles southeast of Athens, GA (**Figure 1.1**). Even though it is relatively close to the highly urbanized area of Athens, the landscape encompassing Lake Oglethorpe is very rural, while also including the small town of Arnoldsville. Lake Oglethorpe's watershed is a part of the Upper Oconee watershed, which is located in the much larger Altamaha River watershed. The Altamaha River discharges into the Atlantic Ocean (**Figure 1.2**). Several studies have been done on the health of the Upper Oconee River watershed, mostly through the Upper Occonee Watershed Network (UOWN). These studies have shown that overall, the water quality of streams and bodies of water within it are below standards, but are not beyond restoration. Examples of bad water quality in the Upper Oconee River watershed include Carr Creek and Brooklyn Creek which both have extremely high dissolved ion concentrations and low overall stream health (Kominoski et al 2007). The goal of these studies was to conclude that the further away you moved from densely populated areas such as the city of Athens, the better the water quality became (Kominoski et al., 2007). Lake Oglethorpe and its watershed sit in the upper right hand corner of the Altamaha River watershed and on the east side of the Upper Oconee watershed located by a red dot in the figure.

Figure 1.1- The major cities of Georgia including Athens, Georgia



F**igure 1.2-** Altamaha River Basin (purple) and Oconee River Basin (black)

2.0 Basic Water Quality Parameters

2.1 Dissolved Oxygen

Dissolved oxygen is the amount of gaseous oxygen dissolved in water, and levels depend on physical, chemical, and biological activity in the water. Oxygen is necessary for all life forms and a very important measurement in any water quality research. Oxygen is produced by aquatic plants, such as algae, through photosynthesis and then is consumed by aerobic bacteria. DO can also be introduced into water through aeration by the atmosphere, most notably during high flows. Chemical processes influenced by DO include redox reactions, dissolution of toxic metals, temperature, movement of water, plants, animals, and organic pollution. If oxygen levels plummet due to various inputs described above, it may cause an entire water body "to die", typically on hot summer seasons with low flow and calm weather (Swenson and Baldwin 1965). Many fish generally need the level of DO to be above 4 mg/L or even higher for trout, if not, they will be stressed to survive. Georgia has standards for DO described in the previous section, and when levels fall below these standards, fish kills may occur

2.2 pH

pH electrodes sense ionic activity by creating boundary potential, in which it measures ions participating in the reaction with the electrode by reading the voltage produced. A pH meter is a scaled meter that typically reads high resistance voltage in millivolts (Snoeyink and Jenkins 1980). The measurement will only reflect the ions that react and not the ones that are just present. The pH electrode system is a two-membrane system with a glass membrane. The outer reference electrode is KCl and the inner pH indicator electrode is AgCl. H^+ ions penetrate the glass membrane and create electric potential across the membrane with respect to AgCl internal electrode to create a voltage that can be transformed into a pH reading based on calibration with no units.

pH meters are typically calibrated using buffer solutions of pH equal to four, seven, and ten. pH generally ranges between 1.0-14.0, with more acidic solutions on the low end and more basic solutions on the high end. Georgia's water quality standards for pH are described above and range between 6.0-8.5 (GA EPD 2008). Any measurements above and below these thresholds have negative consequences to the health of the aquatic ecosystem.

2.3 Specific Conductance

Specific conductance is the ability of a solution to transfer electric current and is the reciprocal of resistivity through water. As ion concentration increases, so does the ability of the water to conduct a current and conductivity increases (Snoeyink and Jenkins 1980). A measurement of the conductivity for a water sample using a sensor also conveys, through conversions, the concentration of total dissolved solids (mg/L) ionized in water and salinity (ppt) (Snoeyink and Jenkins 1980). The unit of measurement for conductivity is recorded as siemens per centimeter (S/cm) and is often micro-siemens (μS) or milli-siemens (mS). It is important to note that temperature affects conductivity as ion activity increases with temperature, but most instruments reference to 25 degrees Celsius. Pure water is a poor conductor because it does not have many dissolved ions resulting in low conductivity and seawater has a large amount of ions and is a good conductor resulting in extremely high conductivity.

2.4 Temperature

Temperature is a highly influential parameter on all water quality parameters. Temperature in water varies due to atmospheric temperature, changes between night and day, seasonal changes, and manmade influences such as electricity generation. Higher water temperatures generally lead to negative consequences to other influential water quality parameters and processes. Temperature standards for Georgia are described above.

2.5 Turbidity

Turbidity is the cloudiness of a liquid sample developed due to the presence of suspended particle matter such as clay, silt, organic matter, and microorganisms in water. There are multiple different causes leading to high turbidity measurements that include, but are not limited to storm events, construction, erosion, runoff, mining, etc. Low turbidity is around 0-5 NTU, whereas, a high measurement may be 4000 NTU and the NTU is described as nephelometric turbidity units. Drinking water standard is 5 NTU for filtration other than direct filtration and less than 1 NTU for direct filtration or conventional methods, while aquatic life should range from 0-50 NTU (Drinking Water Contaminants 2009)**.** Other turbidity units include Formazin Turbidity Unit (FTU) and the Jackson Turbidity Unit (JTU) used in the Jackson Candle method (Wilde and Gibs 2005).

Turbidity can be determined using a nephelometer, commonly referred to as a turbidimeter, which is a physical test that measures scattered light due to the presence of particles. The more particles present the more light that is reflected or scattered. A sketch of a how a turbidimeter works can be seen in **Figure 2.1** below. It cannot be related to suspended particles because dark and white particles scatter different amounts of light and some small particles will reflect more light than equivalent large particles. It is also important to understand brown water may still have low turbidity because it is still clear and lacks suspended matter.

Turbidity effects many processes in waterbodies such as lakes, rivers, and streams. The processes affected include the depths at which light can penetrate through water for aquatic plant growth, habitat quality, recreational values of waterbody, increased bacteria and pollutants, temperature of the waterbody, and even cause a lake to fill up faster (Swenson and Baldwin 1965). Light penetration has an effect on multiple other dependent species connected to aquatic plants by disrupting food chains and decreasing dissolved oxygen availability to fish by producing a low level of oxygen. Turbid waters also increase the absorption of heat into the water bodies due to a darker color of the water, which increase the temperature of the system and leading to negative consequences due to increased temperatures described above.

2.6 Total Suspended Solids

Total Suspended Solids (TSS) is the portion of solids retained from filtering and is used to describe the amount of suspended sediment in a water body. Total suspended solids may include sediment and organic material, such as plants, leaves, insect larvae, eggs, etc. (Smith 2004). TSS relies on a cutoff for particle size determined by the filter size. Results are largely impacted by temperature and time of drying due to the effects on weight losses from volatilization of organic matter, mechanically occluded water, water of crystallization, gases from heat-induced chemical decomposition, and weight gained due to oxidation. Therefore, approved methods should be adhered to. High amounts of

TSS generally lead a cloudy and distasteful appearance to the body of water, along with increased turbidity (Smith 2004).

2.7 Alkalinity

Alkalinity is measured using sulfuric acid to determine total amounts of carbonate, bicarbonate, and hydroxide ions through a titration method. Alkalinity measures the buffering capacity of water to neutralize acids bringing the pH to 4.2 by combining with H+ ions to produce new compounds. Common sources of carbonate and bicarbonate are limestone (CaCO3) when dissolved in water. The Floridan Aquifer, below the site, is made of limestone. **Figure 2.2** depicts alkalinity approximations around the Southeastern U.S. based on thousands of lakes in the United States and range from 100-<400 $\mu eq/L$ (5->20 mg/L $CaCO_3$) in the lake location.

2.8 Fe

Iron is an abundant element and generally present in water as ferrous iron (Fe2+) or ferric iron (Fe3+) and may cause water to be reddish or yellowish in color if levels are too high. Iron levels in freshwater aquatic life should not exceed 1.0 mg/L to support a healthy aquatic ecosystem (EPA 1976). This is the case for most freshwater ecosystems, but iron toxicity to freshwater species depends on the type of system. Higher levels of iron concentrations are found in black and brownish waters due to swamps and wetlands, which tend to have lower dissolved oxygen levels and complexed iron (EPA 1976). Complexed iron tends to be inactive chemically and physiologically, which make it non-toxic to freshwater animals (EPA 1976).

2.9 COD

Chemical oxygen demand (COD) is a measure of oxygen equivalence representing the total amount of organic material in water that is susceptible to oxidation by a strong chemical oxidant. Nearly all organic compounds in water samples may be oxidized to CO2 with a strong oxidizing agent under acidic conditions. It is a simple and inexpensive method that provides results in a short time span.

If water sample is free of toxins and only contains readily oxidizable organic matter then the COD is a good representation of BOD. The COD test is unable to tell the difference between biologically oxidizable and biologically inert organic matter and the dichromate can oxidize materials that would not be oxidized in nature. COD is recorded as mg/L of oxygen used and values vary depending on water sample.

2.10 Nutrients (Nitrogen and Phosphorous)

The presence of nutrients is important to sustaining life in any stream, but too many nutrients may cause eutrophication in a stream and lead to algal blooms and lower availability of oxygen. There are currently no standards for nutrients in Georgia, but the EPA is working to help determine proper levels for the various regions of the nation. Nutrient concentrations can vary even at the local scale depending on numerous contributing factors. Nutrients are introduced to streams through precipitation, runoff, geologic formations, fertilizer, and multiple types of sewage or feces (Mueller et al 1995). The nutrients of particular interest for this research include total phosphorus and nitrogen compounds.

Nitrogen is an important nutrient to all living things making up multiple different types of amino acids and nucleic acids. Nitrogen can take on many forms in natural surface waters that include atmospheric nitrogen, ammonia ($NH3+$) ammonium ($NH4+$), nitrite ($NO2-$) and nitrate ($NO3-$) in order of oxidation state. Total Kjeldahl nitrogen is found during the digestion process used to determine Total Nitrogen. Ammonia concentrations are usually low in streams because they are not stable in most surface water environments and nitrate concentrations were found to be less than 1 mg/L for background sites around the Southeastern United States due to a combination of poor soil drainage, an abundance of soil organic carbon, warm temperatures, forest buffers and high rainfall (Mueller et al 1995). In addition to eutrophication, increased nitrogen can also lead to water acidification and toxicity to animals (Carmango and Alvaro 2006). The EPA recommends total nitrogen from the EPA Region IX to be between 0.07-1.0 mg/L based on ambient conditions of streams in the region (EPA 2000).

Phosphorus is also an important nutrient to consider in surface waters, as all living things need it to survive. Two percent phosphorous on a dry weight basis is required for all living protoplasm, which make up living matter in cells (Snoeyink and Jenkins 1980). Most stream samples within the United States were below 0.1 mg/L of total phosphorus, but in freshwaters, phosphorous is often responsible for eutrophication of lakes (Mueller et al 1995). The EPA also recommends .023-0.1 mg/L for total phosphorus when compared to the ambient conditions of other streams in the region (EPA 2000).

2.11 Chlorophyll-a and Secchi

Chlorophyll *a* is the most common type of chlorophyll in green algae. Its optimal absorption wavelength is in the 400-450 nm and 650-700 nm ranges with the molecular formula $C_{55}H_{72}O_5N_4Mg$, and is used as a means of measuring the amount of algal biomass present in a lake. A lake's trophic state is a measure of nutrients present, which can be correlated to the abundance of algal biomass. There are four trophic states: oligotrophic, mesotrophic, eutrophic, and hypereutropic. Oligotrophic lakes have very little nutrients, and have transparent water with little plant growth. Mesotrophic lakes have a medium amount of nutrients present with algal blooms in late summer causing medium transparency. Eutrophic lakes are considered nutrient rich, and have large algal blooms with murky waters. Hypertrophic lakes are extremely high in nutrients with a lot of plant growth and very poor transparency in the water.

A secci disk is used to measure the murkiness of water. It is a black and white disk that is lowered into the lake by a marked rope and measured off where the disk becomes out of sight. The depth of transparency highly correlates with chlorophyll *a* abundance as well as suspended sediments. Figure 2.3 shows that when chlorophyll a increases, transparency typically decreases. A table below includes differing trophic classes, TP, secchi depth, and trophic index (Carlson 1996)

Table 2.1- Trophic classification (*Relationships between Trophic Index (TI), chlorophyll (Chl), phosphorus (P, both micrograms per liter), Secchi depth (SD, meters), and Trophic Class)*

TI	Chl	P	SD	Trophic Class
<30—40	0—2.6	0—12	>8—4	Oligotrophic
40—50	2.6—20	12—24	4—2	Mesotrophic
50—70	20—56	24—96	2—0.5	Eutrophic
70—100+	56—155+	96—384+	0.5—<0.25	Hypereutrophic

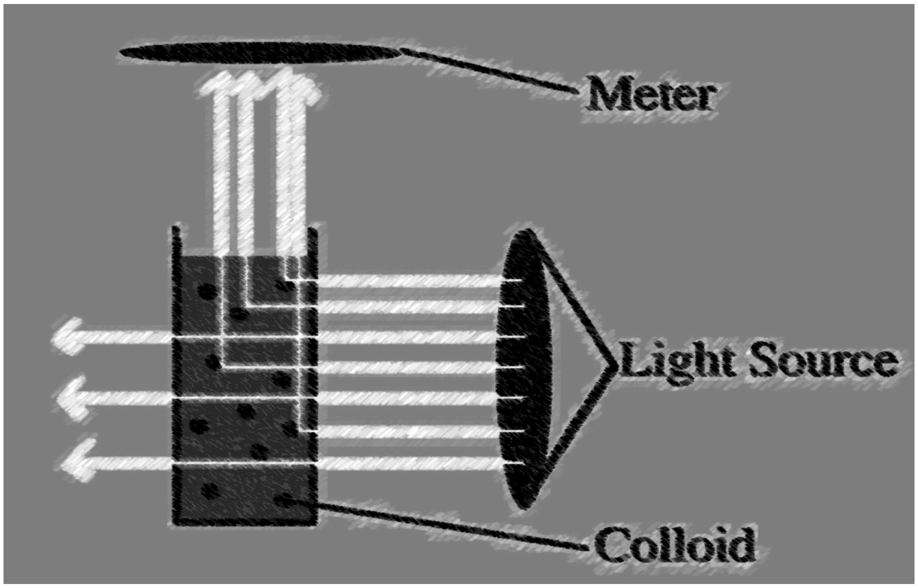


Figure 2.1 Nephelometer (http://water.me.vccs.edu/turbidometer.html)

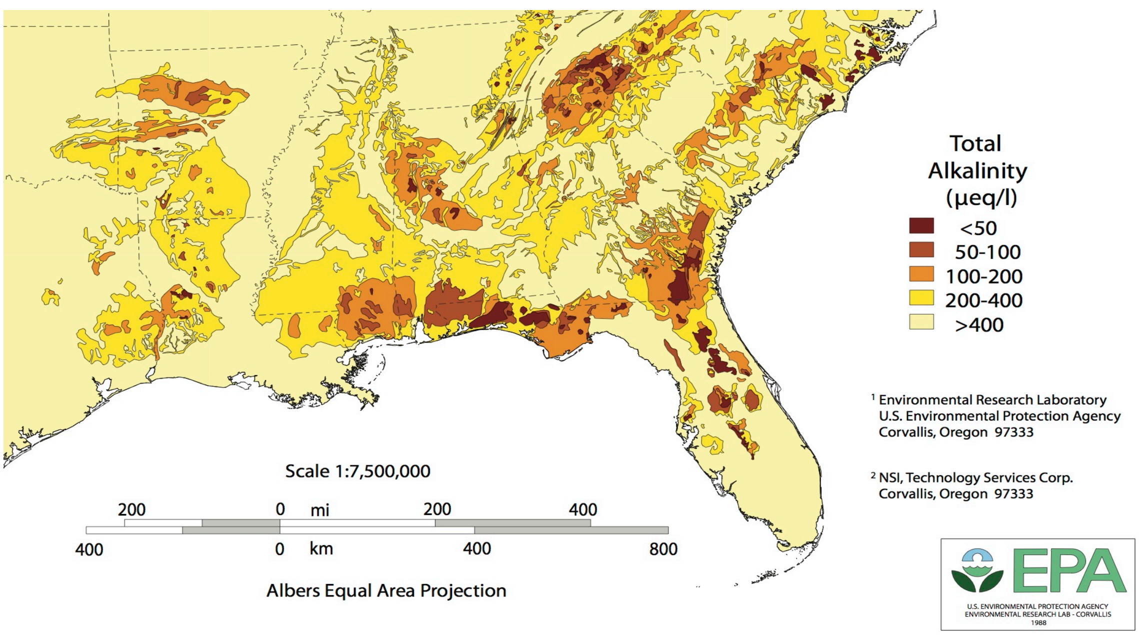


Figure 2.2 Alkalinity map for the Southeastern United States (https://water.usgs.gov/owq/alkus.pdf)

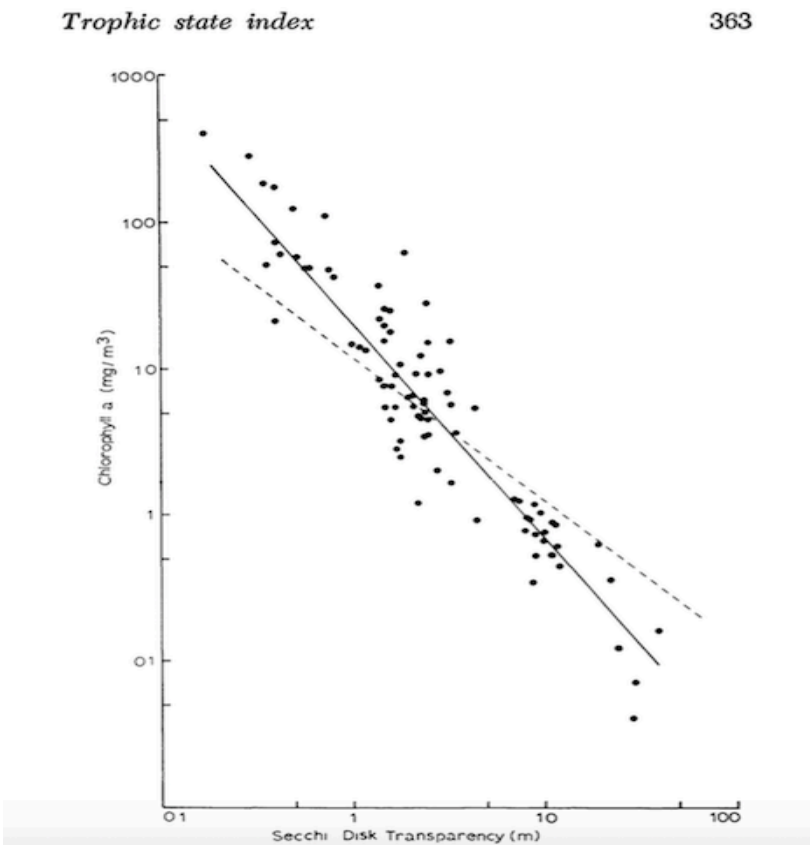


Figure 2.3- Chlorophyll-a and Secchi disk (http://kawishiwiwatershed.com/sites/default/files/Carlson_1977%20TSI%20Index.pdf)

3.0 Nutrient Levels in Lakes:

Nutrients such as nitrogen and phosphorus in lakes can be beneficial; however, in some lakes and small bodies of water, nutrients reaching high levels can lead to eutrophication. Eutrophication causes larger and longer lasting algal blooms in lakes and has the potential to lower levels of dissolved oxygen. In order to better understand the source causes of eutrophication, nutrient concentration inputs and "in lake" samples are important.

Nutrients include anything that an organism can feed off of. In the life cycle of a lake, one-way that these nutrients, or food, can develop is through the decaying of plant or animal matter. As old plants loose leaves or die off during the winter season, the plant matter collects in the bottom of lakes and rivers, along with animal waste and matter, and decays. The decomposed material is full of nutrients like nitrogen and phosphorus, which in the right conditions, will spread throughout the lake or river with the fluctuation of temperature levels. However, this life cycle process has been around since the beginning of time and is natural, making it hard to change. The main problem in this region of the country is an excess of phosphorus, which has the tendency to throw off the balance of an ecosystem.

Pollution is generally described as any undesired release of something into the environment that can cause harm. Pollution often comes from storm water runoff. In agricultural settings, pesticides and fertilizers can cause pollution and in municipal settings, sewage, trash, oil and other "city" waste can cause pollution. Despite the fact that pollution can be labeled somewhat easily into several categories, tracing the root or source of pollution can prove to be quite difficult. Point source pollution is often easiest because it is a single source to identify. Examples of point source pollution could include waste released from a sewage pipe into a stream or lake, intermittent stream that funnels runoff directly from a large cattle farm, effluent from industries, etc. There are many options as to what can qualify as point source pollutants, but the main idea is that they are identifiable and, in turn, can often be fixed with a single solution. A much larger problem arises when there is no single identifiable source of pollution. When this is the case, a single solution is out of the question for controlling inputs into streams and the problem can be very harmful. Examples of this type of pollution, called non-point source pollution, can include agricultural leaching, septic tank leaching, erosion, etc. To address nonpoint source pollution, often the body of water itself will have to be treated as opposed to the source.

When trying to understand the causes for increased nutrient levels, it is also important to recognize that the process of gaining nutrients in a lake or water body can accumulate over time as more nutrients enter the lake than leave. Once things like pollutants and waste collect in a body of water, along with internal inputs, they can create algal blooms. Algal blooms impact habitat of the lake, and when they die it creates more waste matter, which is decomposed by bacteria, consuming more oxygen from the lake. Nutrients such as phosphorous can be re-released in the water body in low dissolved oxygen as well after the algae die (see **Figure 2.4** regarding the phosphorus cycle). The phosphorus is released from lake sediment due to the ferric iron cycle. During the fall turnover, the lake mixes and nutrients from the bottom of the lake are brought into the water column, possibly causing a fall algal bloom. During spring when the water warms again, the change in temperature will initiate stratification. This cycle will continue annually into eutrophication or even hypereutrophication, which is extremely harmful to the quality of a lake and a viscous cycle.

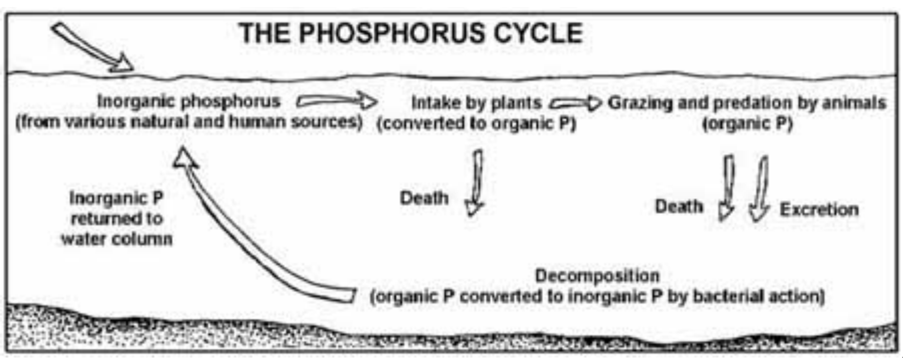


Figure 2.4. Pictorial representation of the phosphorus cycle.

3.1 Lake Eutrophication:

Lake Oglethorpe is a small, monomictic lake, meaning the lake mixes from top to bottom during one mixing period a year. Water residence time in the lake is around 80 days, meaning a drop of water that enters the lake on January 1 will not exit the lake until March 21. This is a fairly long residence time, and long residence time can also contribute to lake eutrophication. For most of the year the lake is stratified, from April to early October, while in the other months of the year it is mixing. During stratification, the lake consists of thermally stratified layers of water, varying in temperature, DO, and SC with depth. However, during the time the lake is mixing, the water temperature is relatively constant throughout the entire water column. **Figure 2.4** depicts this process.

The lake is classified as eutrophic, because of its high nutrient levels in recent studies conducted during August of each year. During the past 5 to 10 years the lake has become increasingly eutrophic, which has led to an increase in large algal blooms (cyanobacteria) and a decrease in water quality. As the nutrients in the lake have increased, so have the amount of cyanobacteria, which consumes nutrients. When cyanobacteria are alive, they transform carbon dioxide into oxygen during photosynthesis. However, once cyanobacteria die, different forms of bacteria that consume oxygen decompose them. This process leads to a net decrease in the dissolved oxygen of the lake. As a result, fish and other organisms are stressed to survive. Therefore, if there is an increase in nutrients, the amount of algae and bacteria will also increase, and the amount oxygen in the lake will become depleted

The lake is becoming increasingly eutrophic primarily from the increase of phosphorus. Phosphorus is normally the limiting nutrient in the production of cyanobacteria. Two nutrients that are essential for the bacteria's growth and reproduction are nitrogen and phosphorus. Without the necessary quantity of either of these two nutrients the bacteria would not be able to reproduce. Of these two nutrients, phosphorus is normally present in lower quantities. Thus, the bacterial growth is highly correlated and often limited by the quantity of phosphorus within the water body. It is evident that the reduction of phosphorus within the water is a critical aspect of controlling the quantity of algae within a given lake. In order to control the level of phosphorus within the lake it is first necessary to understand how phosphorus accumulates. The accumulation of phosphorus can be explained through the phosphorus cycle, which is depicted in **Figure 2.4** of the previous section.

From the above figure, it can be seen that inorganic phosphorus enters the lake from various natural and human sources. Some human sources include farms, chicken houses, septic tanks, and wastewater as discussed in previous sections. Once phosphorus enters the lake, it is used by plants and algae, which are then consumed by various types of biota. These plants and biota eventually die and are decomposed. Once bacteria decompose the algae, plants, and biota, the organic phosphorus is converted back to inorganic phosphorus. The phosphorus then returns to the water column and the process starts over again. What the figure does not show is that some also leaves the lake. However, the amount of phosphorus leaving the lake is less than the amount that enters. Therefore, the result is a net accumulation of phosphorus over time increases due to internal and external inputs over time. This is a natural process that typically happens in any lake with high nutrient runoff. Typically lakes can be considered to have a 50-year lifespan as a rule of thumb. As discussed before, the increase in phosphorus enables cyanobacteria to reproduce in greater amounts, thus leading to the problem of algal blooms.

Unfortunately, the prevention of phosphorus from entering the lake will not necessarily decrease the amount of phosphorus within the lake, because once the phosphorus enters the lake it tends to circulate within it instead of leaving. Though controlling phosphorus input into the lake will certainly help, additional steps to actually remove or trap the phosphorus already within the lake must be taken.

The main eutrophic characteristics in the lake noticed during this project and by locals are large algal blooms and decreased fish population (result of lowered dissolved oxygen). Both of these issues stem directly from increased phosphorus levels. Phosphorus is heavily present in many fertilizer applications and is also a product of animal waste and manure; so, agriculture and livestock production could be a very likely source of pollution in the lake. With only a handful of farms and chicken houses upstream, a further analysis of exactly what goes on in agriculture farms was first needed.

Agriculture plays are large role in society and is vital for human life. As populations continue to increase, so does the demand for food. To meet the growing food demands of the population, agriculture business must be as efficient as possible. This means growing livestock and crops bigger, better, and faster. The plants and animals of the agriculture industry would not be able to grow fast enough and produce enough yield naturally. Adding fertilizer to a crop is the essential to maintain high yields. It results in bigger and better, but there can be some negative consequences. When chemical additives are used in excess, they can turn into pollutants that wash into bodies of water.

Some of the nutrients farmers apply to their crops that can cause ecological damage include phosphorus, nitrogen, and potassium. These nutrients come in the form of manure and chemical fertilizers. Farmers use these additives to make their crops grow more efficiently, but during intense rain events, a proportion of them are washed into surrounding bodies of water. "Water flowing over agricultural land, whether from rain, irrigation, or flooding, carries pollutants to the nearest water body" (River Network). The runoff, depending on what kind of pollution it has in it, can cause "algae blooms . . . kill fish by removing oxygen from the water . . . poison fish and wildlife, contaminate food sources, and destroy the habitat that animals use for protective cover." (Water.epa.gov).

All in all, after an analysis of agriculture and its effect on eutrophication, one should conclude that the agriculture issue is very difficult to address. Many of the practices that lead to runoff are simply irreplaceable in many ways without excessively expensive alterations to farming methods. Therefore, in my opinion, discontinuing farming to decrease nutrient levels is unreasonable for this study. The land in the area was farmed well before the lake was built and should continue to be able to provide resources for humans. What can be done though, is to develop best management practices to decrease the amount of nutrients entering the system.

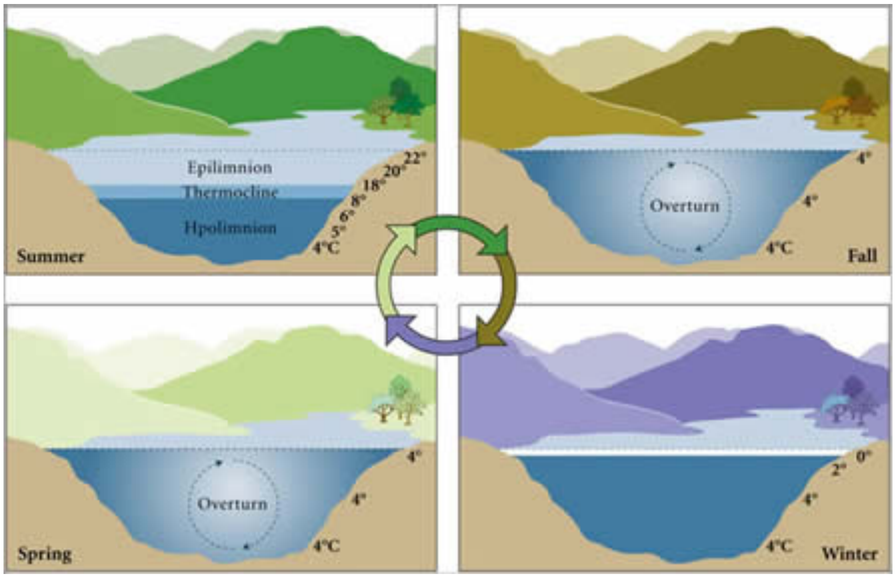


Figure 2.5 Annual Lake Stratification and Mixing Patterns. Image courtesy of the Lake George Association.

4.0 Historical Data and Trends for Lake Oglethorpe (1977-2014)

Water quality data for Lake Oglethorpe is available as far back as 1977 (Porter et al). Some of the relevant data collected since then (including as recently as April 2015) includes temperature variance with depth, stratification patterns, dissolved oxygen (DO) levels, phosphorus concentration, ammonia concentration, chlorophyll concentration, Secchi depth measurements, sedimentation patterns, and microbial activity. In addition, recent data collected in 2015 includes sonar depth measurements and soil samples from within the Lake Oglethorpe water catchment.

In terms of temperature variance, early data gathered in 1979 reveals two broad thermal trends. From November to March, the lake underwent mixing at temperatures ranging from 4 to 12 ^{o}C throughout the entire water column. Summer stratification took place from April to October with epilimnetic temperatures between 26 and 28 ^{o}C. Water column temperatures at 1-meter increments were recorded each subsequent month and year through 1994 (and also more recently). At all depths, a slight warming trend was observed from 1978 to 1994. In general, warming trends were less pronounced in shallow depths and more pronounced in lower depths.

Since nutrient levels are a key indicator of BOD, water chemistry data is very important in assessing the status of a lake. General trends from 1978 to 1994 indicate that total phosphorus (TP) concentration was the highest in April due to copious rainfall, high levels of turbidity, and sedimentation loading. TP levels increased with water depth and increased overall during the 17 year time period. A similar trend can be observed in combined nitrite and nitrate levels over the same time span. These increases in nutrients may be linked to increasing levels of cyanobacteria and other previously discussed eutrophic lake characteristics. Within 2 to 4 weeks of stratification in April, oxygen deficits result in very low levels of DO and zones of anoxia starting at around 2-3 meters of depth (Porter et. al). The lack of oxygen has resulted in a tapering fish population. In 1977 and 1993, fish species at Lake Oglethorpe included bluegill, green sunfish, redbreast, black crappie, golden shiner, and largemouth bass.

Data from 1977 to 2015 is such a large dataset, that it gives an opportunity to see strong trends and long-term correlations in the freshwater ecosystem of Lake

Oglethorpe. Increases in nutrients such as TP and ammonia, and decreasing DO levels have generated consequences on the food web components in the lake. The fish in Lake Oglethorpe prefer to consume cladocerans (a form of zooplankton), but over the last 48 years the density of cladocerans have decreased, thus altering the food source for fish. The other food sources for fish in Lake Oglethorpe are rotifers (also zooplankton), though it has shown to be increasing overtime. The increase in rotifers is the result of more algal biomass forming and then dying every year. Bacteria decompose the dead algae and rotifers consume the bacteria, thus increasing rotifer food sources and allowing them to outcompete cladocerans for energy. These changes in the food web are due to the negative effects of eutrophication overtime, and have resulted in the negative impacts on fish present in Lake Oglethorpe today.

5.0 Methods

To aid in decision making for restoration of Lake Oglethorpe, various methods and techniques were employed for research of the lake. Geographic Information Systems techniques were used to determine catchment areas, land cover, and soils in the area. Sonar data was incorporated with a GPS to determine a bathymetric profile of the lake bottom. To determine inputs and outputs from the lake, stream flow and lake discharge were used based on stage measurements. To assess water quality, monthly grab samples and storm samples were assessed. Soil samples were also taken in all the catchment areas for a wide range of parameters.

Geographic Information System data was analyzed using Arc Map to assess the lake and surrounding area, as well as make maps. Most GIS data can be accessed in the public domain on the Internet from various websites. The GIS data makes working in the field much easier and also provides great mapmaking abilities and visual representation of important data.

In late March of 2015, depth measurement data were gathered on Lake Oglethorpe. A Lowrance model sonar device was set up on a small motorized boat with the transducer attached on the back of the boat a few inches above the water level (this distance will be subtracted from the data points to achieve actual depth readings throughout the lake). Like most sonar devices, the transducer emits a sound wave that propagates through the water. Once it hits an object or the lake bottom, the sound wave is redirected and returns to the sonar transducer. Using a function regarding time of emission and time of return, lake depth can be estimated.

The boat was driven along the periphery of Lake Oglethorpe shooting points as it traveled. For improved accuracy, the boat was driven at relatively low speeds between 5 to 10 mph. Once the periphery was traced out, zigzag lines were traveled throughout the entire lake until enough data points were gathered to create an accurate depth chart of the entire lake (Figure 13 and Figure 14).

A hobo datalogger was installed at Goulding Creek to record stage and temperature of the water into the creek. Rating curves for flow and discharge at multiple stages can then be calibrated to determine total discharge. A second hobo was installed at the dam site near the weir to record stage of the lake. This data could then be used with a weir equation to determine total discharge from the lake.

Sampling was conducted on site once a month for the duration of the study (January 2015 – May 2015). The instances where sampling was done more than once a month were taken after a rainstorm including March 19, 2015 and May 26, 2015. The first storm event sampled was following a ¾ inch event in which sampling was following the first flush determine by observation. The second storm event was following a 1-inch rain event in which the first flush was sampled. These extra samples were collected to provide data on runoff in smaller catchment areas that did not typically have much discharge.

Types of data collected on site for each event included pH, dissolved oxygen (DO), specific conductance (SC), turbidity, and temperature (degree Celsius). Secchi depth (in-lake) and stage measurements were also made on site. A Hydrolab® Quanta was used to collect pH, DO, SC, turbidity, and temperature. Before sampling began, all instruments were calibrated and appropriate amounts of H_2SO_4 were added to containers that would be used for preserving water samples. Amber glass bottles were used as sampling containers.

Samples and data were collected from eight different locations in and around Lake Oglethorpe (**Figure 5.3**). Four of these locations around the lake included the two main creeks, Top Left (TL), Top Right (TR), Goulding Creek after the two combine (TC), and the outflow below lake (BL). Sample locations within the lake included the Lake Mouth (LM), Lake Center (LC), Lake Dam (LD), and Lake Bottom (LB) one meter above the bottom at the Lake Dam site. Once lake stratification started to occur, an additional sample point in the mid depth of the lake 13 feet down was sampled at the Lake Dam Site. Water samples were collected from each site along with using the Hydrolab® Quanta. These samples were preserved and transported back to the lab. Laboratory analysis included Chlorophyll a (CHL-a), Iron (Fe), Nitrates + Nitrites (NO3+NO2), Total Phosphorus (TP), Soluble Reactive Phosphorus (SRP), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Ammonia (NH3), Alkalinity (Alk), and turbidity (Turb). Other recorded parameters included date, time, location, stage and secchi depth for the in-lake samples.

To collect the water samples from the lake, a simple pontoon boat was navigated and then anchored to a set of GPS coordinates for each location. An Alpha Bottle Horizontal® was used to capture water at a depth of a few feet below the surface of the water. The water was poured from the Alpha Bottle Horizontal into the sample bottle. Bottles were dipped straight into the water for sample collection of the tributaries during monthly sampling and storm events. The downstream site (BL) was sampled from the outflow pipe below the dam. Bottles containing each sample and preservative were placed in a cooler with ice. The samples remained here until unpacked and analyzed in the lab.

Other than the sample location closest to the dam, only one set of samples were taken from each location. Two sets of samples were taken at the dam because it is the deepest part of the lake and significant differences in DO, pH, SC, etc. may be present near the surface of the lake than at the bottom. To get an accurate sample from the deep section of the lake (LB) at this location, the Alpha Bottle Horizontal was lowered to one meter above the bottom of the lake. This process ensured no excess sediment from the lake bottom would contaminate the sample. The same technique was used for the mid-depth sample LL.

Sediment samples were collected from three different locations on the lake including LM, LC, and LD. An Ekman dredge was used to collect sediment samples from the lake bottom. The sediment samples were stored in plastic Ziploc bags and then placed in the cooler alongside the water samples. All samples were labeled with the date and location they were collected at. Samples were then transported to the Agriculture and Environmental Services Laboratory in Athens, GA on College Station Road for analysis.

Soil samples were collected from within each of the aforementioned subzones comprising the overall 3.47 square mile catchment area for Lake Oglethorpe (**Figure 5.5**). Careful attention was given to the different forms of land cover that made up each subzone. Find a low-lying area representative of the greater subzone. Remove top-layer of grass/debris from the sampling spot. Clean the stainless-steel hand auger with distilled water. Plunge the auger into the soil near the chosen sampling spot for further cleansing. Remove the auger and dislodge the soil from the cylinder. Plunge the auger into the chosen sampling spot. Retrieve a sampling core (4 inches deep for pasture, 6 inches deep for forest). Empty the sample into a labeled Ziploc gallon bag. A Garmin Etrex GPS device was used to record the position of sampling. Data was documented for the date and time to the nearest minute that the sample was taken.

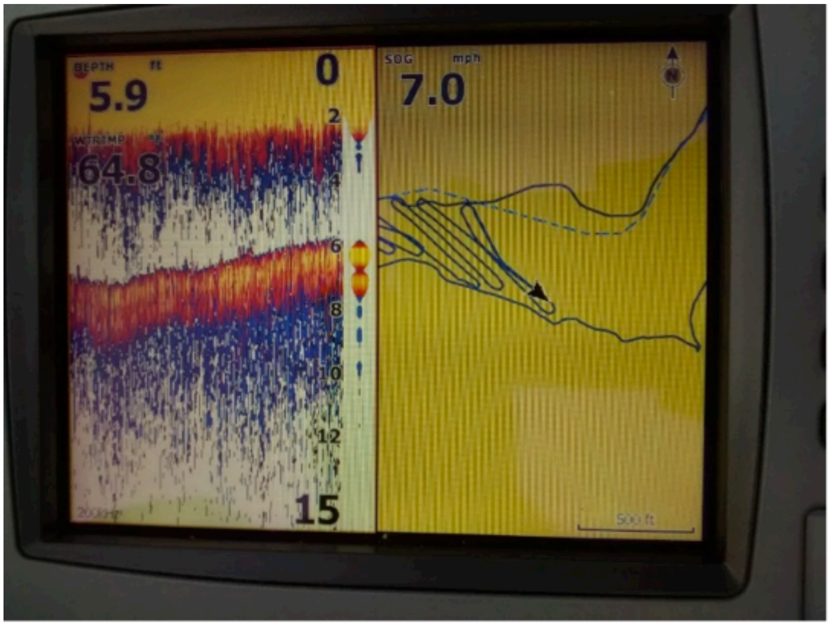


Figure 5.1- *Lowrance Sonar Screen Display.* As demonstrated on the right half of the picture, data points were gathered on the periphery of the lake and also in zigzag lines from bank to bank. Water depth data is displayed on the upper left portion of the screen display.

Figure 5.2. *Oglethorpe Lake Profile Generated from Sonar Data.* Collected sonar data was analyzed via BioBase, a lake monitoring online software. The different colors represent the three different sets of data.

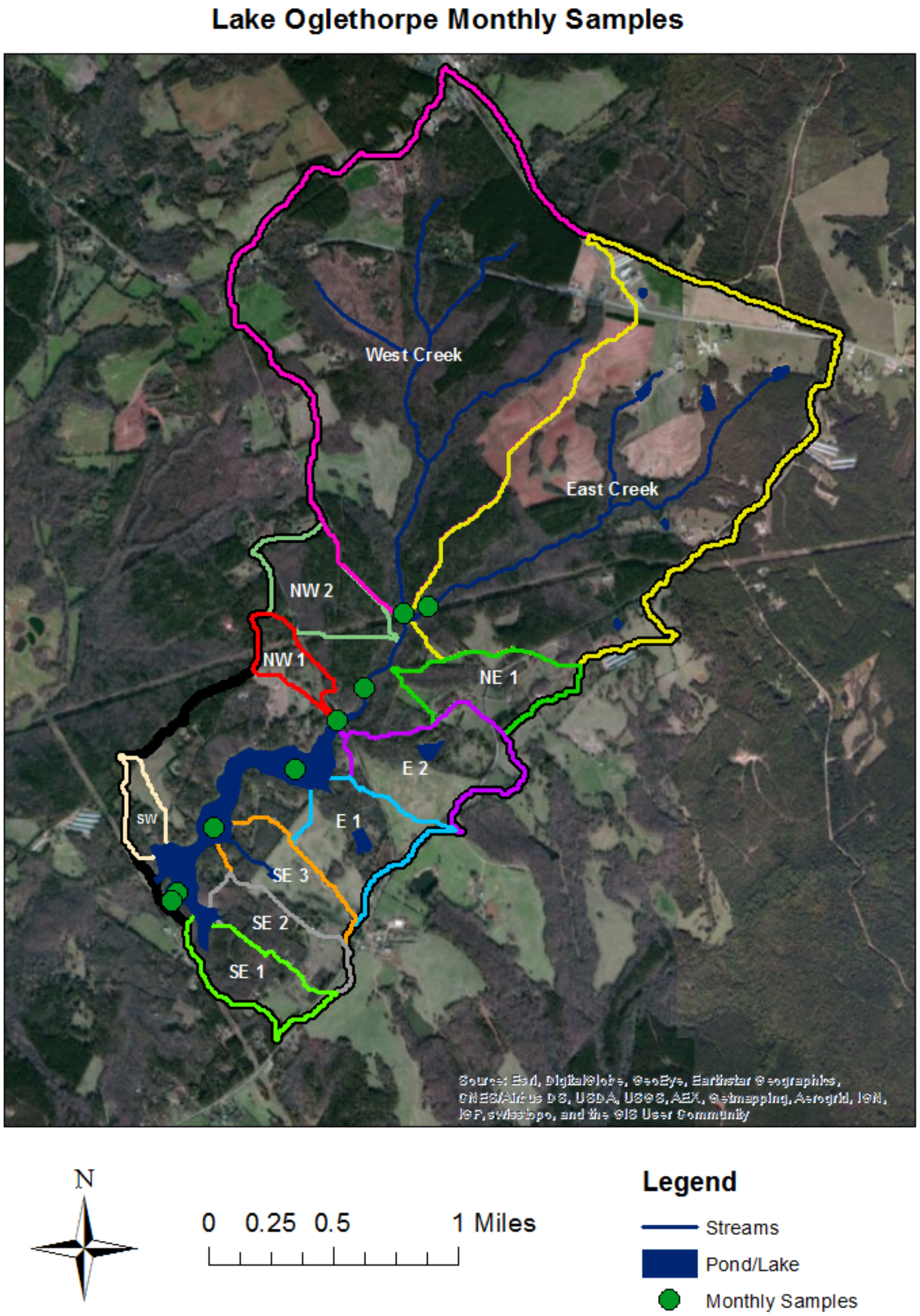


Figure 5.3- Lake Oglethorpe monthly sampling locations

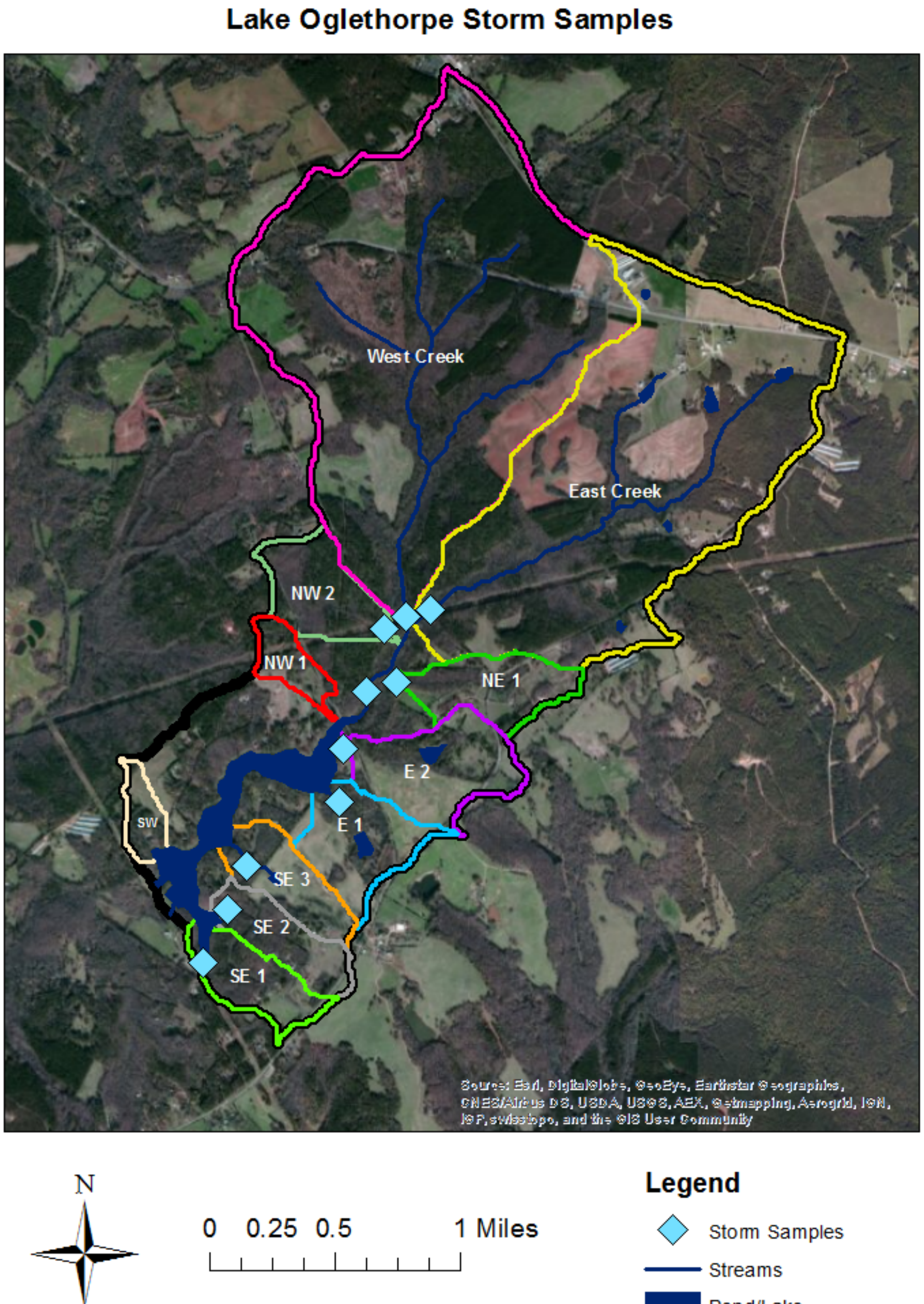


Figure 5.4- Storm Sample locations

Figure 5.5- Soil sampling technique using steel hand auger in pasture

6.0 Results

6.1 GIS

The total catchment area can be seen in **Figure 6.1**, along with the top contributing areas. These areas include SE1, SE2, SE3, E1, E2, NE1, East Creek (TR), West Creek (TL), NW1, NW2, and SW1. These areas were determined based on a Digital Elevation Model (DEM) pictured in **Figure 6.2**. It was determined the areas not outlined did not form streams before entering the lake. While these areas are still important when considering runoff, grab samples were not an option.

Land cover data for the catchment area can be viewed in **Figure 6.3**. The catchment areas defined in **Figure 6.1** can be seen in **Figure 6.4** overlaid above the land cover data. The total catchment area Lake Oglethorpe is 2,223.7 acres, and the percentages of each land cover type can be seen below in **Table 6.1**. The catchment includes 49% deciduous and evergreen forest, 28% hay/pasture, and 9% developed land.

Table 6.1- Lake Oglethorpe catchment area land cover data

Land Cover	**Total Catchment (%)**	**Total Catchment (Acres)**
Open Water	2.4	53.3
Developed, Open Space	8.2	183.3
Developed, Low Intensity	2.4	54.2
Developed, Medium Intensity	0.4	8.2
Barren Land	0.6	13.3
Deciduous Forest	32.3	717.8
Evergreen Forest	16.4	365.6
Mixed Forest	0.7	15.6
Shrub/Scrub	0.0	0.2
Herbaceuous	4.8	105.8
Hay/Pasture	28.1	625.6
Cultivated Crops	0.3	7.8
Woody Wetlands	3.3	72.9
Total	100%	**2223.7**

According to 2006 USGS data, of the 2,224 acres comprising Lake Oglethorpe's watershed, 1675 acres were classified as having Cecil Loam soils. This constitutes nearly 75% of the entire watershed seen in **Figure 6.5** in dark green. Soil acronym descriptions, slope, and percentage of the catchment can be seen in **Table 6.2**. Cecil Sandy Loam soils are prevalent in the Piedmont uplands and comprise a significant portion of Georgia, North Carolina, Alabama, South Carolina, and Virginia. Generally, they are well-draining and moderately permeable soils that are very deep to bedrock. They can result in medium to rapid runoff. Cecil Loam soils are commonly cultivated with crops such as corn, cotton, tobacco, and small grains. Historically, much of the catchment area was farmed for various crops, but predominately cotton.

Table 6.2- Lake Oglethorpe Soils

MuKey	Soil Type	Slope	Total Acres	%
124871 APE	Ashlar Louisburg and Pacolet	15 to 35 percent slopes	4.9	0.2
124873 AmB	Appling coarse sandy loam	2 to 6 percent slopes	24.7	1.1
124874 AmC	Appling coarse sandy loam	6 to 10 percent slopes	24.7	1.1
124875 Ca	Cartecay loam	occasionally flooded	44.5	2.0
124876 CeB	Cecil sandy loam	2 to 6 percent slopes	854.9	38.4
124877 CeC	Cecil sandy loam	6 to 10 percent slopes	375.6	16.9
124878 CfC2	Cecil sandy clay loam	6 to 10 percent slopes; eroded	444.7	20.0
124879 Ch	Chewacla silt loam	0 to 2 percent slopes; occasionally flooded	4.9	0.2
124891 MaB	Madison sandy loam	2 to 6 percent slopes	9.9	0.4
124892 MaC	Madison sandy loam	6 to 10 percent slopes	14.8	0.7
124894 MdC2	Madison sandy clay loam	6 to 10 percent slopes; eroded	14.8	0.7
124897 MeC	Mecklenburg fine sandy loam	6 to 10 percent slopes	9.9	0.4
124898 MeD	Mecklenburg fine sandy loam	10 to 25 percent slopes	39.5	1.8
124901 PaD	Pacolet sandy loam	10 to 25 percent slopes	54.4	2.4
124903 PfD2	Pacolet sandy clay loam	10 to 25 percent slopes; eroded	207.5	9.3
124907 To	Toccoa fine sandy loam	occasionally flooded	29.6	1.3
620398 W	Water		64.2	2.9
		Total	**2223.7**	

Lake Oglethorpe Catchment Areas

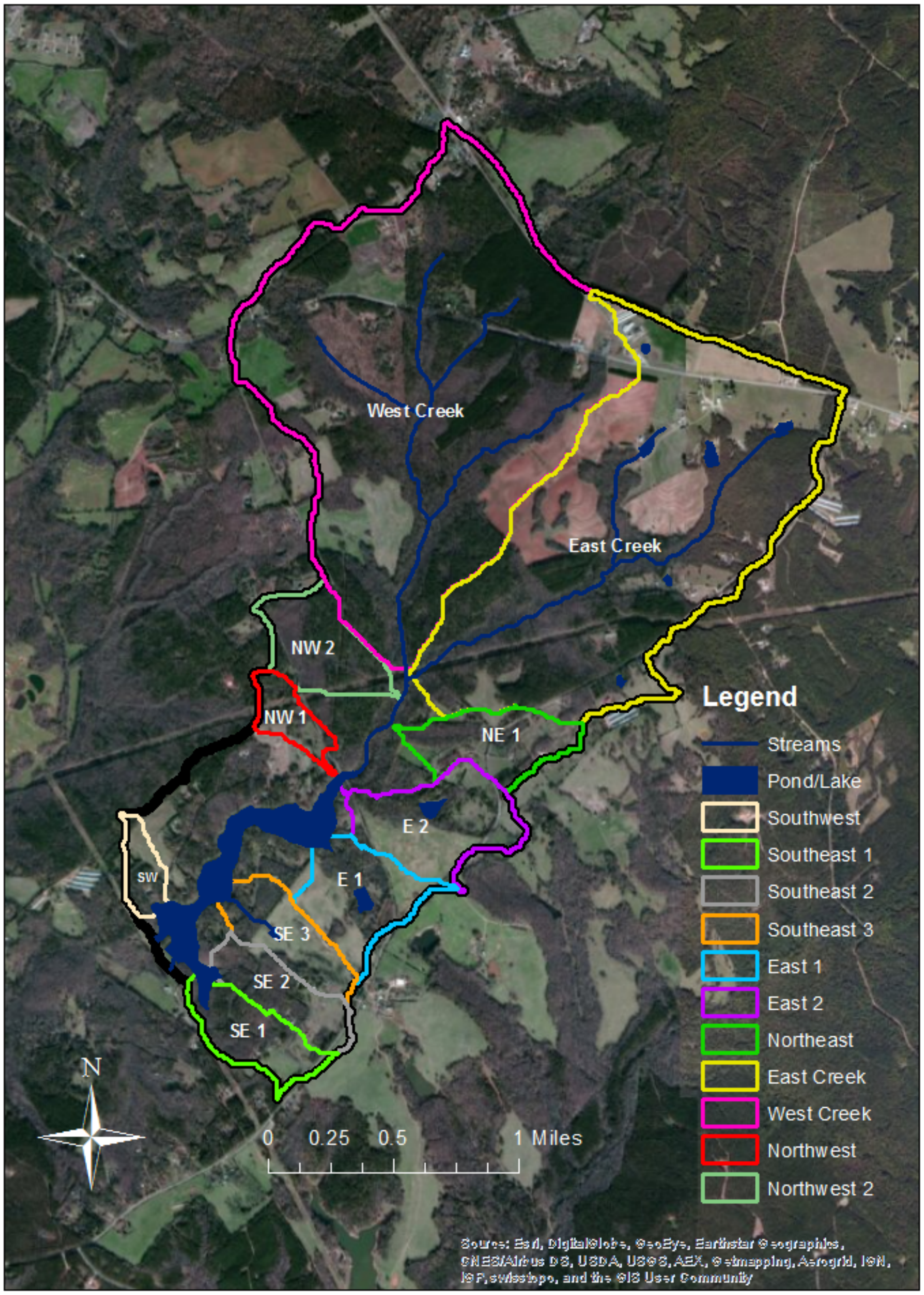


Figure 6.1- Lake Oglethorpe catchment areas and total catchment area

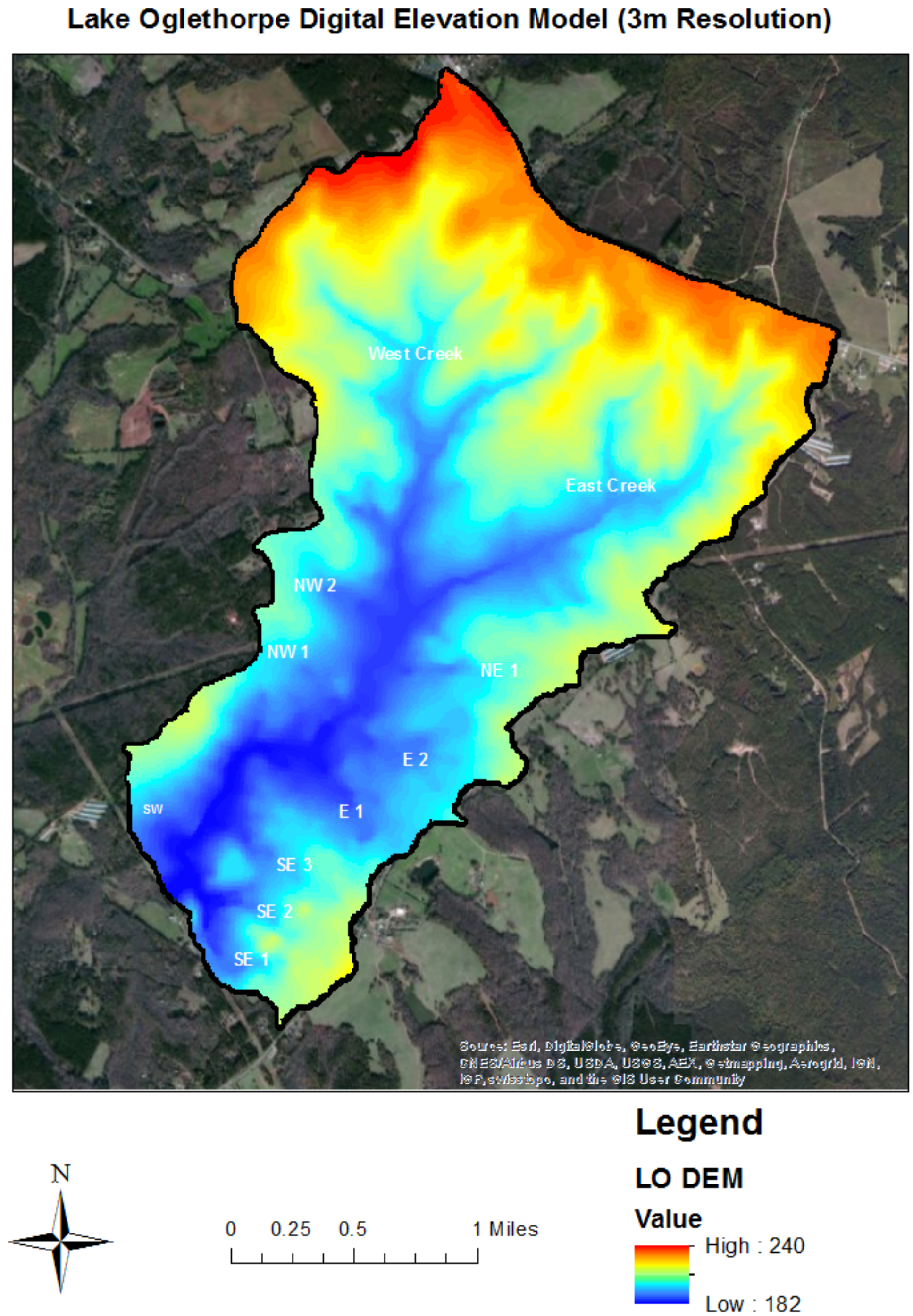


Figure 6.2- Lake Oglethorpe Digital Elevation Model

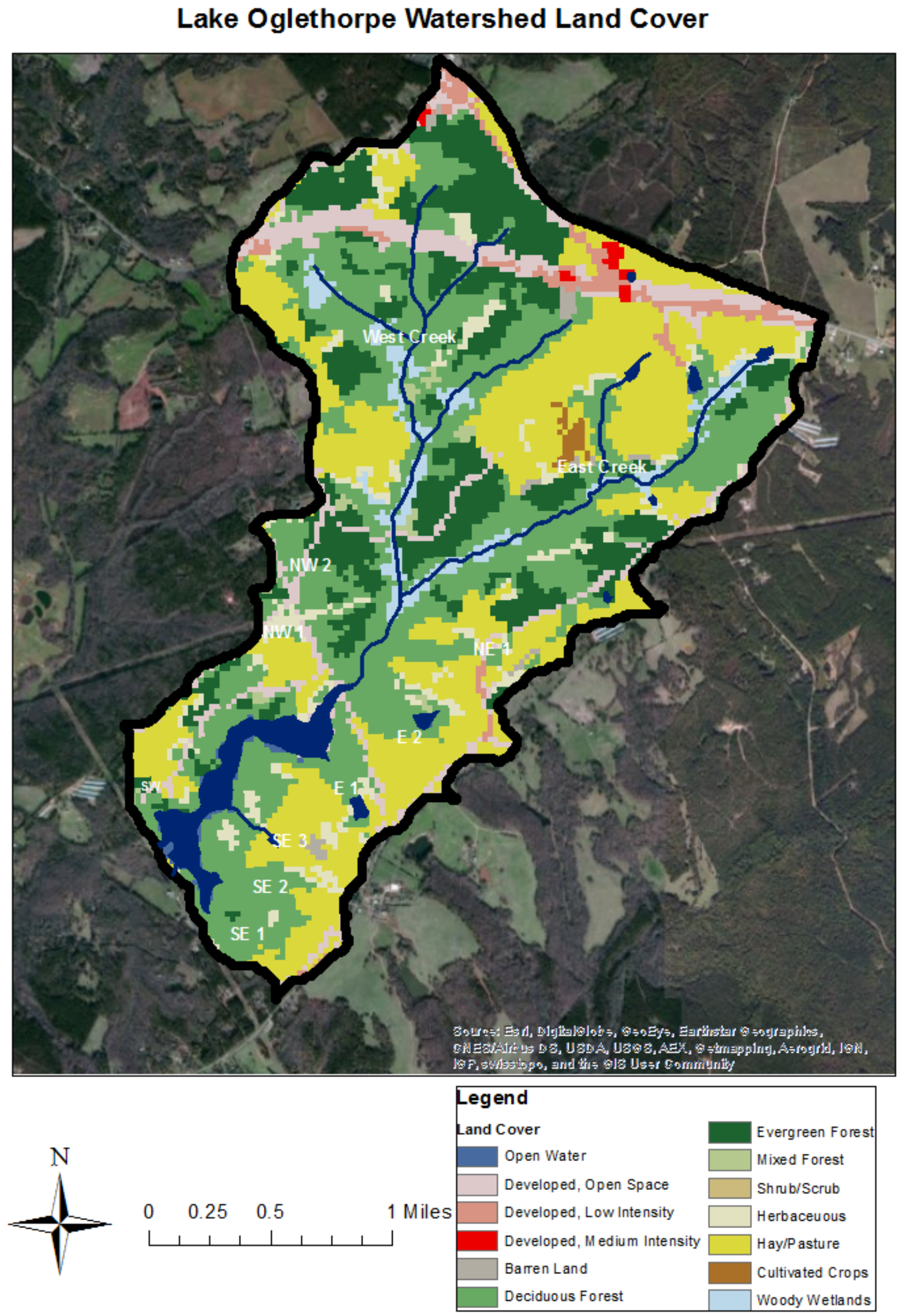


Figure 6.3- 2008 National Land Cover data for Georgia with satellite view

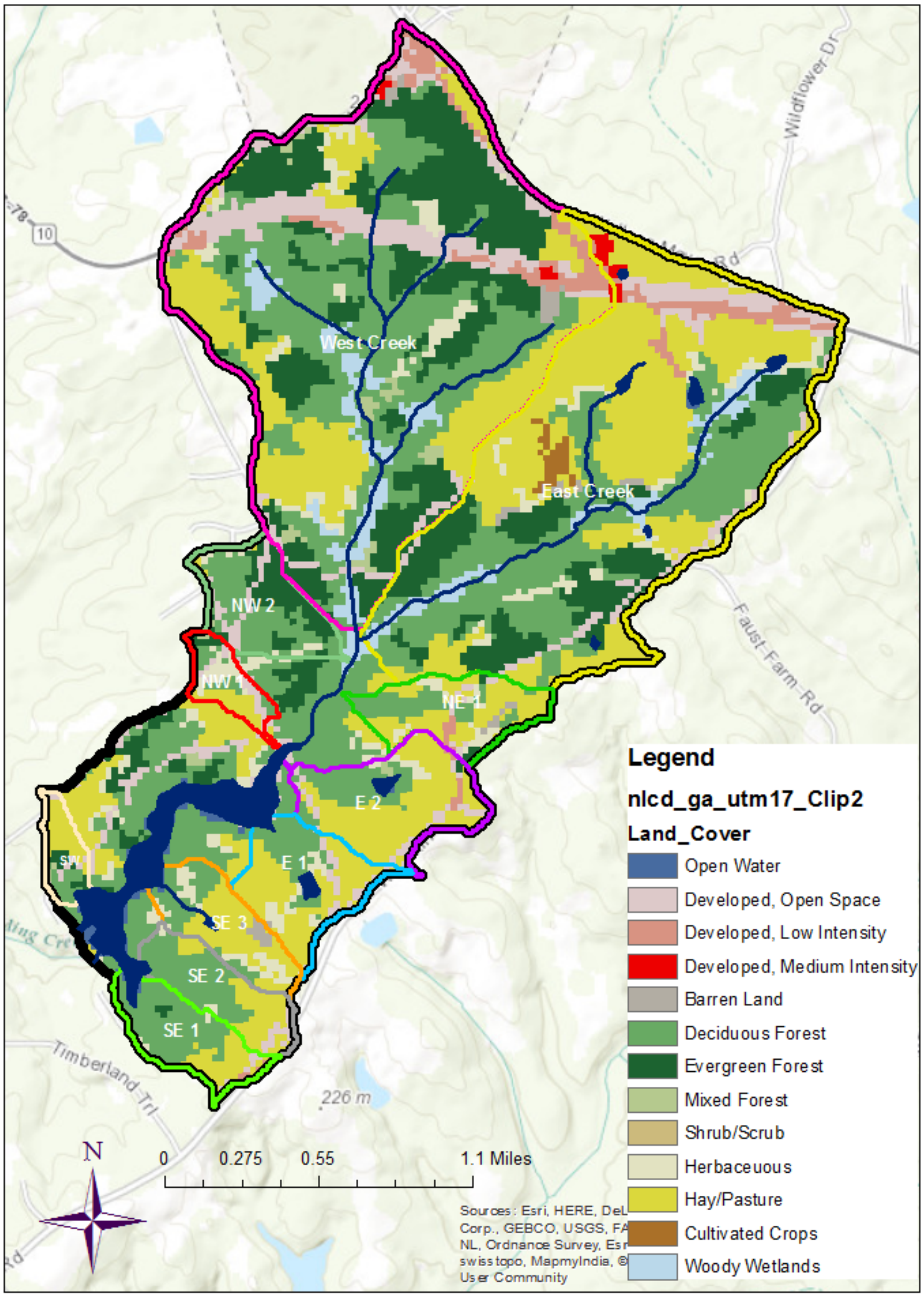


Figure 6.4- 2008 National Land Cover data for Georgia with topographic and boundaries

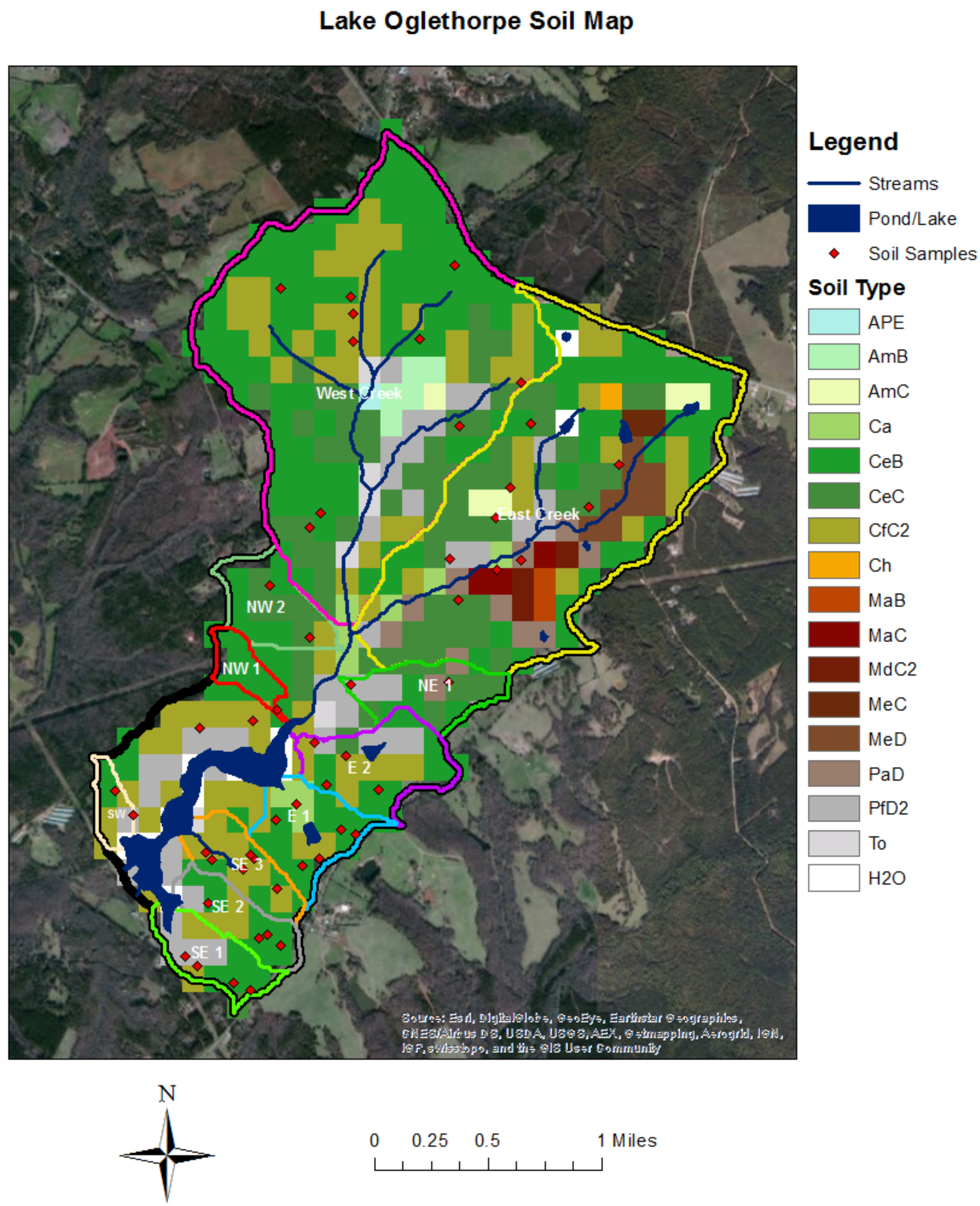


Figure 6.5- SSURGO soil data for Lake Oglethorpe Catchment

6.2 Sonar Data

The oldest available bathymetric data for Lake Oglethorpe can be seen in **Figure 1.1**. This data concluded the lake was a total of 71-acres based on surveyed transects in 1989. Lake Oglethorpe elevation pool data can be seen in the Appendix, **Figure A1**, ranging from 625 feet in elevation to 640 feet in elevation. No other bathymetric surveys were found from 1989 to 2015.

Sonar depth and GPS data was collected on March 31, 2015 and sent to a third party to be analyzed. A total of 4,995 data points were analyzed via online lake monitoring software called BioBase. A completed bathymetric map can be seen in **Figure 6.6**. The area of Lake Oglethorpe was measured to be 61.29 acres with a total volume (as of March 31, 2015) of 510-acre ft., 629,935 m^3, or about 250 Olympic swimming pools. This area did not include the mouth of the lake above the bridge. The largest depth measurement was gathered at a point near the dam and reached 27.1 feet. It was also determined the lake had less than 3% vegetation on the bottom, which is probably due to grass carp.

Until now, no other comprehensive water elevation data has been gathered in the past 25 years, the recent sonar analysis will serve as a base point that can be compared against future analyses to monitor sedimentation build-up and to determine if dredging needs to be done and, if so, where trouble spots of rapid accumulation exist. The current survey is mandatory to aid in determining diffuser locations for lake aeration. A contour map including the flood zone for the lake can be found in the **Appendix**, but comparison is difficult due to different formatting. The deepest area of the lake in 1989 was 28 feet and the deepest point in 2015 was 27.1 feet, but not as large of a zone.

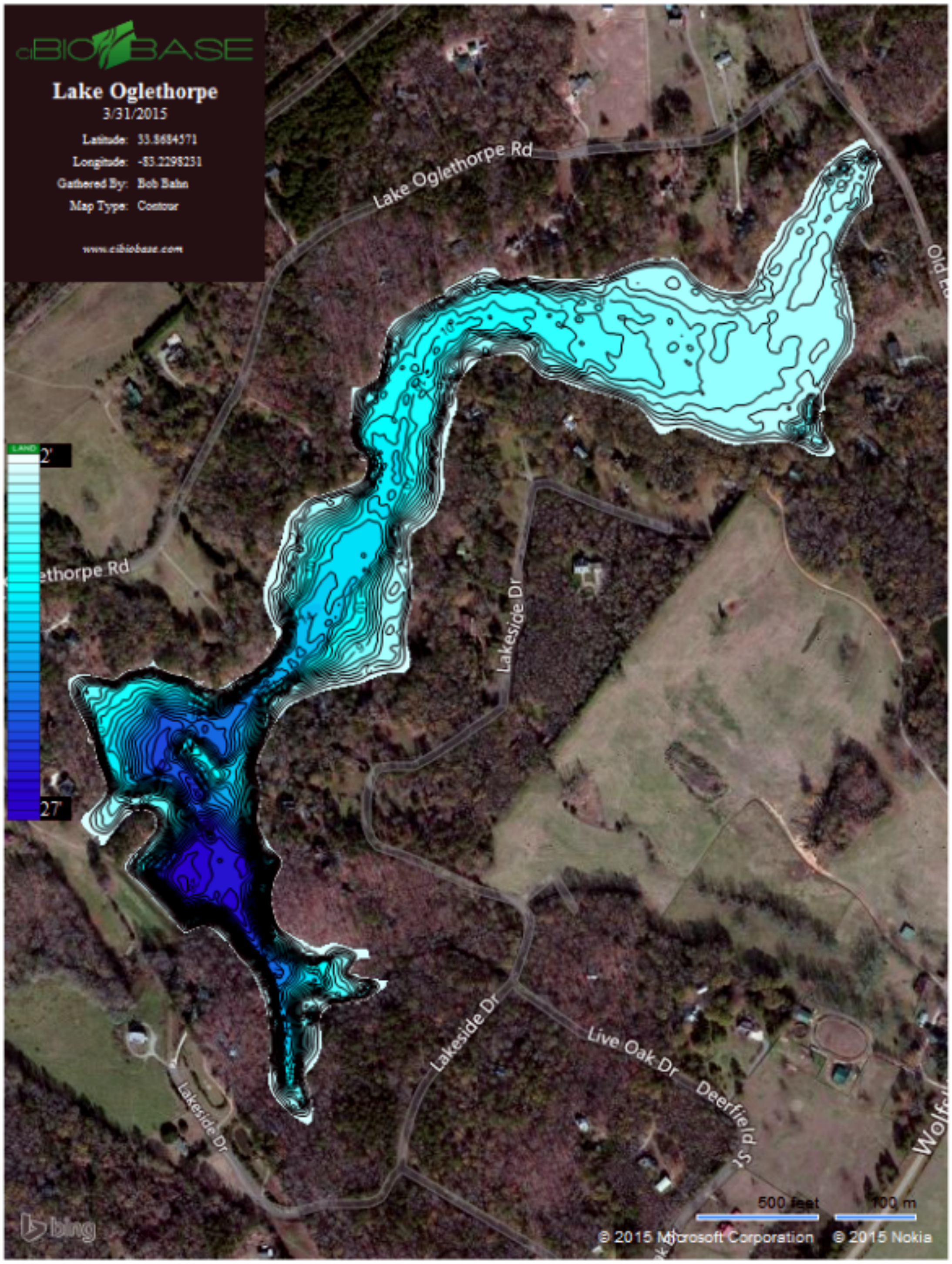


Figure 6.6- Lake Oglethorpe Bathymetric Profile

6.3 Inputs and Outputs

Stage measurements were recorded every ten minutes at the Goulding Creek (TC) Monitoring site just above the lake. These measurements could be correlated to measured discharges at specific stages using a velocimeter and measuring tape. The monitoring location on Goulding Creek can be viewed in **Figure 6.7**. A wide range of discharge measurements are needed to determine a rating curve for the creek and therefore estimate total discharge coming into the lake at all times.

While sampling Goulding Creek, the observation was made that several large beaver dams had been constructed. A photo can be found in **Figure 6.8 and 6.9**. These dams drastically altered the discharge of the main tributaries filling the lake. Where there used to be a base flow of approximately five inches deep, there now were two to three feet of almost completely stagnant water. The beaver dams made it impossible to calculate discharge of Goulding Creek into the lake. A figure of the recorded stage can be seen in **Figure 6.10**. Notice the low stage in the first few months and a gradual incline to around 3 feet. These beaver dams could potentially have an effect on the water quality of Lake Oglethorpe for the better, but more time and data is necessary to make an accurate analysis of this statement. For the future interest of the lake, the beaver dams were left intact.

Dam stage or lake depth was also recorded every ten minutes at the weir that was draining the lake, **Figure 6.11**. The collected data was offset to the staff gauge located on the outlet structure. To complete a full output model, a year of data is needed. The study did not last a full year and this data proved to not be significant to this point. However, the sensors will be left in place over the next few months to get a full year of data. It has been confirmed that a UGA Warnell Senior design project group is hoping to continue research at the lake in the fall of 2015.

Figure 6.7- Goulding Creek monitoring location

Figure 6.8- One of approximately 7 Goulding Creek beaver dams on 3/19/15

Figure 6.9- Goulding Creek dam photo 2

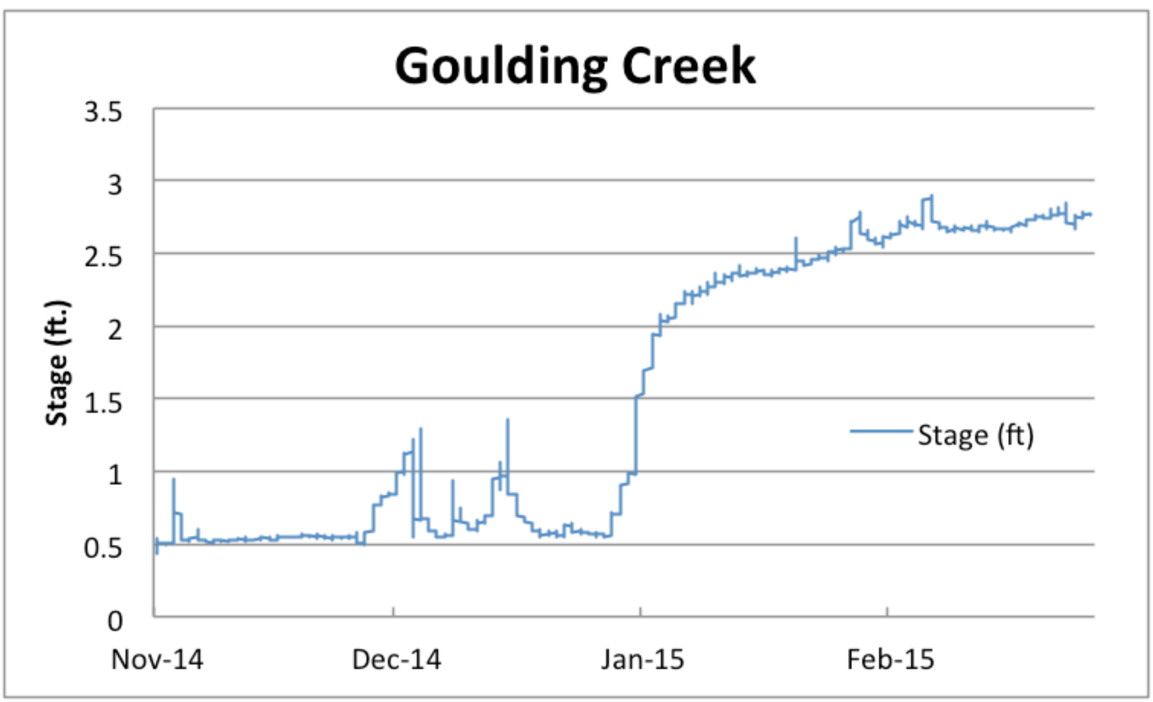


Figure 6.10- Goulding Creek Stage

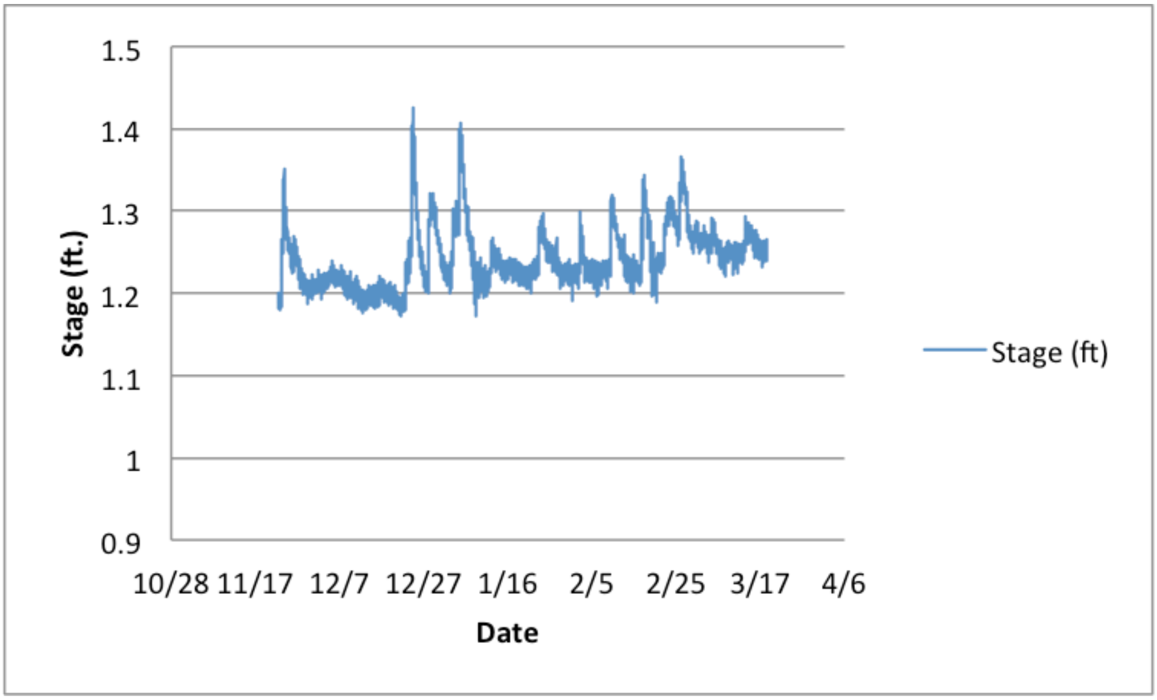


Figure 6.11- Lake Oglethorpe stage based on staff gauge by the outlet structure

6.4 Water Quality Sampling Data

Monthly water quality sampling included a total of 7 events from November 2014 to May 2015. Samples were taken following at least 2 days of where no rainfall occurred. A map of the sample locations can be seen in **Figure 5.3** at the end of section 5. Sample locations included the main contributing tributaries (TL, TR, and TC), in-lake samples (LM, LC, LD, LL, LB) and outflow at BL. In addition to monthly sample events, storm events were sampled March 19, 2015 and May 26, 2015. Samples were taken from all the contributing tributaries, including the two creeks sampled during monthly events. A map of the sample sites can be seen in **Figure 5.4** at the end of section 5. The SW and NW1 tributaries did not generate any significant flow during either sample event. Parameters were the same for both sample events, except that DO and temperature were not sampled during the 2nd event due to sensor availability.

TL was sampled for all monthly sample events and storm events during the study. Data for all events can be found in **Table 6.3**. Iron concentrations met the standards for all sample events other than the May storm event, 3.5 mg/L. NO3+NO2 concentrations were similar to those within the region average of ~0.7 mg/L. When considering anything above 0.1 mg/L of TP can lead to eutrophication, TP concentrations were high on average and extremely high during the May storm event at 0.52 mg/L. TSS increased during storm events as expected. Ammonia concentrations were generally low as is typical of most streams. All pH measurements were within the state of Georgia's standards other than a 6.4 measurement during the storm event in May. Specific conductance remained consistent throughout the study averaging 43 μS/cm and does not pose concern. A decrease in pH can be expected during rain events due to the low pH of rain and a single measurement below 6.4 is not of any concern. DO for the creek was well above the 4.0 mg/L state standard with an average of 10 mg/L. An increase of 25 NTU is considered high, while the first storm event was around this standard, the May event was more than 175 NTU above the standard. Overall, the water quality is considered good, other than TP.

Table 6.3- Top Left (West) Creek water quality data

Lab ID	Date	Time	Site	Fe (mg/L)	NO3+NO2 (mg/L)	TP (mg/L)	COD (mg/L)	TSS (mg/L)	NH3 (mg/L)	Alk (mg/L)	pH	SC (µS/cm)	WT (M)	DO (mg/L)	Turb (NTU)	Stage (ft.)	W
1-001	11/21/14	16:00	TL	0.29	0.46	0.09	4.5	1.6	0.042	9.78	7.67	45	9.3	10.1	1.6	0.48	PC
2-001	12/16/14	12:30	TL	0.38	0.59	0.12	18.4	2.4	0.02	20.72	6.95	44	12.0	10.1	2.1	0.54	PC
3-001	1/21/15	13:00	TL	0.26	0.78	0.12	20.8	1	0.028	BDL	7.45	46	10.5	11.3	2.8	-	S
4-001	2/27/15	15:15	TL	0.22	0.59	0.10	36.8	4.7	0.05	BDL	7.41	38	11.5	10.2	6.3	2.75	S
5-001	3/18/15	18:20	TL	0.67	0.57	0.21	13.3	1	0.051	BDL	7.78	40	15.8	9.6	4.1	2.79	PC
6-009	3/19/15	12:05	TL	0.44	0.63	0.21	13.5	21.3	0.048	BDL	7.14	36	11.9	10.4	35.2	-	R
7-001	4/28/15	12:30	TL	0.37	0.66	0.11	6.6	7.5	0.069	15	6.90	41	15.5	9.0	7.2	0.79	S
8-001	5/18/15	1:10	TL	0.36	0.82	0.09	9.8	8.4	0.129	15	7.05	47	20.4	7.1	10.0	0.90	PC
9-001	5/26/15	7:45	TL	3.50	1.75	0.52	64.8	164.8	0.31	20	6.41	39.5	-	-	218.3	-	R
			Min	0.22	0.46	0.09	4.5	1.00	0.02	9.78	6.41	36.00	9.3	7.1	1.6	0.48	
			Max	3.50	1.75	0.52	64.8	164.80	0.31	20.72	7.78	47.00	20.4	11.3	218.3	2.79	
			Non-Storm Avg	0.36	0.64	0.12	15.7	3.80	0.06	15.13	7.32	43.00	13.6	9.6	4.9	1.38	
			Storm Avg	1.97	1.19	0.36	39.2	93.056	0.179	20	6.775	37.75	11.9	10.4	126.7	-	

TR was sampled for all monthly sample events and storm events during the study. Data for all events can be found in **Table 6.4**. Iron concentrations met the recommendations for all sample events other than the May storm event, 2.84 mg/L. NO3+NO2 concentrations were lower when compared to those within the region average of ~0.7 mg/L. TP concentrations were high on average and extremely high during the May storm event at 0.81 mg/L. TSS increased during storm events as expected. Ammonia concentrations were generally low as is typical of most streams, but increased during storm events. All pH measurements were within the state of Georgia's standards. Specific conductance remained consistent throughout the study averaging 51 µS/cm and does not pose concern. DO for the creek was well above the 4.0 mg/L state standard with an average of 9 mg/L. An increase of 25 NTU is considered high, while the first storm event was around this standard, the May event was more than 200 NTU above the standard. Overall the water quality is considered good, other than TP.

Table 6.4- Top Right (East) Creek water quality data

Lab ID	Date	Time	Site	Fe (mg/L)	NO3+NO2 (mg/L)	TP (mg/L)	COD (mg/L)	TSS (mg/L)	NH3 (mg/L)	Alk (mg/L)	pH	SC (µS/cm)	WT (M)	DO (mg/L)	Turb (NTU)	Stage (ft.)	W
1-002	11/21/14	16:15	TR	0.28	0.10	0.09	11.60	1.6	0.022	BDL	7.5	51	9.43	7.48	1.3	0.48	PC
2-002	12/16/14	12:30	TR	0.33	0.16	0.11	6.50	2.0	0.031	11.7	6.94	49	11.44	9.75	2.27	0.54	PC
3-002	1/21/15	12:30	TR	0.36	0.47	0.108	8.10	1.0	0.016	BDL	7.48	54	9.1	11.02	2.74	-	S
4-002	2/27/15	15:30	TR	0.24	0.45	0.086	14.60	4.0	0.047	11	7.35	47	11.22	9.94	8.3	2.75	S
5-002	3/18/15	18:30	TR	0.51	0.24	0.201	9.30	2.0	0.057	BDL	7.58	49	15.75	9.55	3.26	2.79	PC
6-008	3/19/15	12:10	TR	0.38	0.37	0.214	10.70	16.0	0.037	BDL	7.15	46	11.8	10.35	11.85	-	R
7-002	4/28/15	12:40	TR	0.46	0.41	0.09	6.2	5.5	0.055	20	7.08	51	15.94	8.73	6.5	0.79	S
8-002	5/18/15	1:30	TR	0.41	0.44	0.096	7.8	5.1	0.068	20	7.19	54	21.47	7.22	6.75	0.90	PC
9-002	5/26/15	7:30	TR	2.84	1.48	0.81	70.8	385.6	0.390	20	6.97	44.2	-	-	230.2	-	R
			Min	0.24	0.10	0.09	6.20	1.0	0.016	11.00	6.94	44.20	9.10	7.22	1.30	0.48	
			Max	2.84	1.48	0.81	70.80	385.6	0.390	20.00	7.58	54.00	21.47	11.02	230.20	2.79	
			Non-Storm Avg	0.37	0.32	0.11	9.16	3.0	0.042	15.68	7.30	50.71	13.48	9.10	4.45	1.38	
			Storm Avg	1.61	0.92	0.512	40.75	200.8	0.214	20	7.1	45.1	11.8	10.35	121.025	-	

TC was sampled for all monthly sample events and storm events during the study. During the period in which the beaver dams were constructed, the samples were taken below the final dam before entering the lake. Data for all events can be found in **Table 6.5**. Iron concentrations met the recommendations for all sample events other than the May storm event, 3.14 mg/L. NO3+NO2 concentrations were lower when compared to those within the region average of ~0.7 mg/L. TP concentrations were high on average and extremely high during the May storm event at 0.61 mg/L. TSS increased during storm events as expected. Ammonia concentrations were generally low as is typical of most streams, but increased during storm events. All pH measurements were within the state standards. Specific conductance remained consistent throughout the study averaging 47 µS/cm and does not pose concern. DO for the creek was well above the 4.0 mg/L state standard with an average of 9 mg/L. An increase of 25 NTU is considered high, while the first storm event was well below this standard probably due to the beaver dams, the May event was more than 175 NTU above the standard after the beaver dams gave way. Overall the water quality is considered good at TC, other than TP.

Table 6.5- Top Combined (Goulding Creek) water quality data

Lab ID	Date	Time	Site	Fe (mg/L)	NO3+NO2 (mg/L)	TP (mg/L)	COD (mg/L)	TSS (mg/L)	NH3 (mg/L)	Alk (mg/L)	pH	SC (µS/cm)	WT (M)	DO (mg/L)	Turb (NTU)	Stage (ft.)	W
1-003	11/21/14	16:30	TC	0.36	0.24	0.11	4.70	1.6	0.018	BDL	7.67	48	9.7	9.85	2.3	0.48	PC
2-003	12/16/14	12:00	TC	0.39	0.33	0.13	14.50	2.0	0.022	27.9	6.76	46	11.09	10.04	2.5	0.54	PC
3-003	1/21/15	12:45	TC	0.31	0.58	0.13	7.50	3.2	0.018	BDL	7.51	50	8.85	9.15	2.8	-	S
4-003	2/27/15	15:00	TC	0.36	0.52	0.10	46.40	2.3	0.032	11.6	7.93	41	8.37	11.04	6.1	2.75	S
5-003	3/18/15	17:50	TC	0.26	0.44	0.18	10.00	2.3	0.039	BDL	7.61	46	14.94	9.23	4.5	2.79	S
6-010	3/19/15	11:35	TC	0.48	0.43	0.21	12.40	6.0	0.044	BDL	7.04	44	12.68	9.42	7.6	-	R
7-003	4/28/15	12:00	TC	0.57	0.57	0.11	8.5	4.5	0.072	20	7.20	46	15.22	8.85	5.5	0.79	S
8-003	5/18/15	1:45	TC	0.50	0.68	0.10	10.3	3.6	0.204	20	6.88	50	20.84	6.87	7.1	0.90	PC
9-003	5/26/15	7:50	TC	3.14	1.53	0.61	66.3	231.2	0.33	20	6.91	40	-	-	205.4	-	R
			Min	0.26	0.24	0.10	4.70	1.60	0.02	11.60	6.76	40.00	8.37	6.87	2.3	0.48	
			Max	3.14	1.53	0.61	66.30	231.20	0.33	27.90	7.93	50.00	20.84	11.04	205.4	2.79	
			Non-Storm Avg	0.39	0.48	0.12	14.56	2.79	0.06	19.88	7.37	46.71	12.72	9.29	4.4	1.37	
			Storm Avg	1.81	0.98	0.41	39.35	118.6	0.187	20	6.975	42	12.68	9.42	106.5	-	

SE1 was sampled for both storm events and data for both events can be found in **Table 6.6**. Iron concentration average was above recommended limit of 1.0 mg/L, totaling 1.5 mg/L. NO3+NO2 concentrations similar when compared to those within the region average of ~0.7 mg/L. TP concentrations were high on average when considering anything above 0.1 mg/L can lead to eutrophication with an average of 0.3 mg/L. TSS was much higher in the second storm event, which leads to believe we missed the first flush of the first event. Ammonia concentrations were generally low as is typical of most streams. Both pH measurements were within the Georgia state standards, but on the low end. Specific conductance was similar to the rest of the catchment area averaging 42.15 µS/cm. DO for the creek was well above the 4.0 mg/L state standard with 8 mg/L in the first event. Turbidity for the May sample event was much higher than the March storm event. Overall the water quality is considered good at SE1, other than TP.

Table 6.6- Southeast 1 water quality data

Lab ID	Date	Time	Site	Fe (mg/L)	NO3+NO2 (mg/L)	TP (mg/L)	COD (mg/L)	TSS (mg/L)	NH3 (mg/L)	Alk (mg/L)	pH	SC (µS/cm)	WT(M)	DO	Turb (NTU)	W
6-001	3/19/15	10:30	SE1	0.61	0.31	0.21	10.70	2.3	0.04	3.1	6.71	51	12.04	7.9	11.75	R
9-007	5/26/15	6:45	SE1	2.30	1.00	0.39	60.9	100.8	0.26	15.0	6.49	33.3	-	-	102.8	R
			Min	0.61	0.31	0.21	10.7	2.3	0.04	3.1	6.49	33.3	12.04	7.9	11.75	
			Max	2.30	1.00	0.39	60.9	100.8	0.26	15.0	6.71	51	12.04	7.9	102.8	
			Avg	1.46	0.65	0.30	35.8	51.55	0.15	9.1	6.6	42.15	12.04	7.9	57.28	

SE2 was sampled for both storm events and data for both events can be found in **Table 6.7**. Iron concentration average was below recommended limit of 1.0 mg/L. NO3+NO2 concentrations similar when compared to those within the region average of ~0.7 mg/L. TP concentrations were high on average when considering anything above 0.1 mg/L can lead to eutrophication with an average of 0.217 mg/L. It was the lowest within the catchment area. TSS was higher in the second storm event, which leads to believe we missed the first flush of the first event. Ammonia concentrations were generally low as is typical of most streams. Both pH measurements were below the Georgia state standards, at 6.23. Specific conductance was similar to the rest of the catchment area averaging 42.7 µS/cm. DO for the creek was above the 4.0 mg/L state standard with 6.4 mg/L in the first event. This was the lowest DO measurement in the catchment area. Turbidity for the May sample event was higher than the March storm event. Overall the water quality is considered good at SE2, other than TP and pH.

Table 6.7- Southeast 2 water quality data

Lab ID	Date	Time	Site	Fe (mg/L)	NO3+NO2 (mg/L)	TP (mg/L)	COD (mg/L)	TSS (mg/L)	NH3 (mg/L)	Alk (mg/L)	pH	SC (µS/cm)	WT(M)	DO	Turb (NTU)	W
6-002	3/19/15	10:20	SE2	0.035	0.912	0.195	8.80	10.66	0.021	BDL	6.23	41	14.37	6.38	3.5	R
9-008	5/26/15	6:55	SE2	1.04	0.682	0.238	50.1	28.8	0.182	20	6.23	44.4	-	-	33.5	R
			Min	0.035	0.682	0.195	8.8	10.66	0.021	20	6.23	41	14.37	6.38	3.5	
			Max	1.04	0.912	0.238	50.1	28.8	0.182	20	6.23	44.4	14.37	6.38	33.5	
			Avg	0.5375	0.797	0.217	29.45	19.73	0.1015	20	6.23	42.7	14.37	6.38	18.5	

SE3 was sampled for the March storm event and data the events can be found in **Table 6.8**. The creek was not flowing during the May sample event possibly due to the holding pond located below the old mill site in the catchment area. Iron concentration was just above the recommended limit of 1.0 mg/L. NO3+NO2 concentrations similar when compared to those within the region average of ~0.7 mg/L. TP concentrations two times the region recommendation when considering anything above 0.1 mg/L can lead to eutrophication. TSS was very low for this event. Ammonia concentration was also very low and typical of most streams. The pH measurement was above the Georgia state standard. Specific conductance was similar to the rest of the catchment area averaging 46 µS/cm. DO for the creek was above the 4.0 mg/L state standard with 7.4 mg/L in the first event. Turbidity for the event was low for a storm event. Overall the water quality is considered good at SE3, other than TP.

Table 6.8- Southeast 3 water quality data

Lab ID	Date	Time	Site	Fe (mg/L)	NO3+NO2 (mg/L)	TP (mg/L)	COD (mg/L)	TSS (mg/L)	NH3 (mg/L)	Alk (mg/L)	pH	SC (µS/cm)	WT(M)	DO	Turb (NTU)	W
6-003	3/19/15	10:00	SE3	0.134	0.791	0.196	17.30	0.666	0.041	BDL	6.76	46	11.71	7.37	3.42	R

E1 was sampled for both storm events and data for both events can be found in **Table 6.9**. A hay field within E1 was sampled during the May storm event, **Table 6.10**. Iron concentration average was below recommended limit of 1.0 mg/L for E1 and 1.8 mg/L for the hay field. NO3+NO2 concentrations similar when compared to those within the region average of ~0.7 mg/L for E1 and 2 mg/L for the hayfield. TP concentrations were high on average when considering anything above 0.1 mg/L can lead to eutrophication with an average of 0.29 mg/L, while the hayfield TP was extremely high with 1.2 mg/L. This was the highest recorded TP within the catchment area. TSS was higher in the second storm event, which provides more evidence we missed the first flush of the first event. Ammonia concentrations were generally low as is typical of most streams but high during the May storm event. All pH measurements were within the Georgia state standards. Specific conductance was a bit higher when compared to the rest of the catchment area averaging 56.1 µS/cm at E1 and 51.3 µS/cm in the hayfield. DO for the creek was above the 4.0 mg/L state standard with 8.8 mg/L in the first event. Turbidity for the May sample event was higher than the March storm event. Overall the water quality is considered good at E1, other than TP and the hayfield TP samples were extremely high. It is important to note that the hayfield drains into E1 and that E1 TP concentrations were on the low end when compared to the other catchments. This is most likely due to the forested riparian buffer.

Table 6.9- East 1 water quality data

Lab ID	Date	Time	Site	Fe (mg/L)	NO3+NO2 (mg/L)	TP (mg/L)	COD (mg/L)	TSS (mg/L)	NH3 (mg/L)	Alk (mg/L)	pH	SC (µS/cm)	WT(M)	DO	Turb (NTU)	W
6-004	3/19/15	9:15	E1	0.22	0.67	0.21	14.40	21.3	0.04	BDL	7.40	56	13.23	8.77	9.32	R
9-005	5/26/15	7:10	E1	1.54	0.91	0.37	61.6	107.2	0.18	20	6.58	56.2	-	-	91.2	R
			Min	0.22	0.67	0.21	14.4	21.3	0.04	20	6.58	56	13.23	8.77	9.32	
			Max	1.54	0.91	0.37	61.6	107.2	0.18	20	7.4	56.2	13.23	8.77	91.2	
			Avg	0.88	0.79	0.29	38	64.3	0.11	20	6.99	56.1	13.23	8.77	50.26	

Table 6.10- Hayfield located in East 1 catchment

Lab ID	Date	Time	Site	Fe (mg/L)	NO3+NO2 (mg/L)	TP (mg/L)	COD (mg/L)	TSS (mg/L)	NH3 (mg/L)	Alk (mg/L)	pH	SC (µS/cm)	Turb (NTU)	W
9-010	5/26/15	7:15	Hay	1.8	1.96	1.21	75.4		0.819	15	6.48	51.3	130.2	R

E2 was sampled for both storm events and data for both events can be found in **Table 6.11**. Iron concentration average was below recommended limit of 1.0 mg/L for the first sample event, but very high for the second event, 5.16 mg/L. NO3+NO2 concentrations similar when compared to those within the region average of ~0.7 mg/L for the first event and the highest in the catchment for the second event, 2.31 mg/L. TP concentrations were very high with an average of 0.61 mg/L. TSS was higher in the second storm event, which leads to believe we missed the first flush of the first event. Ammonia concentrations were very high for the May event. Both pH measurements were within the Georgia state standards. Specific conductance was the highest within the catchment area averaging 72.6 µS/cm. DO for the creek was above the 4.0 mg/L state standard with 9.36 mg/L in the first event. Turbidity for the May sample event was much higher than the March storm event. The water quality for E1 meets all the state standards, but there is some concern for high TP, NO3+NO2, NH3, and SC.

Table 6.11- East 2 water quality data

Lab ID	Date	Time	Site	Fe (mg/L)	NO3+NO2 (mg/L)	TP (mg/L)	COD (mg/L)	TSS (mg/L)	NH3 (mg/L)	Alk (mg/L)	pH	SC (µS/cm)	WT(M)	DO	Turb (NTU)	W
6-005	3/19/15	11:15	E2	0.387	0.791	0.208	19.50	21.65	0.058	BDL	7.02	65	12.11	9.36	12.42	R
9-006	5/26/15	7:20	E2	5.16	2.31	1.02	72.1	177.6	0.502	25	7.03	80.2	-	-	190.2	R
			Min	0.387	0.791	0.208	19.5	21.65	0.058	25	7.02	65	12.11	9.36	12.42	
			Max	5.16	2.31	1.02	72.1	177.6	0.502	25	7.03	80.2	12.11	9.36	190.2	
			Avg	2.7735	1.5505	0.614	45.8	99.625	0.28	25	7.03	72.6	12.11	9.36	101.31	

NE1 was sampled for both storm events, and data for both events can be found in **Table 6.12**. Iron concentration average was below recommended limit of 1.0 mg/L for the first event and above the limit for the second event. NO3+NO2 concentrations were slightly higher when compared to those within the region average of ~0.7 mg/L. TP concentrations were high on average when considering anything above 0.1 mg/L can lead to eutrophication with an average of 0.3mg/L, but is on the low end when compared to the rest of the Lake Oglethorpe Catchment. TSS was higher in the second storm event just as all the other samples. Ammonia concentrations were generally low as is typical of most streams, but did increase during the second storm event. Both pH measurements met the Georgia state standards if rounded up. Specific conductance a little higher when compared to the rest of the catchment area averaging 54 µS/cm. DO for the creek was above the 4.0 mg/L state standard with 9.46 mg/L in the first event. Turbidity for the May sample event was much higher than the March storm event. Overall the water quality is considered good at NE1 other than TP.

Table 6.12- Northeast 1 water quality data

Lab ID	Date	Time	Site	Fe (mg/L)	NO3+NO2 (mg/L)	TP (mg/L)	COD (mg/L)	TSS (mg/L)	NH3 (mg/L)	Alk (mg/L)	pH	SC (µS/cm)	WT(M)	DO	Turb (NTU)	W
6-006	3/19/15	11:45	NE1	0.40	0.88	0.21	16.10	8.99	0.04	BDL	6.99	52	11.7	9.46	8.94	R
9-004	5/26/15	7:55	NE1	2.38	1.36	0.39	56.2	71.2	0.21	20	6.46	55.4	-	-	75.3	R
			Min	0.40	0.88	0.21	16.1	8.99	0.04	20	6.46	52	11.7	9.46	8.94	
			Max	2.38	1.36	0.39	56.2	71.2	0.21	20	6.99	55.4	11.7	9.46	75.3	
			Avg	1.39	1.12	0.30	36.15	40.095	0.13	20	6.73	53.7	11.7	9.46	42.12	

NW2 was sampled for both storm events and data for both events can be found in **Table 6.7**. Iron concentration average was above the recommended limit of 1.0 mg/L. NO3+NO2 concentrations were lower when compared to those within the region average of ~0.7 mg/L. TP concentrations were high on average when considering anything above 0.1 mg/L can lead to eutrophication with an average of 0.15 mg/L. It was the lowest TP within the catchment area. TSS was higher in the second storm event, which leads to believe we missed the first flush of the first event. Ammonia concentrations were generally low as is typical of most streams. Both pH measurements were within the Georgia state standards. Specific conductance was the lowest of the catchment area averaging 37 µS/cm. DO for the creek was above the 4.0 mg/L state standard with 7.7 mg/L in the first event. Turbidity for the May sample event was higher than the March storm event. Overall the water quality is considered very good, especially when compared to the other streams.

Table 6.13- Northwest 2 water quality data

Lab ID	Date	Time	Site	Fe (mg/L)	NO3+NO2 (mg/L)	TP (mg/L)	COD (mg/L)	TSS (mg/L)	NH3 (mg/L)	Alk (mg/L)	pH	SC (µS/cm)	WT(M)	DO	Turb (NTU)	W
6-007	3/19/15	12:00	NW2	0.233	0.227	0.208	15.70	7.99	0.03	BDL	6.57	27	11.35	7.77	8.74	R
9-009	5/26/15	7:25	NW2	3.120	0.370	0.097	26.9	29.6	0.11	20	6.57	46.9	-	-	41.65	R
			Min	0.233	0.227	0.097	15.7	7.99	0.03	20	6.57	27	11.35	7.77	8.74	
			Max	3.120	0.370	0.208	26.9	29.6	0.11	20	6.57	46.9	11.35	7.77	41.65	
			Avg	1.677	0.299	0.153	21.3	18.8	0.07	20	6.57	36.95	11.35	7.77	25.20	

LM was sampled during all monthly sample events, **Table 6.14**, and is located at the mouth of the lake on the lakeside of the bridge. The depth at this location was about ~4.5 feet. Chlorophyll-a samples for the site averaged below a recommended limit of 5 µg/L. TP levels were in the hypereutrophic range. TSS levels were generally low, but a maximum of 8 mg/L following a storm event. Turbidity was similar to TSS. NH3 levels were generally low, but there was an extremely high value of 0.74 mg/L in January. Any concentrations above 0.1 mg/L can be toxic to fish. DO levels within the lake were always above state standards. Secchi depth at this location averaged 1.14 meters and falls within the eutrophic range, although, it is very shallow and that measurement is near the bottom. TP and the high NH3 measurement are the most concerning here.

Table 6.14- Lake Mouth water quality data

Lab-ID	Date	Time	Site	CHL-a (µg/L)	Fe (mg/L)	NO3+NO2 (mg/L)	TP (mg/L)	SRP (mg/L)	COD (mg/L)	TSS (mg/L)	NH3 (mg/L)	Alk (mg/L)	pH	SC (µS/cm)	WT (M)	DO (mg/L)	Turb (NTU)	Sec (m.)	Stage (ft.)	W
1-008	11/22/14	10:00	LM	6.67	0.62	0.04	0.23		13.20	5.20	0.09	13.40	7.49	55.00	7.85	8.28	6.15	1.40	1.20	PC
2-005	12/16/14	15:30	LM	3.71	0.35	0.14	0.18		18.40	5.60	0.08	24.80	6.67	51.00	9.00	9.74	4.25	1.25	1.20	PC
3-004	1/21/15	12:00	LM	4.53	0.77	0.55	0.14		9.70	2.80	0.74	BDL	7.38	52.00	8.02	8.61	6.45	1.50	1.21	S
4-004	2/27/15	14:00	LM	1.65	0.78	0.55	0.08		23.40	8.33	0.06	BDL	7.30	43.00	7.04	10.44	15.71	0.75	1.31	S
5-004	3/18/15	17:20	LM	4.36	0.35	0.25	0.18		13.90	3.30	0.05	BDL	7.74	44.00	15.72	11.20	5.86	1.20	1.24	S
7-004	4/28/15	4:30	LM	7.89	0.45	0.17	0.09	0.084	15.90	0.50	0.04	25.00	7.67	39.00	22.88	5.45	5.02	0.95	1.25	S
8-004	5/18/15	3:00	LM	3.84	0.19	0.16	0.08	0.061	17.80	2.10	0.10	20.00	8.28	49.00	24.89	7.10	3.60	1.00	1.21	PC
			Min	1.65	0.19	0.04	0.08	0.061	9.70	0.50	0.04	13.40	6.67	39.00	7.04	5.45	3.60	0.75	1.20	
			Max	7.89	0.78	0.55	0.23	0.084	23.40	8.33	0.74	25.00	8.28	55.00	24.89	11.20	15.71	1.50	1.31	
			Avg	4.66	0.50	0.26	0.14	0.073	16.04	3.98	0.16	20.80	7.50	47.57	13.63	8.69	6.72	1.15	1.23	

LC was sampled during all monthly sample events, **Table 6.15**, and is located near the middle fat part of the lake out from the private boat landing and dock on the North Side. The depth at this location was ~13.5 feet. Chlorophyll-a samples for the site averaged within the mesotrophic range. TP levels were in the hypereutrophic range. TSS levels were generally low and turbidity was similar to TSS. NH3 levels were generally low, but there was an extremely high value of 0.73 mg/L in April 2015. Any concentrations above 0.1 mg/L can be toxic to fish. DO levels within the lake were always above state standards with the lowest reading of 5.33 mg/L. Secchi depth at this location averaged 1.66 meters and falls within the eutrophic range. Overall the water at this location was in good shape other than high TP.

Table 6.15- Lake Center water quality data

Lab-ID	Date	Time	Site	CHL-a (µg/L)	Fe (mg/L)	NO3+NO2 (mg/L)	TP (mg/L)	SRP (mg/L)	COD (mg/L)	TSS (mg/L)	NH3 (mg/L)	Alk (mg/L)	pH	SC (µS/cm)	WT (M)	DO (mg/L)	Turb (NTU)	Sec (m.)	Stage (ft.)	W
1-007	11/22/14	11:00	LC	5.80	0.86	0.08	0.11		12.90	4.00	0.13	15.8	7.1	57	9.52	7.31	7.2	1.2	1.2	PC
2-006	12/16/14	14:45	LC	4.77	0.27	0.13	0.11		15.10	4.40	0.10	11.3	6.77	55	9.63	8.97	3.27	2	1.2	PC
3-005	1/21/15	11:30	LC	4.87	0.21	0.34	0.15		41.10	1.20	0.08	BDL	7.44	53	7.25	9.79	3.84	2	1.21	S
4-005	2/27/15	11:45	LC	3.93	0.26	0.29	0.09		16.00	0.70	0.05	BDL	8.04	45	6.3	10.07	3.37	1.8	1.31	PC
5-005	3/18/15	16:50	LC	3.15	0.26	0.25	0.19		14.80	2.00	0.03	BDL	7.64	45	17.3	10.68	4.01	2	1.24	PC
7-005	4/28/15	4:00	LC	7.45	0.20	0.12	0.10	0.091	16.80	5.50	0.06	20	8.16	38	21.67	5.33	4.3	1.5	1.25	S
8-005	5/18/15	3:30	LC	2.16	0.13	0.15	0.09	0.062	19.20	1.50	0.73	25	7.71	49	27.21	8.08	2.75	1.3	1.21	C
			Min	2.16	0.13	0.08	0.09	0.1	12.90	0.70	0.03	11.3	6.8	38.0	6.3	5.3	2.8	1.2	1.2	
			Max	7.45	0.86	0.34	0.19	0.1	41.10	5.50	0.73	25.0	8.2	57.0	27.2	10.7	7.2	2.0	1.3	
			Avg	4.59	0.31	0.19	0.12	0.08	19.41	2.76	0.17	18.03	7.55	48.86	14.13	8.60	4.11	1.66	1.23	

LD was sampled during all monthly sample events, **Table 6.16**, and is located about 50 feet from the outlet structure at the dam. The depth at this location was about ~27 feet. Chlorophyll-a samples for the site averaged just above 5 µg/L in the mesotrophic range. TP levels were in the hypereutrophic range. TSS levels were generally low and turbidity was similar to TSS. NH3 levels were fairly low throughout the whole study. DO levels within the lake were always above state standards with the average reading of 8.5 mg/L at LD. Secchi depth at this location averaged 1.67 meters and falls within the eutrophic range.

Table 6.16- Lake Dam water quality data

Lab-ID	Date	Time	Site	CHL-a (µg/L)	Fe (mg/L)	NO3+NO2 (mg/L)	TP (mg/L)	SRP (mg/L)	COD (mg/L)	TSS (mg/L)	NH3 (mg/L)	Alk (mg/L)	pH	SC (µS/cm)	WT (M)	DO (mg/L)	Turb (NTU)	Sec (m.)	Stage (ft.)	W
1-005	11/22/14	11:30	LD	7.49	0.81	0.02	0.05	-	19.20	4.40	0.16	13.30	7.00	57.00	9.83	7.2	9.05	1.15	1.2	PC
2-007	12/16/14	13:45	LD	7.57	0.31	0.11	0.05	-	15.50	5.60	0.11	18.50	6.05	55.00	9.90	8.5	5.83	1.8	1.2	PC
3-006	1/21/15	10:30	LD	5.02	0.20	0.31	0.16	-	19.90	1.20	0.09	BDL	7.29	52.00	6.92	9.05	2.79	1.9	1.21	S
4-006	2/27/15	12:30	LD	3.39	0.24	0.27	0.13	-	16.50	0.70	0.04	BDL	7.93	45.00	6.73	10.81	3.26	1.9	1.31	PC
5-006	3/18/15	16:00	LD	3.10	0.22	0.27	0.14	-	11.90	1.30	0.03	BDL	8.18	44.00	17.40	9.63	2.63	2.25	1.24	C
7-006	4/28/15	2:00	LD	6.96	0.17	0.13	0.07	0.062	13.40	2.00	0.04	20.00	7.60	38.00	22.20	6.64	3.7	1.4	1.25	S
8-006	5/18/15	4:00	LD	3.66	0.13	0.10	0.10	0.066	15.20	3.30	0.14	20.00	7.68	49.00	27.36	7.91	3.42	1.3	1.21	C
			Min	3.10	0.13	0.02	0.05	0.062	11.90	0.70	0.03	13.30	6.05	38.00	6.73	6.6	2.6	1.2	1.2	
			Max	7.57	0.81	0.31	0.16	0.066	19.90	5.60	0.16	20.00	8.18	57.00	27.36	10.8	9.1	2.3	1.3	
			Avg	5.31	0.30	0.17	0.10	0.064	15.94	2.64	0.09	17.95	7.39	48.57	14.33	8.53	4.38	1.67	1.23	

LB was sampled during all monthly sample events, **Table 6.16**, and is located about 50 feet from the outlet structure at the dam and 1 meter off the bottom. The total depth at this location was about ~27 feet. Chlorophyll-a samples for the site averaged just above 5 µg/L in the mesotrophic range. Iron levels were relatively low until stratification and concentration went to a maximum of 4.62 mg/L. TP levels were in the hypereutrophic range, with a maximum of 0.67 mg/L in December. TSS levels were generally low and turbidity was similar to TSS, although, TSS increased during stratification. NH3 levels were fairly low until stratification, and levels increased sharply to 1 mg/L in May. Specific conductance also increased drastically during the stratification period when compared to other sites, which went from 50 µS/cm to a maximum of 117 µS/cm in May. DO levels started to decrease in March 2015 and by April 2015 the lake was stratified.

Table 6.17- Lake Bottom water quality data

Lab-ID	Date	Time	Site	CHL-a (µg/L)	Fe (mg/L)	NO3+NO2 (mg/L)	TP (mg/L)	SRP (mg/L)	COD (mg/L)	TSS (mg/L)	NH3 (mg/L)	Alk (mg/L)	pH	SC (µS/cm)	WT (M)	DO (mg/L)	Turb (NTU)	Stage (ft.)	W
1-006	11/22/14	11:45	LB	4.2	1.14	0.166	0.16		12.80	4.0	0.205	BDL	6.9	58	9.42	5.94	7.65	1.2	PC
2-008	12/16/14	13:50	LB	3.91	0.431	0.145	0.67		17.40	4	0.06	18.2	6.47	56	8.61	7.89	5.47	1.2	PC
3-007	1/21/15	10:45	LB	3.96	0.201	0.338	0.167		24.90	2	0.131	BDL	7.07	53	5.9	7.84	3.78	1.21	S
4-007	2/27/15	12:45	LB	4.029	0.32	0.307	0.107		13.90	1.33	0.048	BDL	8.55	45	5.89	9.59	2.84	1.31	PC
5-007	3/18/15	16:15	LB	4.23	0.336	0.241	0.154		13.00	1	0.23	BDL	9.04	46	6.9	5.86	2.1	1.24	C
7-007	4/28/15	2:20	LB	4.6494	1.99	0.128	0.109	0.044	11.5	7.5	0.554	30	7.03	80	8.49	0.11	1.75	1.25	S
8-008	5/18/15	4:50	LB	10.708	4.62	0.175	0.108	0.066	12.2	10.5	0.957	35	6.81	117	8.92	0.18	3.72	1.21	R
			Min	3.91	0.20	0.13	0.11	0.044	11.50	1.00	0.05	18.20	6.47	45.00	5.89	0.1	1.8	1.2	
			Max	10.71	4.62	0.34	0.67	0.066	24.90	10.50	0.96	35.00	9.04	117.00	9.42	9.6	7.7	1.3	
			Avg	5.09	1.29	0.21	0.21	0.055	15.10	4.33	0.31	27.73	7.41	65.00	7.73	5.34	3.90	1.23	

LL was sampled for the April and May events, **Table 6.18**, and was located just below the thermocline ~13.5 feet in depth. The total depth at this location was about ~27 feet. Chlorophyll-a samples for the site averaged just above 27 µg/L, in the eutrophic range with a maximum of 36 µg/L in May. Iron levels increased from April to May. TP levels were in the hypereutrophic range, with a maximum of 0.14 mg/L in December. TSS and turbidity increased from April to May. NH3 levels were fairly low for May and increased to 0.4 mg/L in May. Specific conductance also increased for the May sample, above the typical levels for the lake at 69 µS/cm. DO levels for both April and May were below 0.5 mg/L.

Table 6.18- Lake dam middle depth

Lab-ID	Date	Time	Site	CHL-a (µg/L)	Fe (mg/L)	NO3+NO2 (mg/L)	TP (mg/L)	SRP (mg/L)	COD (mg/L)	TSS (mg/L)	NH3 (mg/L)	Alk (mg/L)	pH	SC (µS/cm)	WT (M)	DO (mg/L)	Turb (NTU)	Stage (ft.)	W
7-009	4/28/15	2:30	LL	9.78	0.56	0.11	0.14	0.08	7.60	4.00	0.07	25.00	6.70	55.00	11.75	0.30	2.90	1.25	S
8-007	5/18/15	4:30	LL	35.76	1.35	0.18	0.12	0.07	16.60	9.00	0.43	30.00	6.50	69.00	13.72	0.42	8.80	1.21	C
			Min	9.78	0.56	0.11	0.12	0.07	7.60	4.00	0.07	25.00	6.50	55.00	11.75	0.30	2.90	1.21	-
			Max	35.76	1.35	0.18	0.14	0.08	16.60	9.00	0.43	30.00	6.70	69.00	13.72	0.42	8.80	1.25	-
			Avg	22.77	0.96	0.14	0.13	0.07	12.10	6.50	0.25	27.50	6.60	62.00	12.74	0.36	5.85	1.23	-

BL was sampled during all monthly sample events, **Table 6.19**, and is located just below the 48-inch drainpipe releasing from the lake. The depth at this location was unknown. TP levels were around 0.1 mg/L, which is considered fairly high for a stream. TSS levels were generally low and turbidity was similar to TSS. NH3 levels were fairly low throughout the whole study other than in May 2015. DO was always above state standards with the average reading of 10.68 mg/L. The higher DO average is due to aerated water falling from the drainpipe. BL data is very similar to LD data since it is the same water that drains over the weir and out of the pipe.

Table 6.19- Below lake water quality data

Lab-ID	Date	Time	Site	Fe (mg/L)	NO3+NO2 (mg/L)	TP (mg/L)	COD (mg/L)	TSS (mg/L)	NH3 (mg/L)	Alk (mg/L)	pH	SC (µS/cm)	WT (M)	DO (mg/L)	Turb (NTU)	Stage (ft.)	W
1-004	11/21/14	17:15	BL	1.23	0.12	0.10	18.10	4.80	0.16	14.00	7.24	59.00	10.04	9.60	9.26	1.20	PC
2-004	12/16/14	14:30	BL	0.32	0.12	0.18	15.10	5.20	0.12	15.80	7.25	56.00	9.63	11.37	4.44	1.20	PC
3-008	1/21/15	11:00	BL	0.19	0.37	0.16	18.00	1.20	0.07	BDL	7.40	53.00	7.04	11.50	2.90	1.21	S
4-008	2/27/15	13:15	BL	0.26	0.30	0.12	14.00	0.70	0.05	BDL	7.83	46.00	6.59	13.00	2.88	1.31	PC
5-008	3/18/15	16:30	BL	0.22	0.24	0.17	14.60	2.00	0.03	BDL	8.08	21.00	16.91	10.64	3.24	1.24	C
7-008	4/28/15	3:00	BL	0.18	0.15	0.12	10.10	1.00	0.11	15.00	7.44	44.00	22.63	8.27	4.18	1.25	S
8-009	5/18/15	4:15	BL	0.09	0.14	0.09	16.40	0.30	0.38	20.00	7.40	50.00	27.40	10.40	3.46	1.21	R
			Min	0.09	0.12	0.09	10.10	0.30	0.03	14.00	7.24	21.00	6.59	8.27	2.88	1.20	
			Max	1.23	0.37	0.18	18.10	5.20	0.38	20.00	8.08	59.00	27.40	13.00	9.26	1.31	
			Avg	0.36	0.21	0.13	15.19	2.17	0.13	16.20	7.52	47.00	14.32	10.68	4.34	1.23	

6.5 Depth Profiles

Depth profiles were sampled in multiple locations around the lake to determine the extent of the anoxic conditions during stratification of April and May lake sample events. Specific conductance, pH, and temperature data were also gathered, although, the pH sensor was determined to be faulty and in need of replacement. The pH data for the depth profiles was discarded. Sampling increments were every meter until we reached the bottom of the lake at each sample location.

A total of 7 sites were sampled around the lake. **Figures 6.12-6.24** include all the data gathered at each location. It can be seen that specific conductance data increases with depth at each stratified location, while it remained similar in the mixed zones. Temperature decreased with depth similarly at each location.

The anoxic zone at each location started around 2.5-3 meter, in which dissolved oxygen fell towards anoxic conditions. Sample locations more shallow than 3 meters were fully mixed. Based on the data, it was concluded any depth below 3 meters could be considered anoxic when the lake is stratified. This data correlates with historical dissolved oxygen data of Lake Oglethorpe and confirms the location of lake aeration diffusers.

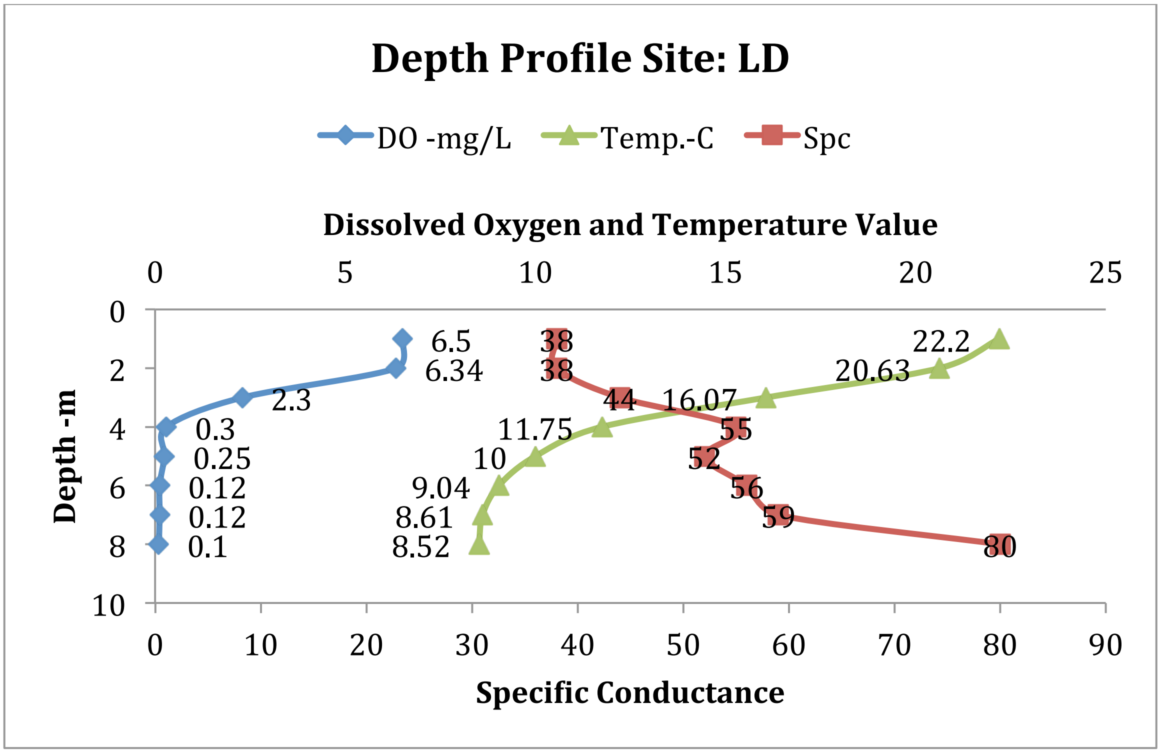


Figure 6.12: Lake Dam site depth profile sampled April 28, 2015

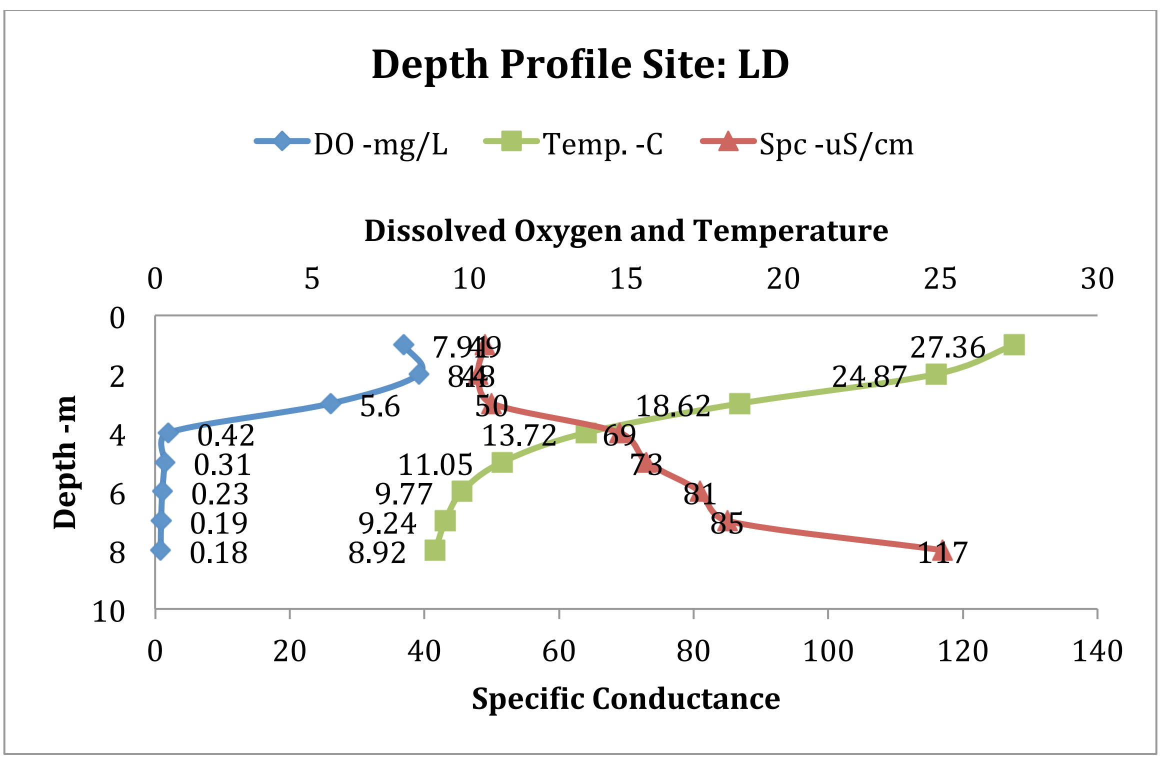


Figure 6.13- Lake Dam site depth profile sampled May 18, 2015

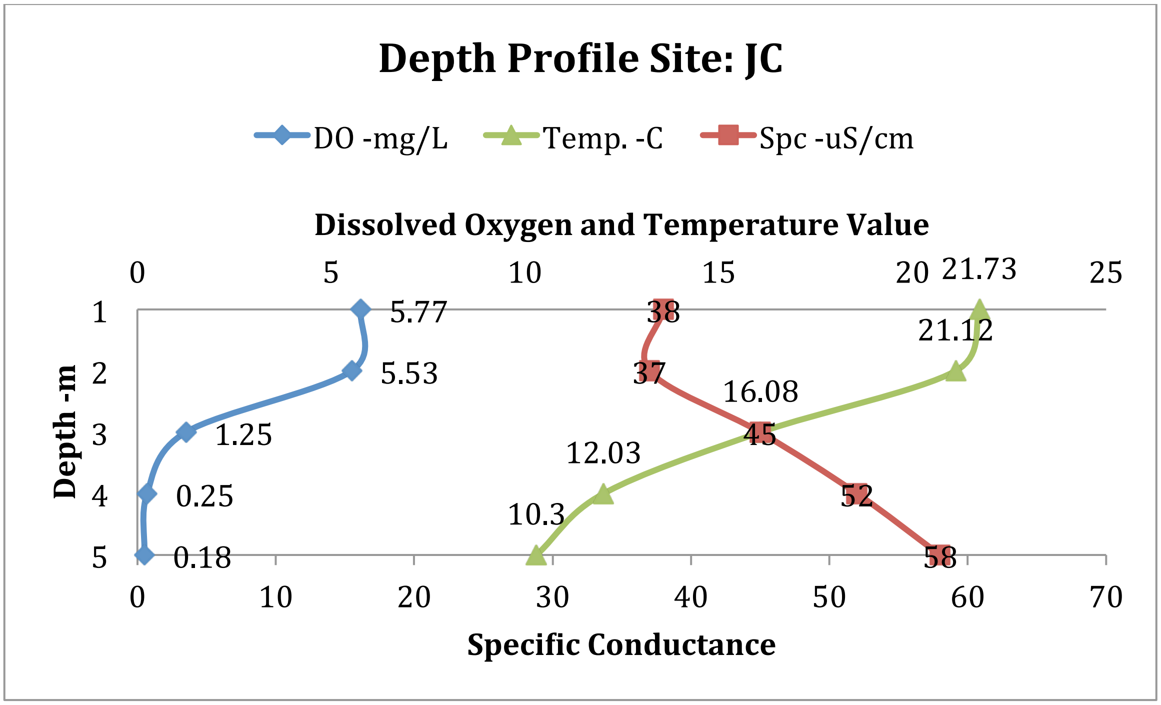


Figure 6.14: Johnson Cove depth profile sampled April 28, 2015

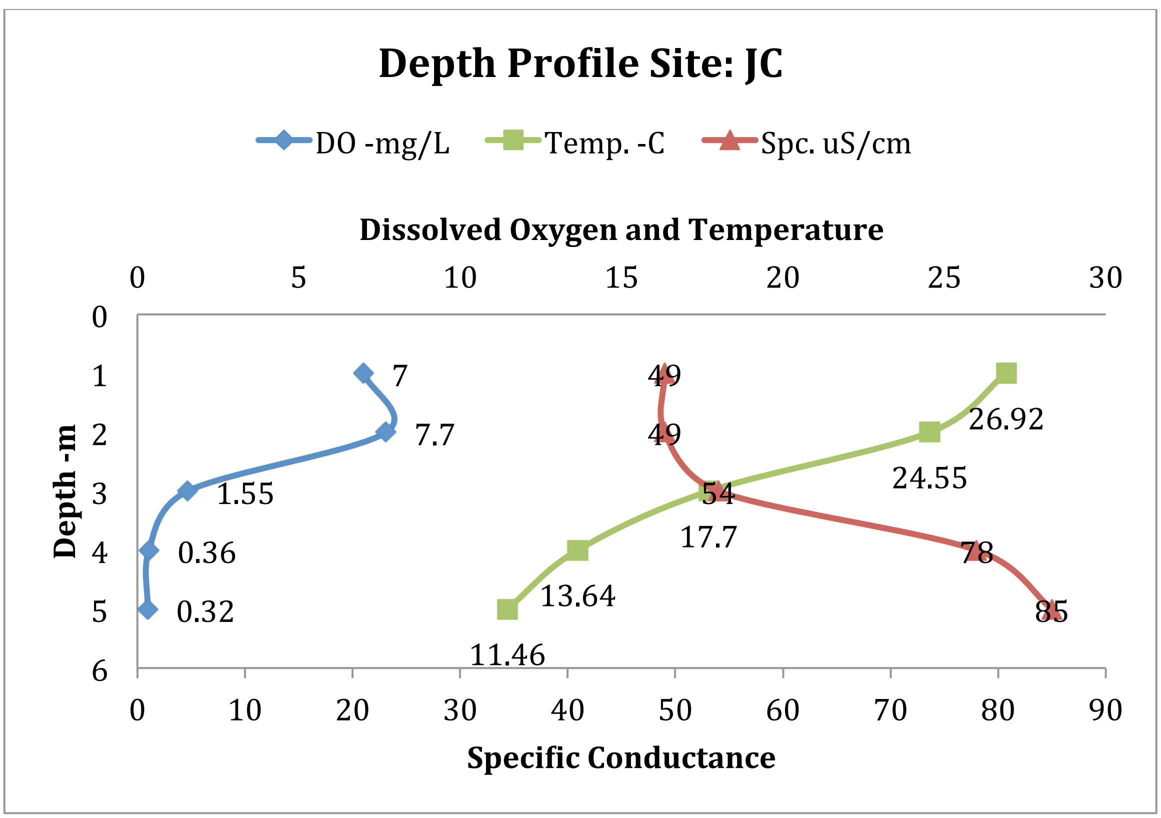


Figure 6.15: Johnson Cove site depth profile sampled May 18, 2015

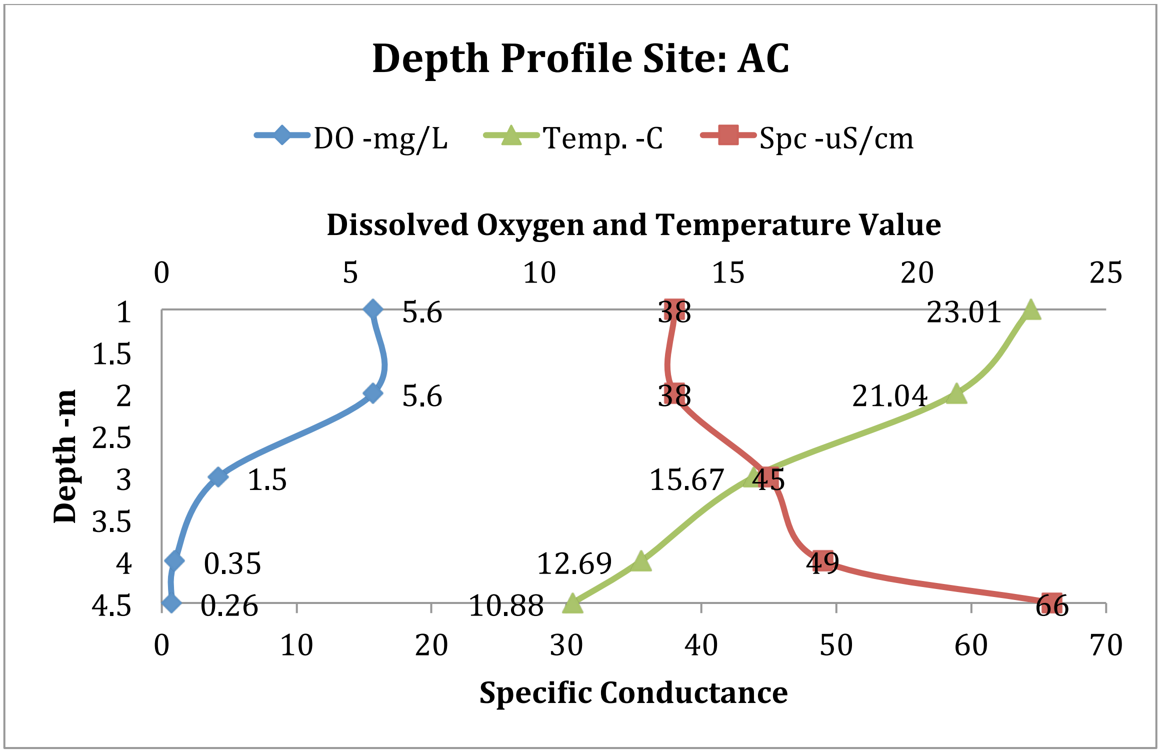


Figure 6.16: Athens Cove depth profile sampled April 28, 2015

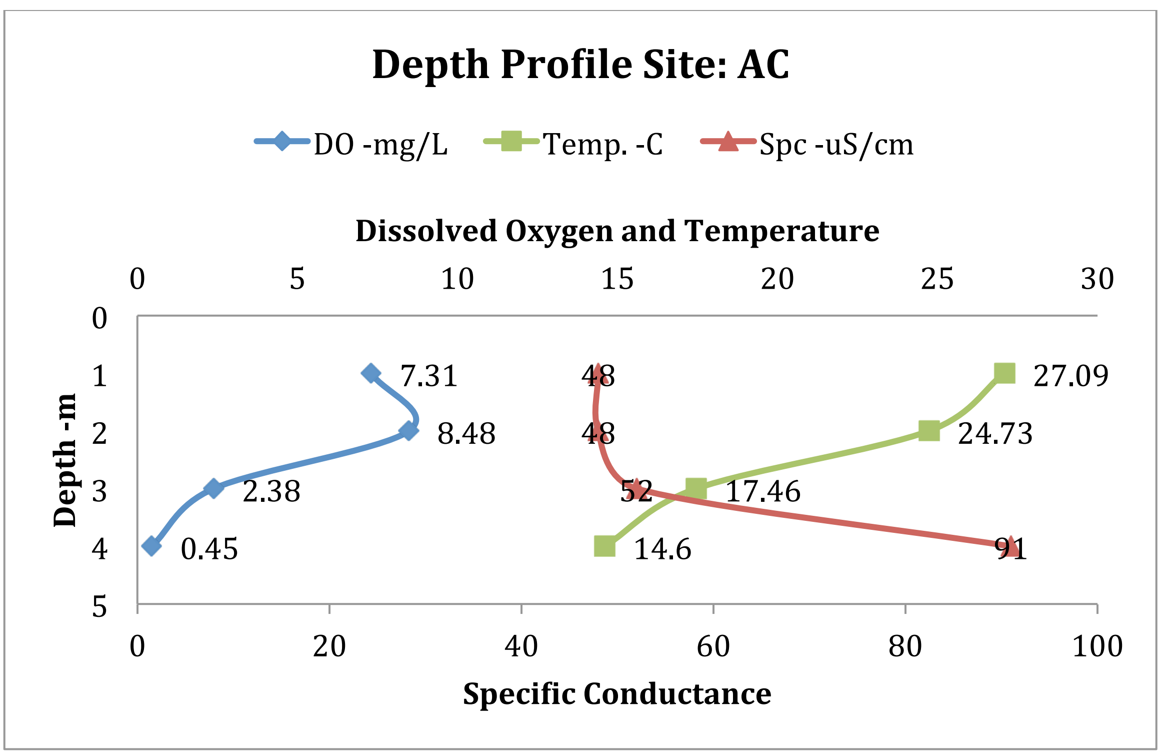


Figure 6.17: Athens Cove site depth profile sampled May 18, 2015

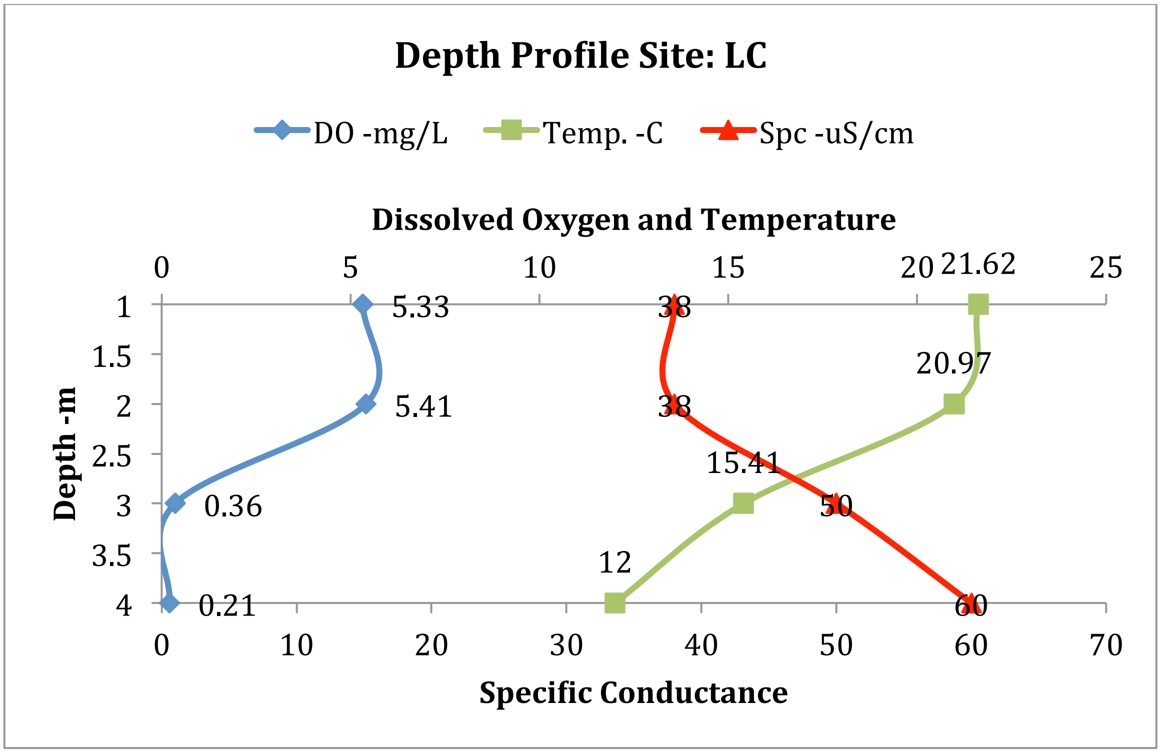


Figure 6.18- Lake Center depth profile sampled April 28, 2015

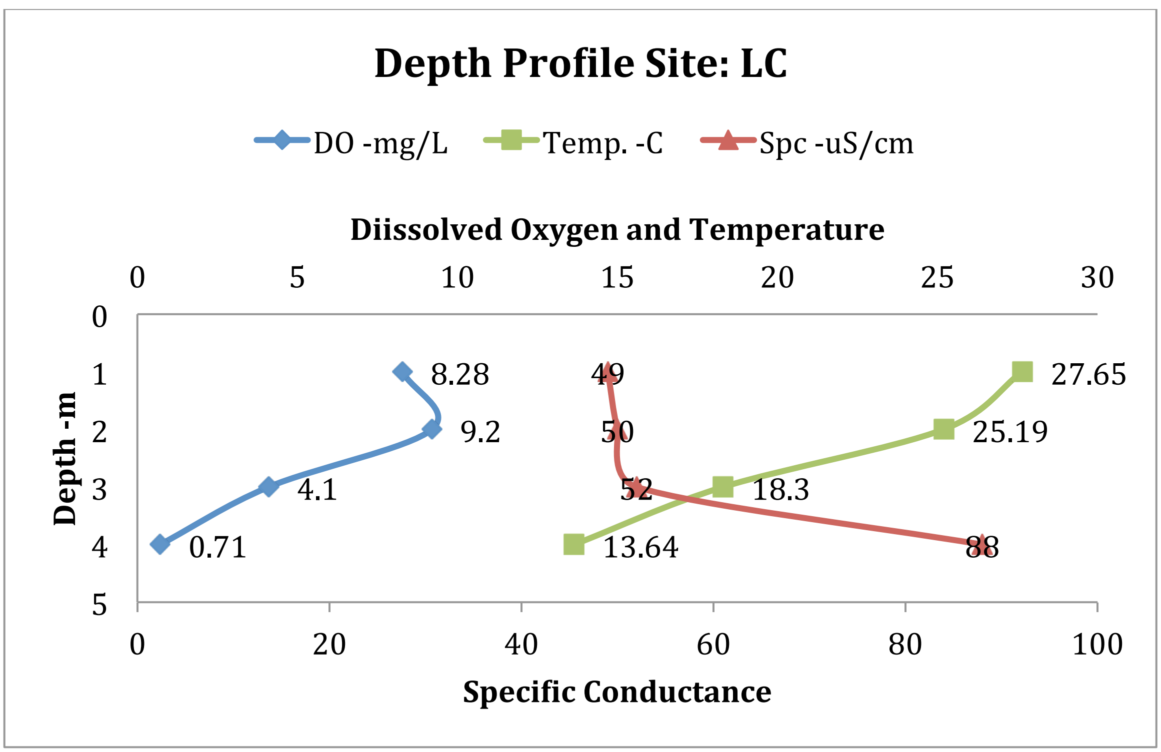


Figure 6.19: Lake Center depth profile sampled May 18, 2015

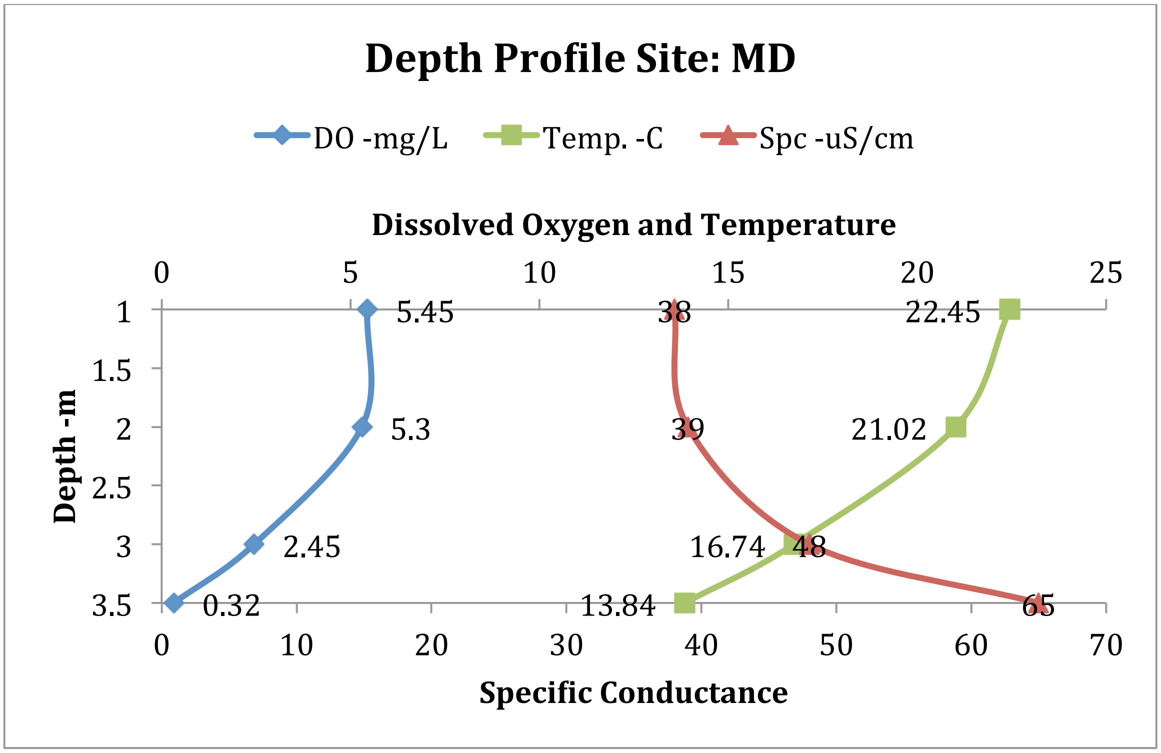


Figure 6.20- Middle Depth lake site depth profile sampled April 28, 2015

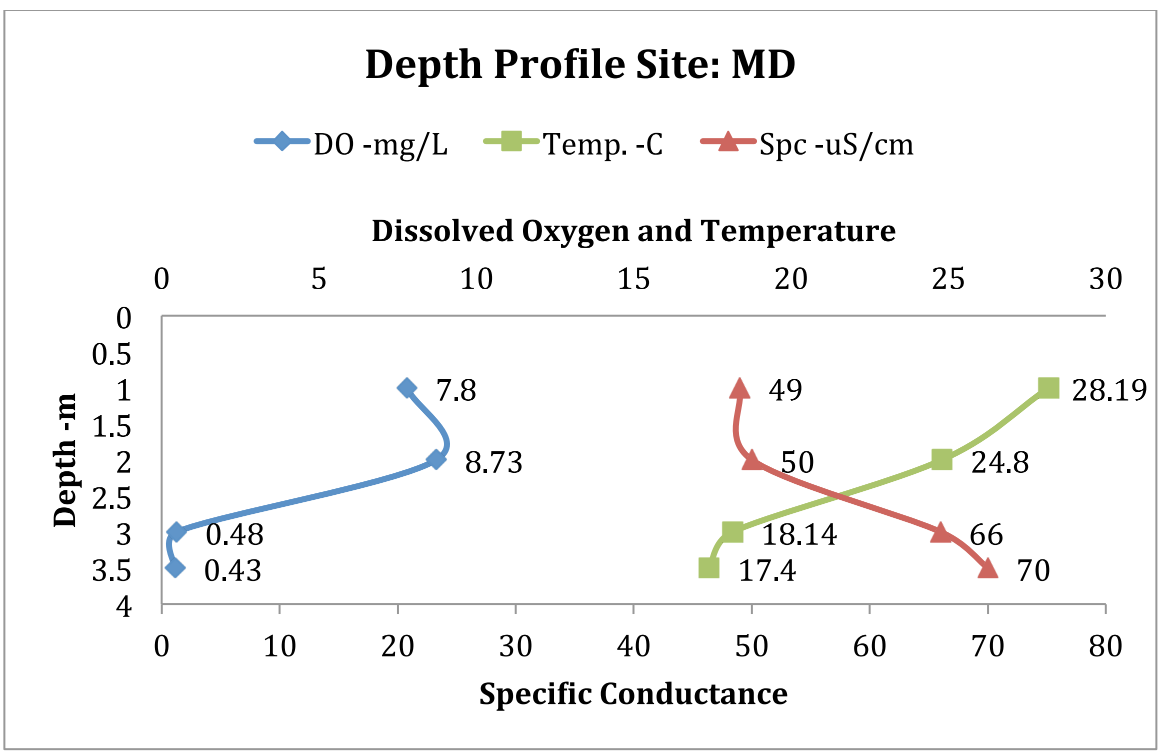


Figure 6.21- Middle depth lake site depth profile sampled May 18, 2015

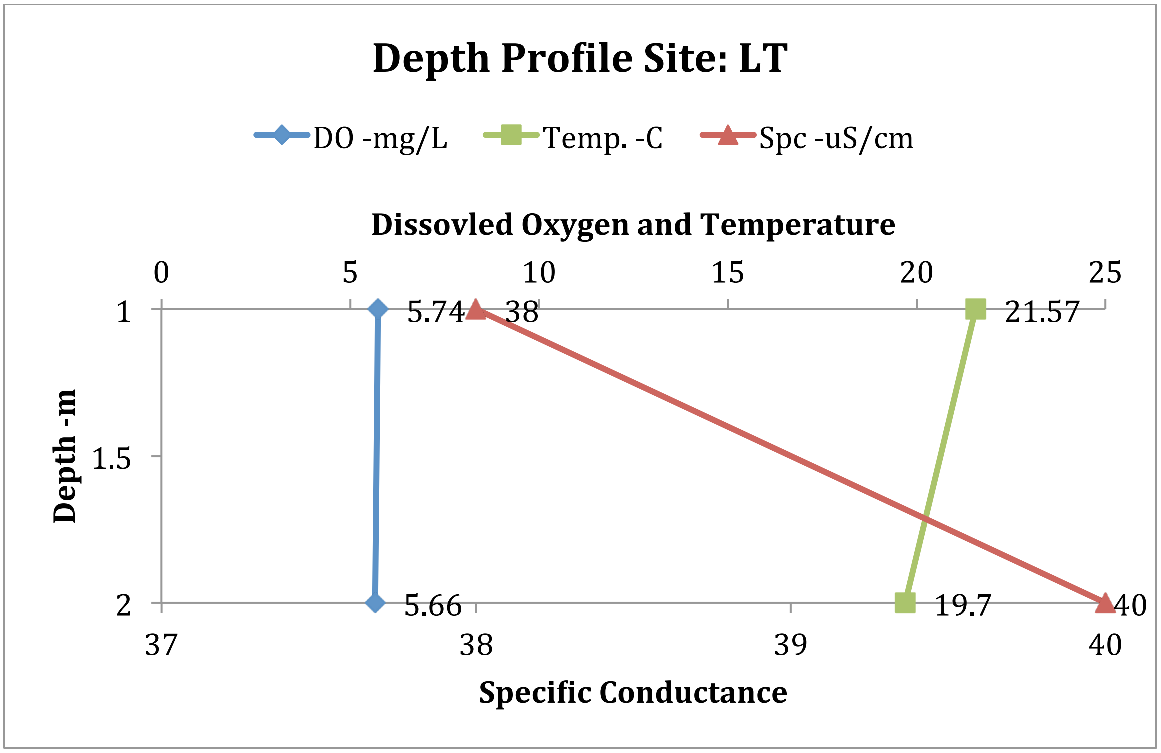


Figure 6.22- Lake Transition depth profile sampled April 28, 2015

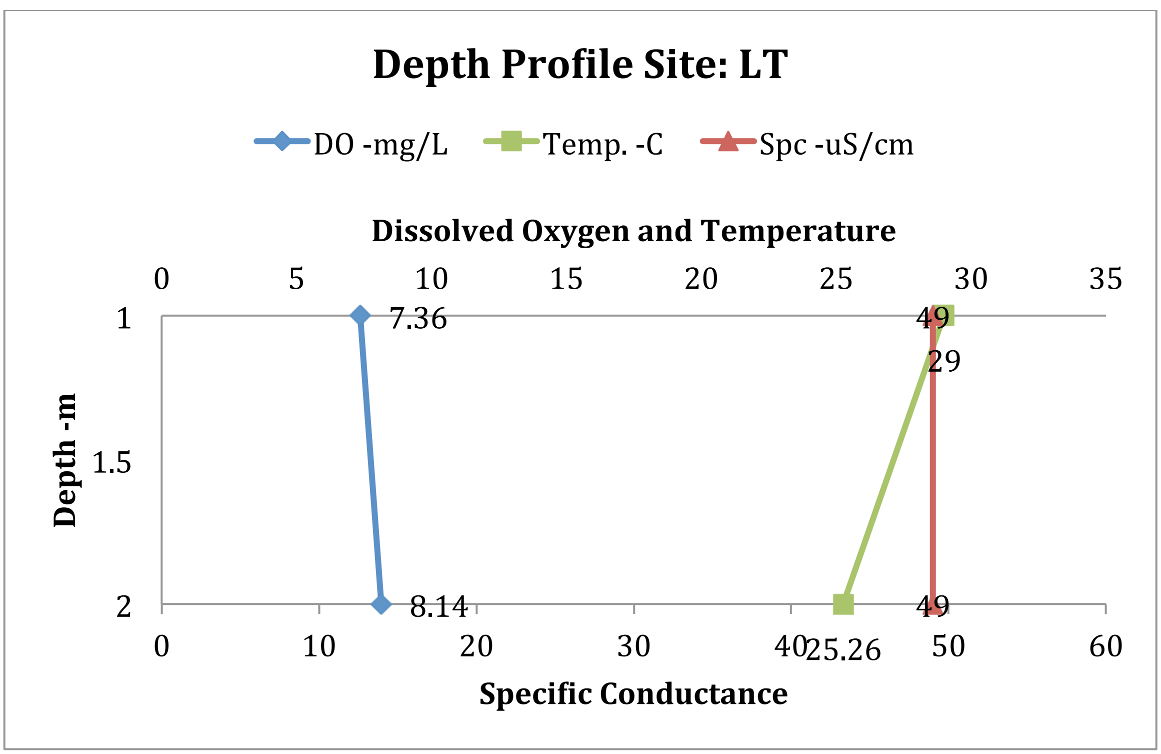


Figure 6.23- Lake Transition depth profile sampled May 18, 2015

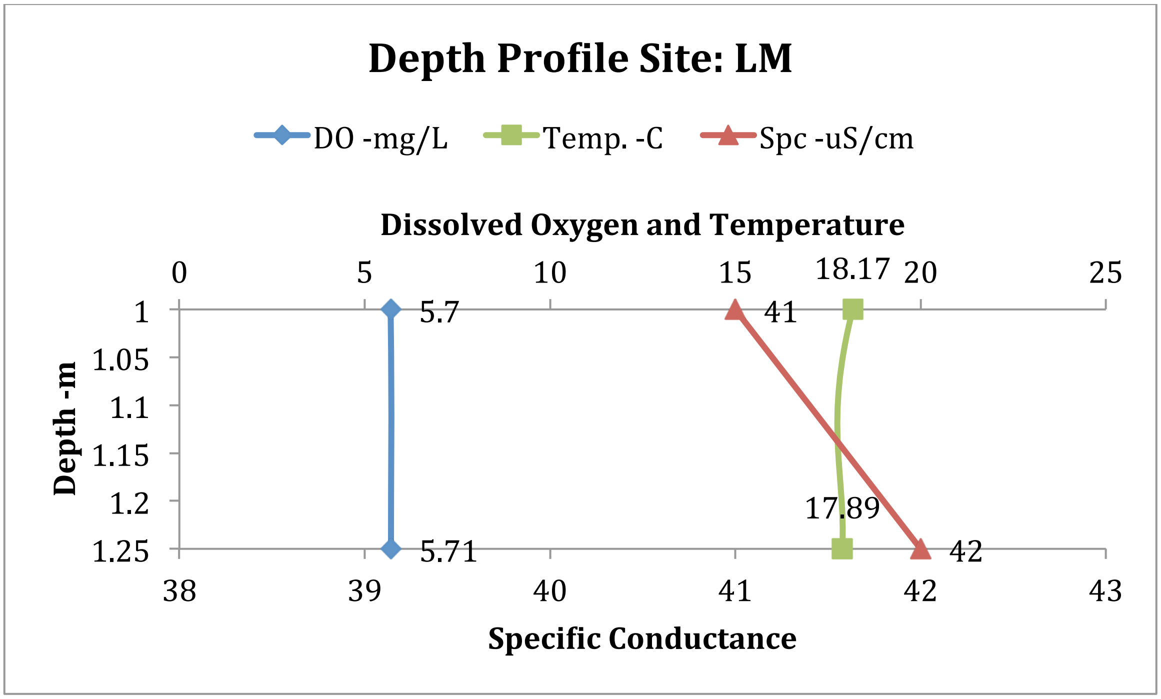


Figure 6.24- Lake Mouth depth profile sampled April 28, 2015

6.6 Soils and Lake Sediment

The soils within the Lake Oglethorpe catchment were sampled over a weeklong period during the end of March 2015 and beginning April 2015. The catchment areas included NE1, East Creek, West Creek, E1, E2, SE1, SE2, SE3, SW, NW1, and an old mill site. All soil sample sites before the composite samples can be seen in the Appendix. A total of 52 subsamples were taken in the catchment with GPS points located in the **Figure 6.25**. For most of the analyzed samples, 2 subsamples were combined and then all samples for each small catchment were averaged. The zones with higher TP included East E (87 lbs/acre), E1A (198.3), E1C (407.3 lbs per acre), E2A (203 lbs/acre), SE1B (128 lbs/acre), SE3B (67 lbs/acre), and West B (76 lbs/acre). Catchment area averages can be found in **Table 6.20**, including many different parameters. The parameter of most concern was total phosphorus and a bar graph comparing averages can be viewed in **Figure 6.26**.

Table 6.20- Soil data catchment averages

Averages				%	meq/ 100g	Mehlich 1 lbs/acre													
Site	LBC [1] (ppm $CaCO_3$/ pH)	pH $_{CaCl2}$ [2]	Equiv. water pH	Base Saturation	CEC	Ca	Cd	Cr	Cu	Fe	K	Mg	Mn	Mo	Na	Ni	P	Pb	Zn
NE	595.0	9.1	5.1	37.6	10.3	1019.0	0.1	0.1	1.6	77.1	168.3	250.9	36.4	0.1	14.8	0.7	5.0	2.0	6
East	445.8	4.7	5.3	41.7	7.8	822.7	0.1	0.1	3.8	30.9	294.2	200.9	48.5	0.1	18.9	0.4	26.9	1.8	5
E1	500.3	5.2	5.8	71.1	12.0	2354.8	0.1	0.1	11.1	46.3	497.9	498.8	57.4	0.1	43.5	0.8	212.7	1.0	29
E2	460.0	4.7	5.3	48.4	9.8	1416.4	0.1	0.1	6.4	54.5	425.0	287.6	28.7	0.1	21.0	0.4	114.6	1.6	18
SE1	371.0	5.0	5.6	64.3	8.9	1617.2	0.1	0.1	3.4	40.7	285.3	334.9	28.2	0.1	16.4	0.3	67.1	1.2	10
SE2	508.0	4.5	5.1	47.3	10.9	1439.7	0.2	0.2	9.8	33.6	225.7	333.5	58.9	0.2	15.5	0.4	27.6	1.4	12
SE3	414.0	5.0	5.6	62.9	9.7	1743.0	0.1	0.1	4.7	45.7	324.5	384.7	33.3	0.1	26.5	0.7	43.9	1.4	25
SW	401.0	4.7	5.3	51.5	8.4	1130.9	0.1	0.1	3.6	61.0	264.7	264.4	29.4	0.1	25.8	0.4	16.5	1.2	8
West	396.2	4.5	5.1	37.1	7.0	693.6	0.1	0.1	4.7	93.8	112.4	146.2	34.2	0.1	15.3	0.2	24.4	3.2	6
NW	494.0	4.2	4.8	30.8	9.2	660.2	0.1	0.1	1.1	89.4	325.5	184.3	30.2	0.1	15.1	0.4	7.8	2.2	31
Mill	979.0	5.8	6.4	91.8	42.7	15251.8	0.3	0.3	2.7	334.5	114.0	198.5	101.1	0.3	35.3	1.6	25.8	1.1	18
Total	505.8	5.2	5.4	53.1	12.4	2559.0	0.2	0.2	4.8	82.5	276.1	280.4	44.2	0.2	22.5	0.6	52.0	1.6	15

According to the Soil Test Handbook of Georgia for agronomic crops, phosphorus levels may be categorized by low (0-20 lbs./acre), medium (21-40 lbs./acre), high (41-75 lbs./acre), and very high (75+ lbs./acre). Averages of phosphorus in catchments E1 and E2 are in the very high range when considering grassland crop type in the piedmont soil type region. They are also well above the total average of phosphorus for the entire watershed of the lake. A value in excess of 75 lbs./acre of phosphorus is considered to be an overload of nutrients and can have negative water quality impacts associated with it. Of the 5 samples taken from catchments E1 and E2, 3 were more than twice the minimum amount of the VERY HIGH range. These can be seen in the **Appendix**.

Focusing on catchment E1 in **Table 6.21,** data collected before litter application in different areas, reveal phosphorus levels are high to very high before litter application in March. It is important to note levels in the high range have less of an impact on water bodies. When there is over application, phosphorus can accumulate to very high levels. However, it is also important to note that phosphorus is removed in the form of hay from pastures in E1.

Table 6.21- Soil sampling data from October 2014

EAST 1 SITE										
Sample ID	**Date**	**P (lbs/acre)**	**K (lbs/acre)**	**Ca (lbs/acre)**	**Mg (lbs/acre)**	**Zn (lbs/acre)**	**Mn (lbs/acre)**	**pH (lbs/acre)**	**LBC**	**Observation**
11661	10/16/14	41	173	1369	241	10	83	5.7	357	Cloverleaf
15385	11/12/14	33	148	537	116	8	16	5.2	273	Hay field --bottom dredged dirt
15386	11/12/14	62	227	1302	233	9	29	6	261	Hay field--above lake dirt area
15387	11/12/14	91	235	2071	195	15	30	6.3	323	Hay field--near saw mill pile

It is recommended the hay farmers develop nutrient management plans for the hay fields around the lake. Very helpful information about developing plans is available on the AWARE website (Animal Waste Awareness in Research and Extension). A local county agent should also be able to help assess the P Risk Index for the hay fields.

Timing is the key for successfully applying fertilizer to maintain crop yield, while also having a minimum impact on water quality. Soil should be tested annually as phosphorus levels can change from year to year. It is recommended that fertilizer not be applied in the rainy season from November to March when excess nutrients can easily enter the lake through stormwater runoff events. If possible, it's best to apply when rain events are less intense and have shorter duration, enough to allow fertilizer to soak into the ground but not runoff as overland flow. This also applies to homeowners when they are fertilizing their lawns.

Lake sediment samples, **Table 6.22**, were analyzed for the same parameters of the soil samples, but from lake sediment at locations LM, LC, and LD. Sediment samples were also analyzed for additional parameters, including NH4, NO3, NO2, and Organic Matter content. The Fe:P ratio to possibly control lake surface sediment is recommended around 15. Within Lake Oglethorpe the Fe:P ratios are 74.8, 104.8, and 160.8 for sites LD, LM, and LC. Unfortunately, a sediment core sampler was not available to determine more helpful parameters.

Table 6.22- Lake sediment laboratory analysis results

					%	meq/ 100g	Mehlich 1 lbs/acre													
Lab	Samp	LBC [1] (ppm $CaCO_3$/ pH)	pH $_{CaCl2}$ [2]	Equiv. water pH	Base Saturation	CEC	Ca	Cd	Cr	Cu	Fe	K	Mg	Mn	Mo	Na	Ni	P	Pb	Zn
61401.0	LD	1232.0	4.4	5.0	17.6	17.8	810.0	0.3	0.7	9.1	5122.0	198.0	174.0	2364.0	<.1	55.8	2.2	68.4	9.8	25.1
61402.0	LM	1421.0	4.1	4.7	18.4	23.1	1236.0	0.4	1.1	9.9	3986.0	224.2	175.0	416.0	<.1	64.0	2.8	38.0	5.5	27.9
61403.0	LC	1674.0	4.4	5.0	30.2	27.7	2076.0	0.4	1.5	14.0	4690.0	476.8	531.0	912.0	<.1	153.2	3.5	29.2	7.3	34.1

		lbs/acre			%
Lab	Samp	NH_4-N	NO_2-N	NO_3-N	OM [3]
61401	LD	277	<0.33	<0.33	9.87
61402	LM	104	<0.31	<0.31	7.99
61403	LC	79	<0.34	<0.34	8.33

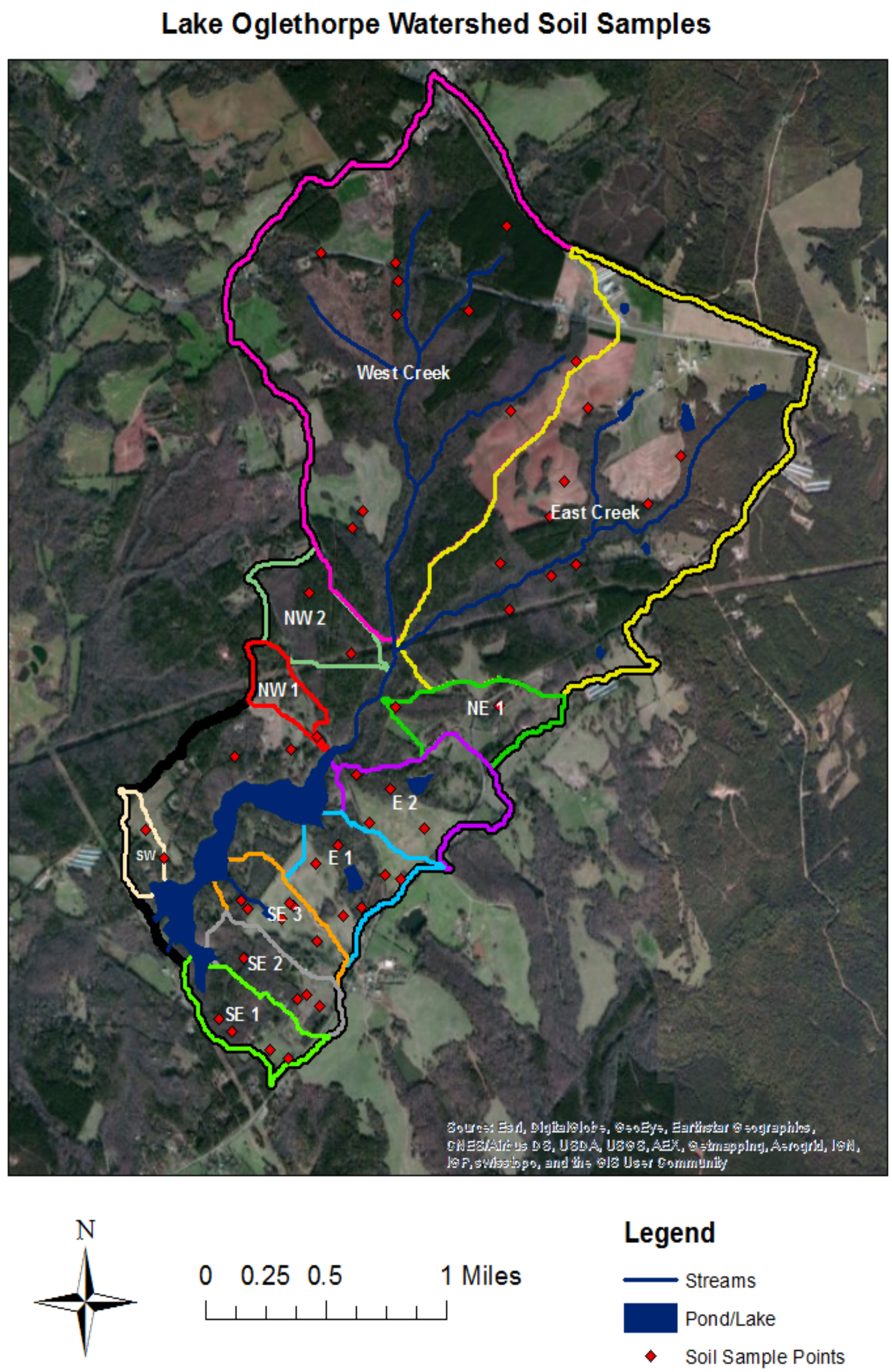


Figure 6.25- Soil Sampling sites

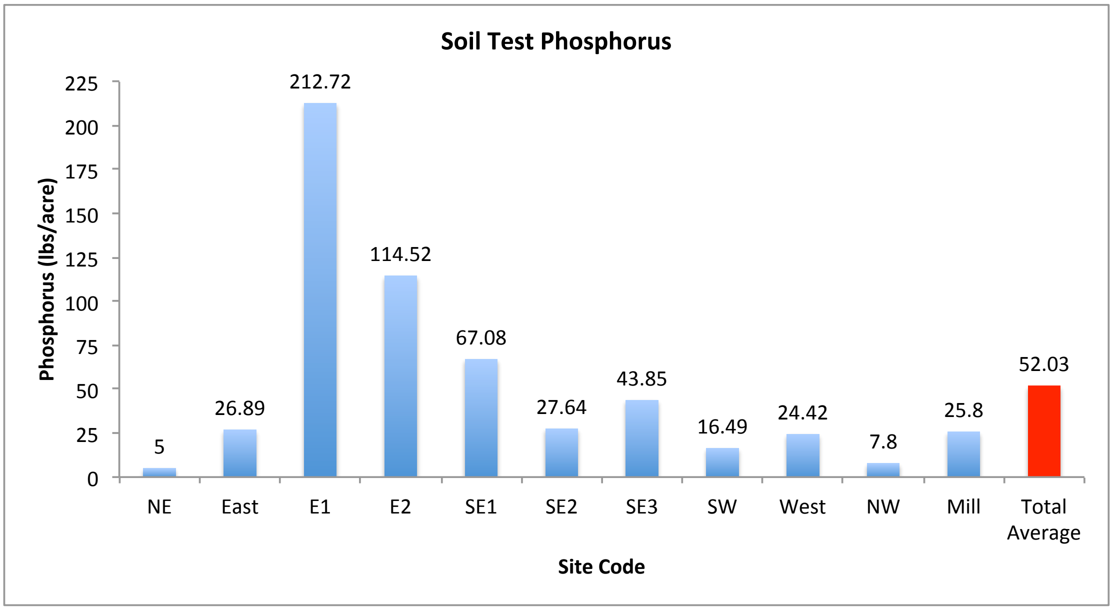


Figure 6.26- Total phosphorus for each catchment area

7.0 Possible Solutions

With the nutrient concentrations present in the lake, action is necessary if the goal is to prevent continual large algal blooms from further hindering recreation. It is important to remember that no matter the decision made by the LOA, steps should be taken in the future to try and reduce high nutrient concentrations from getting into the lake. It also important to realize land management alone will not fix the problem due to internal nutrient loading of the lake. The more promising approach is to make affected waters less hospitable for CHAB (Cyanobacteria harmful algal blooms) by 1) altering the hydrology to enhance vertical mixing and/or flushing and 2) decreasing nutrient fluxes from organic rich sediments, phosphorus adsorption, physically removing the sediments or capping sediments with clay. Effective future lake management approaches must incorporate both N and P loading dynamics within the context of altered thermal and hydrologic regimes associated with climate change. Widely used means of controlling algal blooms include: dredging, chemical treatment, and aeration (**Table 7.1**). Methods of aiding in the reduction of excess nutrients are constructed and floating wetlands, along with vegetative buffers that restrict direct runoff into the lake

Table 7.1- Lake Remediation Techniques

Method	Description
Dredging	• Removal of most in-lake sediment nutrient sources (~2 feet) • Sediment disposal is an environmental issue • Long term solution • Very Expensive
Artificial de-stratification	• Increases the circulation of water between deeper and shallower parts of a water body (destratification) • Short-term solution • Installs a propeller or impeller in or near a dam wall • Introduces a plume of bubbles near the bottom of the water body • Starves algae of nutrients and sunlight
Phosphorus precipitation	• Reduces the availability of phosphorus that algae can consume • Short-term solution • Only uses a low dose of chemicals to provide temporary control of algae
Phosphorus inactivation	• Reduces the availability of phosphorus that algae can consume • Long-term solution • Uses as much amount of chemicals as possible within the limits of environmental regulations

Method	Description
Algaecides	• Chemicals that are toxic to and kill algae • Short-term/emergency solution • Releases toxins from the cells of algae when they die • Can kill other plants and animals due to a reduction in the concentration of oxygen
Biomanipulation	• Introduces predatory fish that remove fish that eat zooplankton • Increase in zooplankton can lead to a decline in blue-green algae • Introduces aquatic plants that compete with algae for nutrients and light
Catchment Area Management	• Construction of an artificial wetland system upstream of a water body • Plant trees or shrubbery around the area adjacent to a water body • Prevent the use of fertilizers around a water body • Fence off waterways to prevent farm animal access in the catchment area around a water body • Long-term management

7.1 Dredging

Dredging is the process of removing bottom sediments and associated nutrients and transferring them to a new location. Limnology expert Dr. Amy Rosemond of the UGA School of Ecology recommended the dredging method. Dr. Rosemond believes it best to remove all of the organic matter causing the algal problems in the lake. Dredging can be done underwater, negating the need to drain the lake. There are two basic methods for dredging: hydraulic and mechanical. Mechanical dredging involves the use of heavy machinery, such as an excavator. The excavator removes sediment by reaching to the lake bottom and scooping the sediment out. Hydraulic dredging uses a pump to move solids via pipeline to a desired location. This method is not as limited by depth as mechanical dredging, as sometimes an excavator cannot reach to greater depths. After the sediments are removed, they can either be hauled away or used nearby, possibly as a field dressing. A small portion near the mouth of Lake Oglethorpe was previously dredged and placed in an adjacent field.

Dredging plans for the lake would include removing a set volume of solids, in cubic yards, from the bottom of the lake. Two bathymetric maps were obtained for Lake Oglethorpe, one being from the present and the other from 1989. In comparison, it seemed that roughly two feet of sediment had accumulated in the lake over the previous 25 years. Being that the data represented only about half of the lake's history, it was concluded that another two feet may have accumulated before the 1989 bathymetric map was recorded. Much of this material has likely gone through chemical changes and it is probable that only the top foot of sediment would need to be removed.

After speaking with a contact from River Sand Incorporated, a company with years of experience in both hydraulic and mechanical dredging, it was understood that a lake of this size typically needed no more than 100,000 cubic yards of sediment dredged. The contact, John Bryant, also stated that the volume could actually be even less, and that it would take core sampling to develop an exact depth. Core sampling may also narrow the prospective dredging area, as they would be able to pinpoint which areas of the lake needed to be dredged and which areas did not. He suggested a hydraulic dredge be used. The sediment dredged from the lake would have to be disposed of in some manner. Hauling the material away from the site would be the most effective method, but would greatly increase the cost. If the sediment can be used on site, say as composted material, with provisions to prevent it being reintroduced to the lake, the cost would be much lower. This would also depend on the results of sediment analysis and toxicity.

Environment dredging, unlike navigation and construct dredging, is a technique used to remove contamination from targeted areas in lakes (*Environmental Dredging*). It requires the use of very precise technology and "is designed to minimize re-suspension of small sediment particles that may be contaminated with PCBs, heavy metals, or other toxic materials. Because environmental dredging must be precise and controlled, technologies like hydraulic dredges are commonly used. The core purpose of environmental dredging, which is to remove contaminated sediment from a water body, makes it unlikely that dredging Lake Oglethorpe will result in the discharge of dredged or fill material into the lake itself and, thus, unlikely that the LOHA will have to obtain a §404 permit.

However, if sediment analysis shows that toxicity is of concern, environmental dredging will require the LOHA to dispose of the contaminated sediment that is removed from Lake Oglethorpe. Disposal of dredged material into a water of the U.S. requires a §404 permit under the CWA. At first glance, it seems that the LOHA can avoid obtaining a §404 permit by disposing of the dredged material at an upland confined disposal facility (CDF) as opposed to disposing of the dredged material into open water on the coast. CDFs are engineered structures that are designed to manage contained sediments (CDF 2000). It is certainly more practical for the LOHA to dispose of the material at an upland

CDF since Oglethorpe County is hours away from the coast. Disposal of dredged material at an upland CDF will not require the LOHA to obtain a §404 permit under the CWA unless that CDF is a fill created in the waters of the U.S (CDP 2012).

According to John Bryant, costs for dredging range from $10 per cubic yard minimum to $30 per cubic yard maximum (Bryant 2015). If sediment is kept on site, it would be closer to the minimum end of the scale, where-as hauling it away pushes toward the maximum end of the scale. For a rough estimate, Bryant recommended using $15 dollars per cubic yard. Using Bryant's estimate from experience, the cost would be near $1.2 million, but could be upwards of $1.5 million for material disposal. We recommend that core sampling be performed on the lake by a professional dredging service to provide a more accurate quote, if the HOA prefers this method. Removal of loose sediment and associated nutrients though hydraulic dredging as recommended in the lake is projected to extend the life of the lake by another 40 years, as if it had just been impounded.

7.2 Aeration

Artificially induced mixing of hypoxic water bodies holds value in eutrophication control. Typical circulation techniques can be broken down into two categories: destratification, in which water or air is forced into the bottom of the water column, thereby encouraging mixing and destroying the temperature gradient, and hypolimnetic aeration, where water is removed, aerated and returned to its original depth. The latter aims to actually inhibit mixing and preserve the natural biochemical cycling of the water body (McNeary 2013). As many of these setups use pneumatic technologies, the associated capital costs and energy consumption rates are quite high, which limits the applicability of artificial circulation to smaller inland water bodies.

Artificial mixing of lakes and ponds, by air bubbling or other mixing devices, enhances vertical mixing of the phytoplankton, and counters formation of surface blooms of buoyant cyanobacteria. Additionally, by oxygenating the hypolimnion, redox sensitive internal loading of P from the sediments is often reduced.

Horizontal flushing, by increasing the water flow through lakes or estuaries, reduces water residence time, thus providing less time for the development of cyanobacteria blooms. In small reservoirs, turbulence generated by bed roughness also increases with higher flow velocities and the resultant natural vertical mixing can disrupt or prevent stratification and surface blooms of CHABs. While these hydrologic manipulation efforts can yield positive results (decreased CHAB intensity), hydrologic changes can be quite expensive and restricted to relatively small water bodies, and freshwater supplies for flushing may be limited.

After reviewing the results of the UGA Limnology sampling, along with the results from monthly sampling and storm sampling, it was decided that de-stratifying the lake would be an incremental part of increasing dissolved oxygen (DO) levels in Lake Oglethorpe. This would allow for the iron present in the lake to retain its chemical bond with P and help to combat the pervasive algal blooms. By placing diffusers at the bottom of the lake, microbubbles travel up through the stratified layers. This helps to stir the entire lake, which results in higher DO, lake-wide mixing of nutrients (which prevents one large release), and can lead to an increase in fish population over time.

When used in conjunction with flocking agents such as alum, aeration has produced remarkable results in case studies, particularly in the Bahia Del Mar Lake in St. Petersburg, Florida (Lake Restoration 2015). Vertex Water Features, our primary contact for designing an aeration system, directed the Bahia Del Mar project. By adding diffusers at various points around the lake and using subsequent treatments of alum, oxygen levels at the bottom of the lake increased from 0 mg/L to 8 mg/L, bottom water phosphate levels decreased by 99%, and there was a 72% reduction in algal abundance over an 11-month period To estimate the compatibility of Lake Oglethorpe with their systems, Vertex used the results from water tests of the lake collected over the past 6 years, along with bathymetric mapping, to create a design specific to this lake.

Aeration design is based upon many factors, including water depth, shape of the lake, acreage, availability of power sources, and water quality. Because Lake Oglethorpe is relatively large, long, and narrow, with only one power source located near the dam, it may be necessary to add more power outlets near the middle and top of the lake to reduce the amount of tubing needed. As the concentrations of phosphorus increase and concentrations of DO decrease as depth increases, placing the diffusers in the deepest areas of the lake is the best option to produce the desired results. Similarly, spacing diffusers along the length of the lake keeps the water column well-mixed and oxygenized

Figure 7.1 shows the diffuser layout created for us by Vertex Water Features. They recommended 24 AirStations™ powered by 3 Large Lake Compressors, delivering 60 cfm of air to the lake. Because 2 designs were requested – one displaying 1 power source and a second displaying 2 power sources –Vertex also sent a length comparison of how much tubing would be needed for each design, with a total difference of 9,300 feet (See Table 7.1). Due to the added cost of tubing that would be required for the design with one power source, we recommend that the HOA consider adding a second power source to reduce overall costs.

Table 7.2- AirStation Coordinates and Bottom Line Tubing Length with One or Two Power Locations.

Lake Oglethorpe										
Two power locations						One power locations				
AirStation #	Latitude	Longitude	Tubing Length ft	Depth ft		AirStation #	Latitude	Longitude	Tubing Length ft	Depth
1	33°51'55.31"N	83°13'59.53"W	250	26		1	33°51'55.31"N	83°13'59.53"W	250	26
2	33°51'54.28"N	83°13'58.56"W	350	26		2	33°51'54.28"N	83°13'58.56"W	350	26
3	33°51'56.13"N	83°13'58.06"W	400	25		3	33°51'56.13"N	83°13'58.06"W	400	25
4	33°51'55.27"N	83°13'57.98"W	400	24		4	33°51'55.27"N	83°13'57.98"W	400	24
5	33°51'54.22"N	83°13'56.89"W	500	24		5	33°51'54.22"N	83°13'56.89"W	500	24
6	33°51'53.09"N	83°13'56.25"W	600	23		6	33°51'53.09"N	83°13'56.25"W	600	23
7	33°51'55.33"N	83°13'56.39"W	550	24		7	33°51'55.33"N	83°13'56.39"W	550	24
8	33°51'57.26"N	83°13'58.04"W	450	23		8	33°51'57.26"N	83°13'58.04"W	450	23
9	33°51'58.65"N	83°13'58.81"W	500	23		9	33°51'58.65"N	83°13'58.81"W	500	23
10	33°52'0.40"N	83°13'57.54"W	750	19		10	33°52'0.40"N	83°13'57.54"W	750	19
11	33°51'51.01"N	83°13'54.47"W	850	19		11	33°51'51.01"N	83°13'54.47"W	850	19
12	33°51'50.75"N	83°13'52.69"W	1000	11		12	33°51'50.75"N	83°13'52.69"W	1000	11
13	33°51'48.74"N	83°13'54.10"W	1050	15		13	33°51'48.74"N	83°13'54.10"W	1050	15
14	33°52'0.02"N	83°14'0.37"W	600	21		14	33°52'0.02"N	83°14'0.37"W	600	21
15	33°52'1.38"N	83°13'59.62"W	800	20		15	33°52'1.38"N	83°13'59.62"W	800	20
16	33°52'1.44"N	83°13'56.82"W	850	18		16	33°52'1.44"N	83°13'56.82"W	850	18
1	33°52'2.99"N	83°13'54.65"W	450	15		17	33°52'2.99"N	83°13'54.65"W	1050	15
2	33°52'4.97"N	83°13'52.59"W	350	13		18	33°52'4.97"N	83°13'52.59"W	1350	13
3	33°52'6.86"N	83°13'51.87"W	350	12		19	33°52'6.86"N	83°13'51.87"W	1550	12
4	33°52'8.95"N	83°13'50.26"W	500	12		20	33°52'8.95"N	83°13'50.26"W	1800	12
5	33°52'11.12"N	83°13'48.78"W	750	12		21	33°52'11.12"N	83°13'48.78"W	2000	12
6	33°52'13.47"N	83°13'48.71"W	1000	10		22	33°52'13.47"N	83°13'48.71"W	2300	10
7	33°52'16.07"N	83°13'47.38"W	1300	10		23	33°52'16.07"N	83°13'47.38"W	2600	10
8	33°52'17.78"N	83°13'42.78"W	1650	9		24	33°52'17.78"N	83°13'42.78"W	3000	9
			16250						25550	
							Difference	9300		

Because Lake Oglethorpe is primarily used for recreational purposes and is surrounded by homes, noise from the compressors was taken into account. **Figure 7.2** shows the decibel levels for each size of QuietAir™ cabinet with or without the Vertex Sound Kit compared to a conversational level, and Vertex also notes that “All 'Large Lake' cabinets have an integrated muffler for quieter operation.” One power source is located by the dam and the second one between two homes on the western shore of the lake, putting both as far out of earshot as possible while still maintaining a close enough proximity to electricity lines. With the added insulation that comes with the Large Lake cabinets, our team does not believe the compressors will cause a noticeable disturbance to homeowners.

Vertex Water Features has systems that have been in place for over 10 years, all still fully functional with the original components; however, regular maintenance is performed on the larger systems to increase longevity. The tubing has a nearly indefinite lifespan, but also comes with a 15-year warranty. Each AirStation™ has a "No questions asked" 5-year free replacement guarantee and requires little maintenance because of its self-cleaning flexible membrane, which prevents clogging. On their website, Vertex notes "Over 50,000 disks [have been] installed since 2006 without a single plugged up or blown out membrane". The cabinets have a lifetime warranty against rusting. The compressors have a 2-year warranty, with a 2-4 year life, so they would most likely need to be replaced every 2 years if the system is kept running 24/7 all year long as Vertex has recommended.

Lake aeration, which typically involves either injecting air, mechanically mixing or agitating the water, and injecting pure oxygen, is conducted to increase dissolved oxygen levels in a lake. It does not appear that any federal, state or local permits will be required to perform lake aeration at Lake Oglethorpe.

The subcontractor of Vertex, AQUA DOC, sent a formal price quote on April 29th, 2015. If the HOA chooses to have only one location to power the compressors, the cost of the project will be $81,305.25. If the HOA is able to negotiate two power sources, the cost of the project will be $66,864.03, with the difference being only for the necessary extra tubing. For 80 members, that would equate to $835.80 per household. Vertex would require a 50% down payment with the remainder capable of being put into installments. We would highly recommend that the HOA consider diverting power to a second source to greatly reduce costs.

Each situation is unique, and each system depends on many different variables. We included continuous power usage, minor maintenance and labor involved for implementation, and the cost of replacing the compressors averaged over three years in the annual cost estimate. The lifetime of the aeration system is 30 years, while biologically it can last forever as long as aeration continues. The bid includes a total of 12 compressors with an average lifespan of two years each ($2354.69 every 2 years), meaning that 6 compressors would need to be replaced each year, on average, at a cost of $1177.35. Using 0.116 cents per kWh, the annual cost for running three systems (4 compressors in each) is $5,325.84. When a total of 80 homeowners are considered, the monthly costs are $6.78 per homeowner.

A second company, Pentair, recently submitted a presentation including a quote for lake aeration. They supplied two options to choose from. Option one included a single compressor that would require less maintenance and consumables with a price tag of $55,000. Additional fees include a small shed needing to be built around the compressor due to no housing unit being large enough and iron piping to connect the compressor to the valve manifold. The second option utilizes multiple smaller compressors. This would allow for stratification in some parts of the lake if the system were to ever go down. It could also allow installation of different sections as funds are made available. Annual maintenance of these compressors generally involves just replacing the air filter (≈$15 per compressor) and then seals every three to four years (≈$100 per compressor). The total cost for option 2 is roughly $40,000.

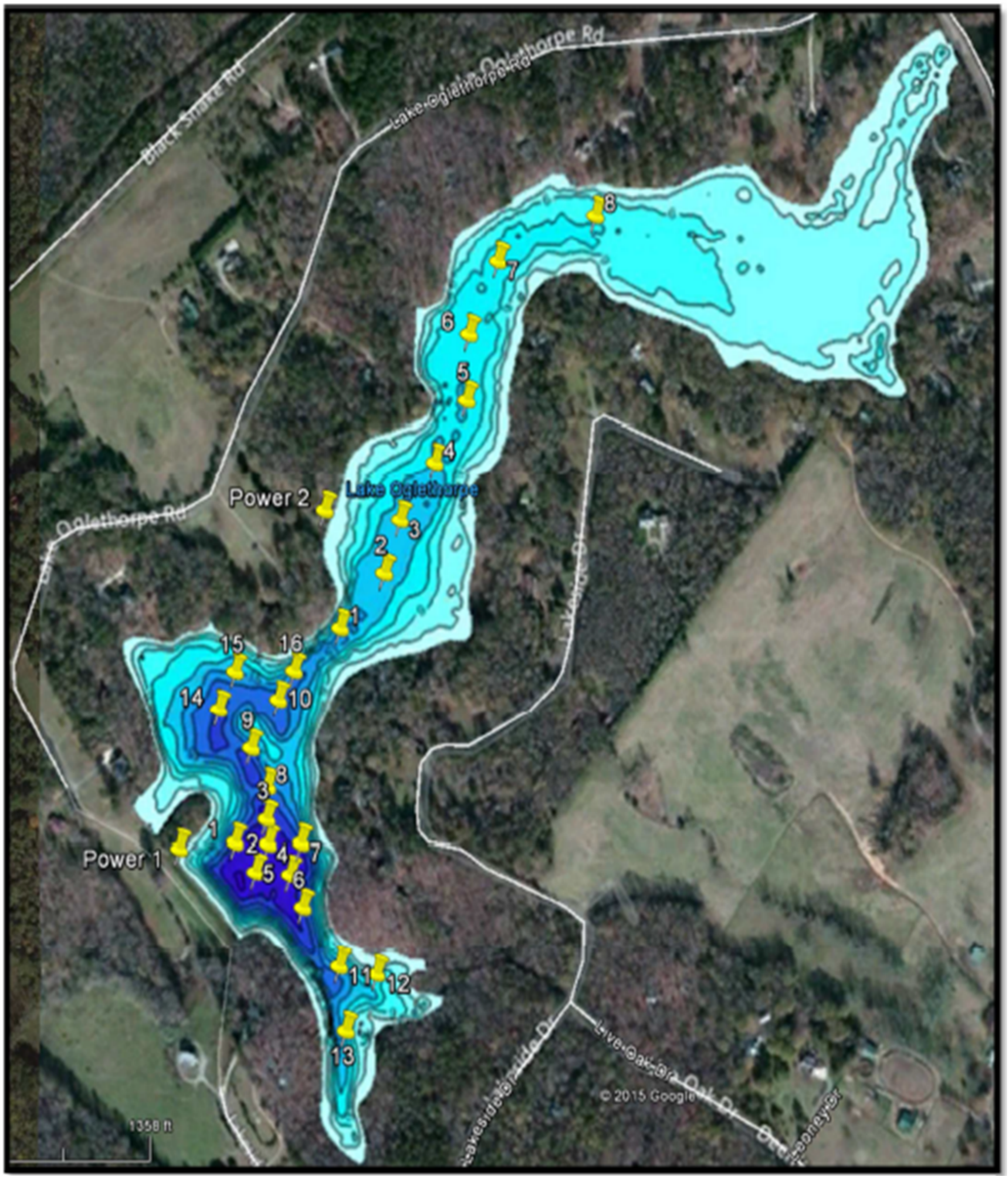


Figure 7.1- Diffuser layout recommended by Vertex Water Features.

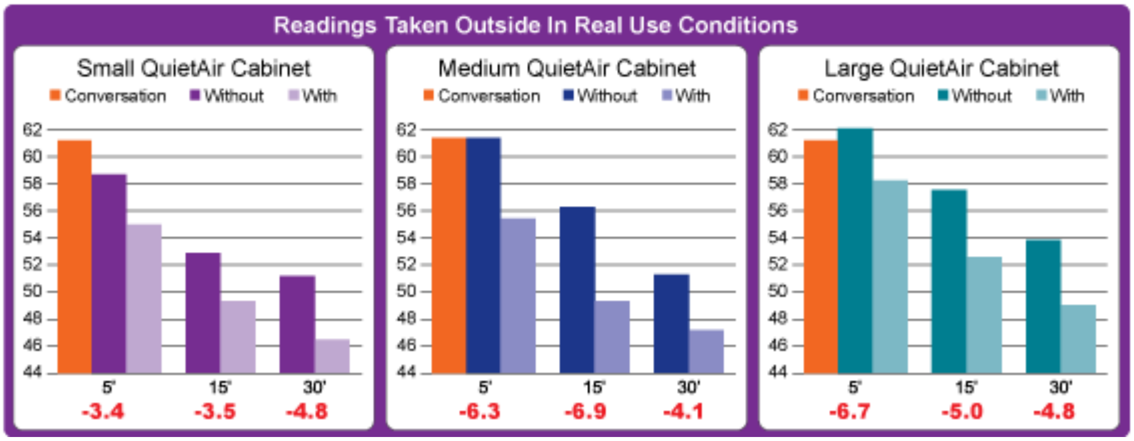


Figure 7.2- Difference in decibels between cabinets with and without the sound kit

7.3 Chemical Additives

Chemical control involves the use of chemical or mineral compounds to kill, inhibit, or remove harmful algal blooms cells. Chemicals have been used to treat blooms in drinking water supplies and other enclosed freshwater systems and typically last from 1-7 years. These include copper compounds, barley straw, and chemical oxidants such as chlorine, peroxide, ozone, and chloramines. However, all these methods have the potential to indiscriminately kill many co-occurring algae and other organisms. As they are not strictly benign and may have unintended effects on the pond ecology, we focused our attention on physical-chemical treatment options.

These treatments involve chemically precipitating P from affected water bodies and keeping it "locked up" in the sediments. When applied at the surface, these treatments effectively precipitate P to concentrations that limit algal growth. On the sediment surface, the thin layer of alum or clay can form an effective barrier to phosphate diffusing out of the sediments. The chemical restoration methods thus mainly aim at reducing the P release from the sediment by improving the P binding capacity and thus creating P limitation of the phytoplankton. As Lake Oglethorpe appears to have minimal direct impervious and agricultural runoff, which suggests internal P loading from sediments is likely a significant percent of the P budget, mitigating the in-lake sediment P reflux is the main goal of the chemical treatment.

Among the popularly used materials for water treatment, we looked into alum (aluminum sulfate), calcite, modified zeolite and Phoslock^{TM} (lanthum modified clay). Summary of innovative P-inactivation materials for reducing internal nutrient load can be found in **Table 7.3**. The table includes application method, adsorption capacity, pH range in which the material shows the maximum efficiency for P-activation, and harmful effects.

Table 7.3- Chemical additives for phosphorus inactivation

Chemical Method	**Application**	**Phosphate adsorption capacity mg P/g material**	**pH range**	**Harmful effects**
Phoslock	Applied as a slurry or as granules	10.5	5-8	No toxic effect because i rapidly settles after application
Modified zeolite	Applied as a slurry or as granules	12.7	5-7	No discernable changes in plankton species compositions when MZ is applied as a coarse-grained material that rapidly settled out of the water column rapidly.
Alum	Applied as a liquid	12-13.8	5.5-8.2	Lake water pH reductior acidification, Toxicity Settling floc— smothering of the benthos
Calcite	Applied as a slurry	6.4	5-6	No concerns

Table 7.4- Chemical additive comparisons

	Lake O	Alum	Phoslock	Modified Zeolite
Wind exposed lakes	Yes	NR	R	R
Deep lakes	?	R	R	R
Highly turbid lakes	Yes	NR	R	R
High sedimentation	X	R	NR	NR
Low alkalinity and poor buffering capacity	Yes	NR	R	R
Long period of stratification and anoxia	Yes	NR	R	R
High ammonium concentrations		NR	NR	R
	NR= Not recommended		R= Recommended	

Comparing these four products, we found Phoslock to be the best choice among the available chemical treatments. Phoslock is a modified bentonite clay product containing lanthanum, a rare earth element that is in relative abundance in the Earth's crust compared to other rare earth elements. It is very potent when removing P from the water with ratio of 1:1. Phoslock forms a highly stable mineral known as Rhabdophane ($LaPO_4$) in the presence of P species.

Unlike the other products which are common industrial chemical/flocculent used in water treatment/ clarification processes and are not specific to phosphorus, Phoslock is highly specific to available phosphorus (lanthanum cation binds with phosphate ion) and is thus used specifically for phosphorus inactivation in natural and constructed ponds, lakes and reservoirs. Water quality conditions impacts alum demand and dose and in high alkaline waters floc formation can be impeded. Phoslock efficacy is not interfered by the water chemistry. The phosphorus binding integrity of Phoslock is stronger than all the other products. Rhabdophane does not release bound P in natural aquatic environments. Alum can release bound P under certain environmental conditions ($pH<5$, $pH>8$), alum floc is prone to suspension and can decrease sediment stability. Similarly, modified zeolite and calcite can precipitate or temporarily bind P but do not provide permanent P sequestration.

In terms of impacting water quality, Phoslock has no negative impact on water quality parameters that is known at this point (pH, alkalinity etc.). Alum on the other hand can remove significant amount of essential ions in water and can crash pH and alkalinity if dose is not calculated correctly. The sulfate added through an alum application can create sulfides, which can bind reduced iron- these conditions make a ripe environment for H_2S gas to be generated, which causes unwanted odors and risks to non-target organisms. There is also the risk of potential aluminum toxicity to zooplankton, fish and invertebrates. Studies show that modified zeolite and calcite have not been proven to be environmentally viable solutions for use natural in freshwater lakes and reservoirs either. The results of acute and chronic toxicity tests of Phoslock and lanthanum using a number of sensitive organisms including: several species of water flea (Daphnia); several species of Rainbow fish; freshwater shrimp; benthic organisms such as amphipods, mayflies and midge larvae; demonstrated no toxicity of Phoslock to aquatic organisms at the dose rates used to remove free reactive phosphorus (FRP) from surface waters. Phoslock is acceptable to apply for recreational water bodies (it has a favorable exotoxicity versus the other products) and is also approved for drinking waterbodies. (NSF/ANSI standard 60 certified).

We found documented case studies where Phoslock has been effectively used in ponds such as Lake Oglethorpe to tackle similar issues. Given the favorable features of Phoslock, such as its very low toxicity, its ability to permanently bind FRP over a wide range of water chemistries, and the fact that it does not form flocs, we have recommended application of Phoslock as the most effective phosphorus locking technology for phosphorus management in Lake Oglethorpe.

Phoslock™ is applied to the treated water using two main application techniques. Spreading it in granular form or as a thick suspension, a solid/water slurry through spray is created. As it settles through the water column, it binds the orthophosphates permanently and rests on the sediment, acting as a capping material to prevent phosphorus being released from the sediment.

The development of a Phoslock phosphorus mitigation program is based on the assessment of site specific conditions such as water quality objectives, nutrient loading (internal and external) and water quality and sediment conditions. There are two general categories of Phoslock programs developed waterbodies:

1. "Comprehensive" treatments targeting a majority of phosphorus in water and upper sediment layer with goal to last for years, at some point will need maintenance dose to account for new P.
2. "Maintenance" treatments (much lower dose) could occur annually or every couple of years to gradually chip away at phosphorus (in water column and eventually some sediment P) and also inactivate new P that is loaded into the lake over time.

It is estimated the cost of Phoslock using a maintenance approach which would be done annually or every 2 years.

It does not seem like the practice of chemical application as stated here would require any permits. It appears that some states, likes Washington and Wisconsin, require state-issued NPDES permits for discharging chemical pollutants, such as alum, for nutrient inactivation. It appears that there is no federal permitting required and Georgia does not appear to have state-issued NPDES permits that cover application of alum or other chemicals.

Cost of doing the sediment sampling test: Cost to perform modified Psenner fractioning for sediments at the SePRO Research and Technology Campus laboratory is $490/sample. For a lake this size, a minimum of 5 samples should be collected from around the lake. If a budget allows for more samples, the understanding of P fractions in different regions of the lake and improve the precision of the treatment program design and budget estimate. It is also recommended to have the water tested prior to Phoslock application by an EPA certified laboratory to estimate current total phosphorus concentrations at that time.

Cost for Phoslock programs (product and implementation) typically falls in the range of $180-220/lb of P inactivated. With TOP ~ 0.2 mg/l, which translates to 400 lb of P to be inactivated over a 70 acres surface area, the cost of Phoslock treatment is estimated at ~ 400 lb x $ 200/lb =$ 80,000.

The efficacy of any chemical treatment is likely to be futile unless allochthonous nutrient inputs are concurrently managed. Therefore, sediment manipulation techniques are only a temporary "fix" without parallel, long-term nutrient input reductions.
The chemical lake restoration methods are not a panacea and their implementation should be considered as a part of an integrated management plan. The longevity of the treatment effectiveness using P-inactivation agents is reduced if not given the necessary importance in managing the external nutrient loads. P-inactivation agents would need to be reapplied over time.

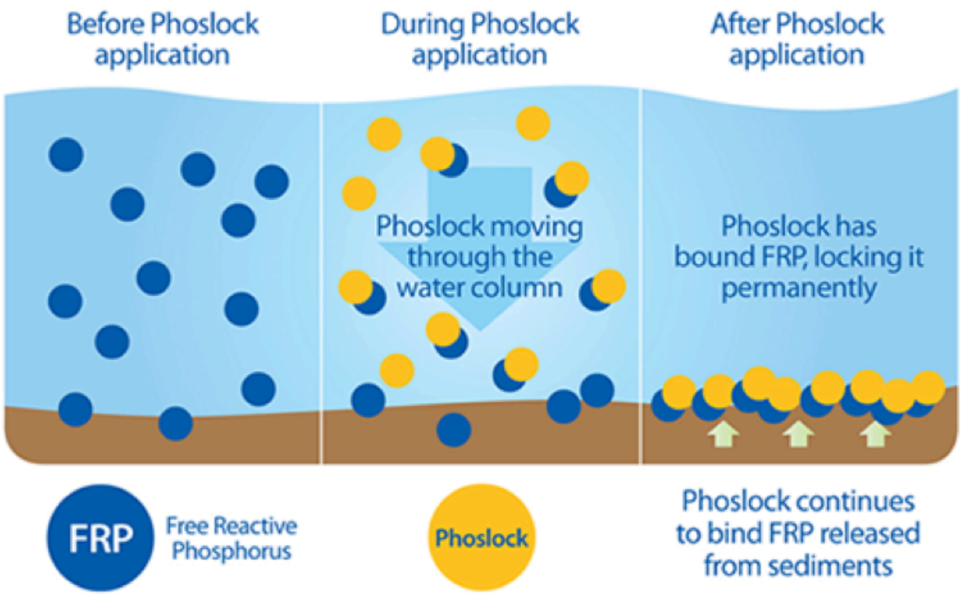


Figure 7.3- Phoslock process description (Source: Phoslock, SePro)

Figure 7.4- Phoslock application boat

7.4 Buffer Zones, Floating Wetlands, Constructed Wetlands

The planting of native vegetation can be used as a preventative method for nutrient inputs into the lake in buffer zones and also a restoration technique to remove nutrients from the water body. While these methods will not solve the eutrophication problem, the will help to extend the life of the lake. Constructed wetlands can also be utilized to mimic these same natural processes preventing nutrients from entering the lake.

Buffer zones for agricultural fields and lakeside residence are vital in controlling nutrient inputs into the lake. Buffer zones keep stormwater spread out and moving slowly. **Figure 7.5** depicts a good buffer zone of native grasses around a lake.

A floating island of growing vegetation can efficiently utilize the surface area of the roots of macrophytes, or wetland plants, to extract and retain these excess nutrients in the water column. By expanding the root zone that is in contact with the water column we can increase the thickness of the aerobic layer, resulting in increased nitrification and accelerating the process in which nitrogen is cycled from the aquatic environment to the atmosphere. They greatly expanded root mass also facilitates increased uptake and storage of inorganic phosphorus in the plant tissues by creating more surface area for beneficial bacterial colonization. It is also important note the creation of fish habitat within the lake.

Through seasonal removal of the mature macrophyte growth from the floating plant mat, accumulated nutrients are prevented from re-entering the aquatic ecosystem. Those plants can then be composted, allowing bacterial decomposition to release some of the organic phosphorus so it can be recycled and used as fertilizer.

These are islands of plants, floating on mats, and capable of being built to any size and shape, **Figure 7.6-7.7**. As the plants grow, the excess nutrients in the water are taken up and stored in their tissues. Periodic harvesting of the mature plants prevents the stored nutrients from re-entering when the plants die and decompose.

The Beemat floating wetland system provides an easy way to remove the entire plant and replant the mats to increase nutrient removal, but plant removal is pertinent. Using interlocking mats, combined with aquatic plants in perforated pots, a simulated shallow water environment can be created and applied to any water body. This produces oxygen, takes nutrients and pesticides out of the water, and provides habitat for wildlife.

The floating plant mat consists of puzzle cut mats held together by nylon connectors. These mats may be assembled in any size or shape. After the mats are connected, plants are inserted into pre-cut holes. The plants may be any species of emergent aquatics. The mats can be attached to anchors or shoreline stakes.

Provided all purchased and sourced plants are native to the state and appropriate for Temperate Zone 7, it is likely that any perennials will continue to prosper for the life of the plant. A list of native plants can be found in **Table 7.5**. Annuals that do not reseed themselves would obviously need to be replanted year to year. It is recommended that any vegetation that typically dies back in the fall, including that on the floating wetlands, be trimmed and removed. Any removed surface vegetation and trimmings would be a great addition to composting bins for use in the spring.

Table 7.4- Plants for floating wetland and buffer zones (OBL- obligate wetland; FAC- facultative;FACU- facultative upland; FACW- facultative wetland)

Lake-Shoreline (Buffer) Plants - Native in Georgia			
Common Name	***Scientific Name***	**Notes**	**Wetland preference**
Flowers, grasses, ferns			
Nodding beggarticks	*Bidens cernua*	up to 1- 6 feet, yellow flowers	OBL
Iris spp (natives)i.e. Southern blueflag	*Iris spp*	up to 1 feet, showy, purple, blueish and white flowers	OBL
Pickerelweed	*Pontederia cordata L.*	blueish flowers, showy	OBL
Joe-Pye weed	*Eupotarium purpureum*	up to 7 feet tall, pink-purple flower	FAC
Southern swamp aster	*Eurybia paludosa (Aiton) G.L. Nesom*	purple flower	FACW
New England aster	*Aster norvae-angliae*	up to 3-5 feet, violet-purple flower	
Blue vervain	*Verbena hastata*	4-6 feet, bluish-violet flowers	FACW
New York ironweed	*Vernonia noveboracensis*	up to 7 feet, small purple flowers	FACW
Seedbox	*Ludwigia alternifolia*	2-3 feet high, yellow flowers	FACW
American water plantain	*Alisma subcordatum Raf.*	up to 3,5 feet tallwhite-pinkish flowers	OBL
Jewelweed	*Impatiens capensis Meerb.*	2-4 feet tall, orange-yellow flowers	FACW
Cardinal flower	*Lobelia cardinalis*	up to 4 feet, red flowers	FACW
Arrowhead	*Sagittaria latifolia*		OBL
Big bluestem	*Andropogon gerardii*		FAC
Lizards tail	*Saururus cernuus*	1-2 feet, long spikes of white flower	OBL
Horsetail	*Equisetum hymale*	"living fossil" , fern,	FAC
Fowl Mana grass	*Glyceria striata*		OBL
Sensitive fern	*Osmunda sensibilis*	good ground cover	FACW
Arrow arum	*Peltandra virginica*	1-2 feet tall	OBL
Crown beard	*Verbesina alternifolia*		FAC
Jewelweed	*Impatiens capensis*	hummingbirds, orange flower	FACW
Cattail	*Typha latifolia*	do not plant	OBL
Shrubs			
Common winterberry	*Ilex verticillata*	berries for birds, attractive	FACW
Southern arrowwod	*Viburnum dentatum*		FAC
Common bottonbush	*Cephalantus occidentalis*	attractive	OBL
Possumhaw	*Ilex decidua Walter*	berries for birds	FACW
Swamp rose	*Rosa palustris Marsh*	attractive, showy	OBL
Serviceberry	*Amelanchier arborea*	berries for birds, attractive	FACU
Trees			
Box elder	Acer negundo		FACW
Red maple	Acer rubrum		FAC
Tag alder	Alnus serrulata		FACW
Bald cypress	Taxodium distichum		OBL
River birch	Betula nigra		FACW
Ironwood	Carpinus caroliniana		FAC
Green ash	Fraxinus pennsylvanica		FACW
Sweetgum	Liquidambar styraciflua		FAC
Black gum	Nyssa sylvatica		FAC
Hop hornbeam	Ostrya virginiana		FACU
Sycamore	Platanus occidentalis		FACW
Elderberry	Sambucus canadensis	berries for birds, shrub/tree	FACW
Slippery elm	Ulmus rubra		FAC

A CWA §404 permit, issued by the U.S. Army Corps of Engineers (Corps) and the U.S. Environmental Protection Agency (EPA) to regulate the discharge of dredged or fill material into waters of the U.S, will not be required for a floating wetland of this design, as no dredge or fill material is used.

The cost would depend on a number of factors yet to be determined. These include number and size of floating wetlands, and type of marginal plants chosen to be used. Beemats are priced at $3.50 per square foot, unassembled. Plants, shipping and assembly are not included in the price. Plants can be locally sourced for a greatly reduced cost. Assembly is quite simple and straightforward, with instructions also available at beemats.com. For a 40x40ft area (1600ft^2) to be shipped and filled with ~4000 plants, an approximate cost would be $10,000. This is based on the cost of $5,600 for the stated square footage of Beemats material, plus estimated shipping of $600, along with cost of plants and assembly materials, such as zip-ties and anchors. There would be minimal upkeep or maintenance cost as the materials are UV resistant, and the plants would regrow from root as they would be rated for North Georgia's winter hardiness zone (7b-8a) The main cost would be for the HOA to pay for the trimming and removal of surficial vegetation prior to the fall die-back. This would aid in the removal of nutrients accumulated in the stalk and leaf matter associated with the plants. An illustration including buffer zones in red and possible floating wetland locations can be seen in **Figure 7.8**.

Constructed wetlands are an important option to consider for Lake Oglethorpe restoration. During the lake study, a family of beavers built a series of dams, some of which are pictured in Section 6.3. Due to natural construction of the dam, constructed wetlands were not researched as an option. Following some intense rain events in in May of 2015, the beaver dams blew out due to the high flows. The dams have since not returned to their original state, but it is our hope that the beavers will return.

Figure 7.5- Buffer zone around a lake

Figure 7.6- Photographic representation[1] of floating wetlands on the water and flowering plants used as a buffer in front of the lake.

[1] Credit: Margit Pap, UGA CEPD

Figure 7.7- Illustration of floating wetland and native buffer plants

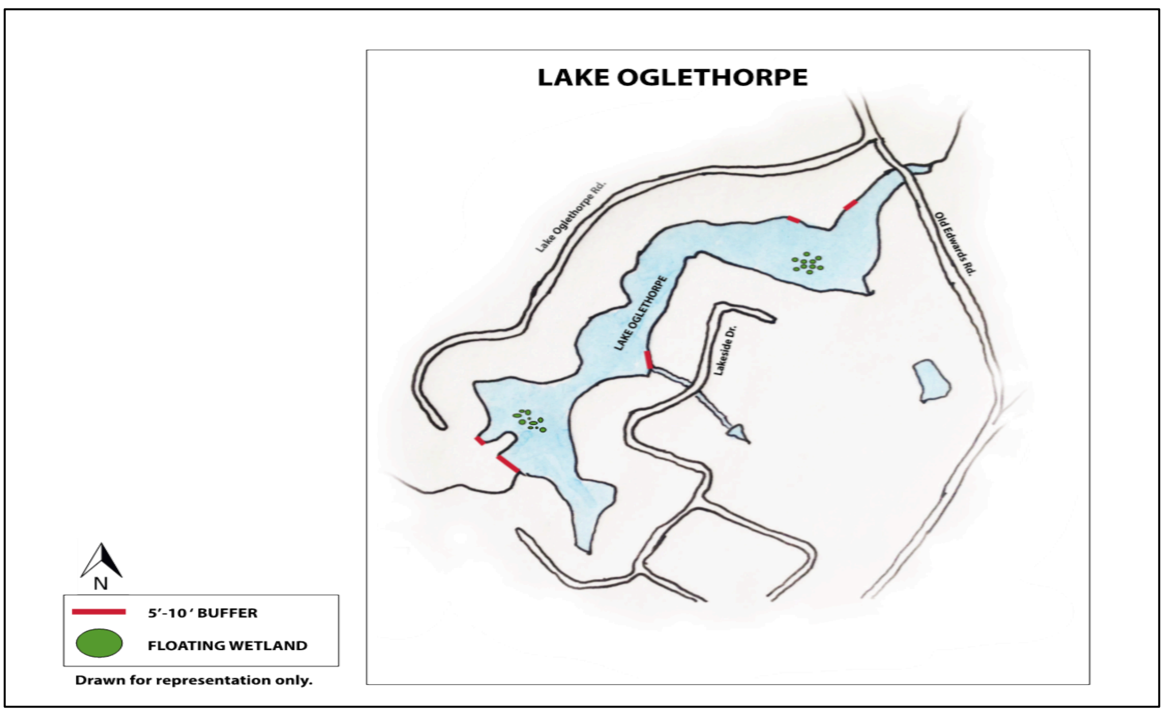


Figure 7.8- Illustration[2] representing possible layout of floating wetlands and locations for recommended vegetative buffers. Currently, the locations depicted in red provide little protection from surface runoff into the lake. This can be a source of excess nutrients from lawn fertilizer and pesticides.

2 Credit: Margit Pap, UGA CEPD

Conclusion

Lake Oglethorpe is a ~45-year old lake located south of Athens, Georgia, just outside a small town call Arnoldsville, Georgia. The lake has recently been exhibiting a eutrophic status based on recent studies by Dr. Amy Rosemond of the University of Georgia and recent algal blooms. This study was aimed at assessing the state of the lake and future remediation needed in order to restore the lake for recreational and fishing activities.

GIS was used to analyze a multitude of different map layers to aid in assessment of the Lake Oglethorpe catchment, while also providing the ability to make maps for visual representation of data and sampling locations. The Lake Oglethorpe catchment area is a total of 2224-acres comprised of almost 50% forest, 28% hay/pasture, and 9% developed land. The soil within the catchment is predominately cecil sandy loam that was historically farmed for cotton many years ago. The catchment area is comprised of 11 main drainage basins, 10 of which were sampled. East Creek and West Creek drainage basins come together to form Goulding Creek and contribute most of the flow to Lake Oglethorpe.

The oldest bathymetric survey of the lake from 1989 concluded the lake was around 68-acres and 28 feet deep at its deepest point. The new bathymetric survey recorded the deepest point of 27.1 feet deep. The bathymetric survey was needed to allow the aeration system to be designed.

Determining inputs into the lake was attempted, but were made difficult due to beaver activity. We wanted to develop a rating curve for discharge and stage, but that was impossible. It is recommended to have the discharge modeled through SWAT or similar modeling software. A new class will be doing a senior project on the lake Fall 2014 semester and this will be recommended. Hopefully they will also use stage data to determine outputs from the lake and aid in a nutrient budget.

Monthly water quality sampling data included samples from TL, TR, TC, LM, LC, LD, LB and BL from November 2014-May 2015. An additional sample was taken at LL during stratification in April and May. Storm events were sampled in March and May of 2015 including SE1, SE2, SE3, E1, E2, NE1, TL, TR, TC, NW2, and also an additional sample in a very small tributary draining a hayfield in E1 creek.

Lake Oglethorpe streams met Georgia water quality standards for DO, pH, and temperature, other than SE2, which had a low pH. Overall, the streams were in good condition other than high TP above recommended levels in every stream other than NW2 and large increases in turbidity during storm events. In some cases the concentrations were **extremely high** for TP during the May Storm event. While any decrease in TP would be a positive influence in Lake Oglethorpe, it will not fix the problem, which is largely due to inputs within the lake. The larger creeks, which are not included in the Lake Oglethorpe Association, also had extremely high amounts of TP input to the lake during the large May storm event. These two main creeks contribute ~65% of the total flows to the lake, when compared to the hayfield, which contributes about 2% of the total flow. NW2 water quality was the best for the catchment area, while E2 was the worst water quality in the catchment.

Water quality within the lake is overall a eutrophic status based on TP and Secchi depth in some locations. Chl-a was in the mesotrphic at all locations other than LL, which became eutrophic in May 2015. It is important to note as the summer moves along and the lake continues to stratify, Chl-a will likely increase. Another interesting period will be during fall overturn when the lake mixes and many of the nutrients on the bottom become more available to the algae.

The lake started to stratify in March and by the end of April, the lake was fully stratified. The anoxic zone began around 3 meters from the surface and extended to all locations below this depth in the lake. This was confirmed by depth profiles at 7 sites around the lake. The UGA fisheries class collected data for fish community surveys seine hauls for young of the year assessment in May of 2015, but that data was not made available after multiple requests. It is my hope the data will be made available soon.

A total of 52 subsamples were grabbed over the entire Lake Oglethorpe Catchment to analyze the soil. Each small catchment area was averaged for representation. E1 and E2 had higher averages than any of the other catchment areas, but there were multiple locations with high phosphorus around the catchment. Nutrient management plans would be helpful in all the agricultural areas around the lake.

We were not able to obtain lake sediment core samples due to the cost of sampling instrumentation. Lake sediment was sampled from the sediment surface from 3 spots around the lake. An Fe:P ratio greater than 15 is usually signs of a good candidate for aeration due to the adsorption capacity of Fe on P at these levels. For Lake Oglethorpe, Fe:P ratios are 74.8, 104.8, and 160.8 for sites LD, LM, and LC, which is very high.

Lake remediation techniques included dredging, artificial de-stratification, phosphorus precipitation and inactivation, algaecides, biomanipulation, and catchment area management. All were discussed in detail within the report other than biomanipulation and algaecides. Of all the remediation techniques researched, a combination of destratification, floating wetlands, and catchment area management will possibly provide the most benefit.

Recommendations

Based on the research collected and analyzed from the many resources, we propose a combination of lake aeration, floating wetlands, and catchment area management to provide restoration of Lake Oglethorpe. While phosphorus inactivation would be helpful, it is only a band-aid and increases the costs associated with remediation. Dredging of the lake is not an option due to the costs associated with it and algaecides or biomanipulation can have a wide range of unintended consequences.

Lake aeration will provide oxygen to the anoxic zone and in return, help to de-stratify the lake and trap phosphorus in lake sediments. It is recommended Fe:P ratio averaging above 15 to help control phosphorus inputs from lake sediment and Lake Oglethorpe sediment averages an Fe:P ratio above 100. It is also important to note, high NH3 concentrations at the bottom of the lake, when oxygenated, will transform to nitrate. Higher nitrate levels will decrease the likelihood of cyanobacteria algal blooms similar to the blue/green blooms seen the past. The higher oxygenated waters will also lead to more areas for fish to populate. By de-stratifying the lake, the lake will also become clearer. Of the remediation techniques, lake aeration is the most important. If funds are an issue, the system can be set up in increments. The total cost will be between $40,000-$60,000 depending on the chosen company.

In addition to lake aeration, floating wetlands are recommended to provide fish habitat and a phosphorus sink. The wetlands can be constructed to any size or shape and installed at various locations around the lake. Annual maintenance would be needed to remove old growth each year. It may be possible for Laurie Fowler to acquire grant funding for these floating wetlands.

The third recommendation for Lake Oglethorpe is to incorporate better management of the catchment area. For lakeside residents, buffer zones should be created using native plants described in Section 7.4 where possible. Buffer zones slow runoff and increase infiltration. Best management practices for the agricultural areas are recommended, specifically, the Animal Waste Awareness in Research and Extension website (aware.uga.edu). The website provides many nutrient management tools such as a nutrient calculator, field nutrient balance sheets, and a Georgia phosphorus index used to assess bioavailable P.

Appendix

Table A1- Lake Oglethorpe Study Site Names

Site	Name
TL	Top Left Creek; West
TR	Top Right Creek; East
TC	Top Combined Creek
LM	Lake Mouth
LC	Lake Center
LD	Lake Dam
LL	Lake Dam Middle Depth (4.5 meters)
LB	Lake Dam Bottom + 1 meter
BL	Below Lake
NE1	Northeast Tributary
NW1	Northwest Tributary
SE1	Southeast Tributary 1
SE2	Southeast Tributary 2
SE3	Southeast Tributary 3
E1	Eastern Tributary 1
E2	Eastern Tributary 2
SW	Western Catchment Area
AC	Athens Cove
JC	Johnson Cove
LT	Lake Transition
CL	Cloverleaf
HD	Hayfield Dredge Deposit
HA	Hayfield above dredge deposit
HS	Hayfield below sawdust

Table A2- Water Quality codes

WQ codes	Description
CHl-a	Chlorophyll-a
Fe	Iron
NO3+NO2	Nitrate+Nitrite
TN	Total Nitrogen
TKN	Total Kjeldhal Nitrogen
TP	Total Phophorus
TSS	Total Suspended Solids
NH3	Ammonia
Alk	Alkalinity
pH	pH
SC	Specific Conductance
WT	Water Temperature
DO	Dissolved Oxygen
Turb	Turbidity
M	Metric
NTU	Nephelometric
Sec	Secchi depth
S	Sunny
C	Cloudy
PC	Partly Cloudy
R	Rain

Table A3- Soil codes

Soil Code	Element
P	phosphorus
K	potassium
Ca	calcium
Mg	magnesium
Zn	zinc
Mn	manganese
Cd	cadmium
Cr	chromium
Cu	copper
Fe	iron
K	potassium
Mo	molybdenum
Na	sodium
Ni	nickel
Pb	lead
LBC	Lime Buffer Capacity
pH	Acidity
CEC	Cation exchange capacity

Table A4- Soil sample GPS

ID	Description	Latitude	Longitude
1	SE1A	33.86066	-83.22973
2	SE1A	33.86122	-83.23055
3	SE1B	33.85941	-83.2264
4	SE1B	33.85978	-83.22746
5	SE2B	33.86179	-83.22447
6	SE2B	33.86232	-83.2253
7	SE2A	33.86213	-83.22586
8	SE2A	33.864	-83.22905
9	SE3A	33.86671	-83.2292
10	SE3A	33.86631	-83.2288
11	SE3B	33.86583	-83.22679
12	SE3B	33.8648	-83.22465
13	MILL	33.8664	-83.22611
14	MILL	33.86658	-83.22633
15	E1A	33.86839	-83.22476
16	E1A	33.866	-83.22307
17	E1B	33.86925	-83.22342
18	E1B	33.86637	-83.22198
19	E1C	33.86788	-83.22059
20	E1C	33.86766	-83.21967
21	E2A	33.87004	-83.21824
22	E2A	33.87026	-83.22155
23	E2B	33.8725	-83.22232
24	E2B	33.87181	-83.22029
25	EA	33.88439	-83.21071
26	EB	33.886	-83.20983
27	EB	33.8894	-83.20848
28	EC	33.88718	-83.2029
29	EC	33.88497	-83.20483
30	ED	33.88217	-83.20915
31	ED	33.88162	-83.21064
32	EE	33.88008	-83.21312
33	EE	33.88222	-83.21366
34	WA	33.89153	-83.20914
35	WA	33.88927	-83.21303
36	NE1A	33.8757	-83.21374
37	NE1B	33.8756	-83.21999
38	SWA	33.86996	-83.23495
39	SWA	33.86865	-83.2338
40	SWB	33.8733	-83.2296
41	NW1	33.87364	-83.22622
42	NW1	33.87424	-83.22465
43	NW2	33.8781	-83.22263
44	NW2	33.88084	-83.22517
45	WB	33.88387	-83.22256
46	WB	33.88465	-83.2219
47	WC	33.89522	-83.21984
48	WC	33.8937	-83.21986
49	WD	33.89607	-83.22
50	WD	33.89656	-83.22442
51	WE	33.89776	-83.21333
52	WE	33.89388	-83.21558

Table A4- Lake Oglethorpe Catchment Soil data

					%	meq/ 100g	Mehlich 1 lbs/acre													
Lab	Samp	LBC [1] (ppm $CaCO_3$/ pH)	pH $_{CaCl2}$ [2]	Equiv. water pH	Base Satur- ation	CEC	Ca	Cd	Cr	Cu	Fe	K	Mg	Mn	Mo	Na	Ni	P	Pb	Zn
61370	NE1A	576	4.76	5.36	43.68	9.73	1122	<0.12	<0.12	1.24	46.4	165.1	288.4	47.8	<0.12	13.73	0.33	5.9	2.74	4.42
61371	NE1B	614	4.31	4.91	31.57	10.88	917	<0.14	<0.14	1.96	107.7	171.5	213.3	24.9	<0.14	15.87	1.16	4.2	1.31	7.82
61372	East A	418	4.74	5.34	40.73	6.79	799	<0.13	<0.13	1.59	47.7	162.4	128.7	51.1	<0.13	11.65	0.18	5.4	1.81	1.90
61373	East B	412	5.15	5.75	57.92	7.10	1020	<0.12	<0.12	1.58	13.1	685.6	158.2	68.1	<0.12	11.18	0.16	9.9	0.75	3.45
61374	East C	404	4.12	4.72	18.79	6.58	339	<0.12	<0.12	4.47	28.2	69.9	67.0	45.2	<0.12	8.69	0.16	27.0	2.53	5.13
61375	East D	508	4.58	5.18	39.14	8.81	687	<0.14	<0.14	0.96	28.0	236.3	334.6	31.3	<0.14	15.72	0.86	5.0	1.95	3.27
61376	East E	487	4.77	5.37	52.06	9.60	1269	<0.13	<0.13	10.21	37.5	317.0	316.2	46.6	<0.13	47.36	0.62	87.1	2.17	12.73
61377	E1A	458	5.22	5.82	70.41	10.59	2077	<0.12	<0.12	19.60	41.6	429.3	365.9	55.6	<0.12	87.23	1.19	198.3	0.73	25.43
61378	E1B	472	5.05	5.65	64.00	10.27	1615	<0.14	<0.14	1.48	26.0	399.4	476.4	64.9	<0.14	16.30	0.46	32.6	1.38	7.79
61379	E1C	571	5.43	6.03	78.98	15.28	3372	<0.14	<0.14	12.15	71.4	665.0	654.2	51.7	<0.14	27.04	0.87	407.3	0.77	56.40
61380	E2A	498	5.10	5.70	69.91	12.48	2318	<0.15	<0.15	12.08	53.2	749.8	459.2	36.3	<0.15	24.23	0.65	203.2	0.74	33.78
61381	E2B	422	4.25	4.85	26.91	7.20	515	<0.13	<0.13	0.71	55.7	100.3	116.1	21.2	<0.13	17.69	0.24	26.0	2.41	3.29
61382	SE1A	387	4.51	5.11	48.38	8.22	941	<0.14	<0.14	0.75	38.7	174.5	328.0	29.9	<0.14	15.89	0.28	6.5	1.71	2.48
61383	SE1B	355	5.48	6.08	80.26	9.60	2294	<0.13	<0.13	5.96	42.7	396.2	341.8	26.4	<0.13	16.84	0.34	127.6	0.74	18.12
61384	SE2A	581	4.21	4.81	28.10	10.26	664	<0.13	<0.13	1.72	29.6	224.4	217.0	68.0	<0.13	15.09	0.32	13.4	1.64	3.61
61385	SE2B	435	4.86	5.46	66.58	11.62	2215	<0.15	<0.15	17.85	37.6	227.0	449.9	49.8	<0.15	15.93	0.41	41.9	1.13	21.13
61386	SE3A	376	4.67	5.27	49.32	7.44	785	<0.14	<0.14	1.28	27.4	347.6	296.0	32.2	<0.14	14.14	0.38	20.8	1.26	36.48
61387	SE3B	452	5.32	5.92	76.46	12.03	2701	<0.13	<0.13	8.17	64.1	301.5	473.4	34.4	<0.13	38.78	0.92	66.9	1.58	14.39
61388	SWA	420	4.71	5.31	54.80	9.11	1298	<0.13	<0.13	4.93	44.4	386.3	281.4	33.7	<0.13	35.30	0.37	27.8	1.29	9.50
61389	SWB	382	4.62	5.22	48.12	7.60	963	<0.14	<0.14	2.31	77.6	143.0	247.4	25.2	<0.14	16.32	0.47	5.2	1.10	8.20
61390	West A	296	4.45	5.05	35.07	5.16	451	<0.13	<0.13	2.63	36.6	182.1	100.2	42.1	<0.13	13.28	0.26	6.0	1.30	5.29
61391	West B	347	5.02	5.62	60.28	6.99	1203	<0.12	<0.12	14.23	39.8	94.5	248.8	31.0	<0.12	22.65	0.22	76.3	1.02	16.59
61392	West C	606	4.05	4.65	10.25	9.20	179	<0.14	<0.14	1.88	185.8	67.8	89.6	47.8	<0.14	16.87	0.19	6.9	8.18	2.98
61393	West D	379	4.82	5.42	54.64	7.66	1231	<0.12	<0.12	3.49	169.6	145.0	214.3	26.0	<0.12	12.32	0.25	26.6	2.56	4.82
61394	West E	353	4.30	4.90	25.27	5.75	404	<0.13	<0.13	1.05	37.0	72.8	78.2	24.3	<0.13	11.35	0.21	6.3	2.99	1.24
61395	NW1	480	4.32	4.92	39.66	9.60	924	<0.13	<0.13	1.40	117.1	302.9	257.7	28.2	<0.13	15.93	0.52	10.8	1.78	59.83
61396	NW2	508	4.07	4.67	21.95	8.80	397	<0.11	<0.11	0.86	61.7	348.1	110.8	32.2	<0.11	14.32	0.30	4.8	2.61	2.57
61397	Mill	979	5.78	6.38	91.76	42.70	15252	<0.34	<0.34	2.68	334.5	114.0	198.5	101.1	<0.34	35.29	1.62	25.8	1.10	18.83

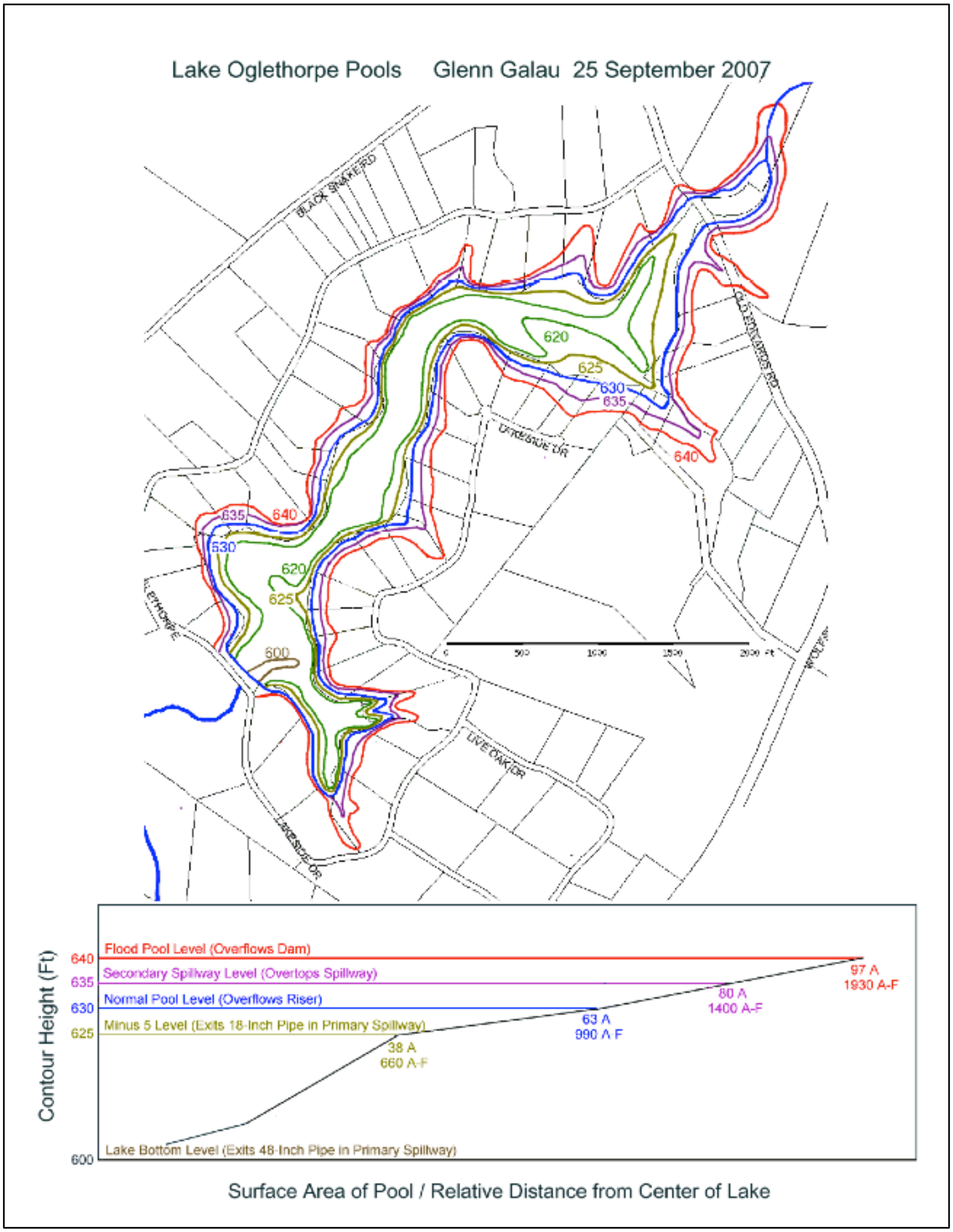


Figure A1- Lake Oglethorpe pools at different elevations

Figure A2- Aeration diffusers

Figure A3: Floating Wetland below surface

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