# Evaluating the Effectiveness of Water Remediation Techniques for Nutrient Reduction and the Control of Cyanobacteria Blooms in Municipal Drinking Water Reservoirs in the SE United States

By

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# Abstract

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This project focused on three drinking water reservoirs in the SE United States in order to evaluate if current procedures are effective at reducing nutrient levels to an extent that would inhibit the formation of harmful algal blooms. The three lakes of interest chosen for the study were Falls Lake, NC, Jordan Lake, NC, and Lake Okeechobee, FL. All three lakes currently, and historically, exhibit eutrophic conditions, frequent algal blooms, and are the sites of legislative and corrective actions aimed at nutrient reduction and the reduction of cyanobacteria. While several techniques have been applied, including the use of solar-powered lake mixers, and constructed wetlands, eutrophication and algal blooms events continue to occur at these sites. This study used the parameters of total phosphorus and total nitrogen in conjunction with levels of chlorophyll-a in order to determine the effectiveness of current techniques for the control of cyanobacteria. It was found that current protocols and remediation efforts are not effective at the control of nutrient levels and algal productivity in these lakes.

# Biography

Ian Olson is a graduate student in the Masters of Environmental Assessment program at North Carolina State University. Ian earned a B.A. in Biology from the University of North Carolina at Greensboro in 2012. He currently lives in Hillsborough, NC with his wife Jennifer, and three year-old daughter Isabella. When he isn't working on his graduate degree, Ian works full-time as a cook at a busy retirement community just outside Chapel Hill, NC. In the future he hopes to change careers for a position related to environmental health, environmental policies, and/or the remediation of environmental issues. In his free time Ian enjoys hiking, weight lifting, playing the electric guitar, and playing games with Isabella.

## Acknowledgements

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# Introduction

Many genera of cyanobacteria (also called blue-green algae) including, *Aphanizomenon*, *Anabaena*, and *Microcystis* are capable of producing large blooms that have negative toxic impacts on municipal water supplies, and can cause harm to human populations. These blooms are associated with the introduction of excessive amounts of N or P from anthropogenic activities including agricultural practices, urban development, and associated runoff. Some genera of cyanobacteria produce toxins, such as *microcystin* that can be toxic to humans and other animals that consume the affected water (Paerl & Otten 2013). Toxic effects of metabolites (such as *microcystin*) from cyanobacteria include kidney and liver damage, damage to neurons, dermal lesions, and gastro-intestinal inflammation (Paerl & Otten 2013). Another implication for water quality is that large quantities of algae can lead to cloudiness, poor taste (off-flavor), and bad smelling water (Cooke *et al.* 1986). In addition to the potential for harmful effects to humans, other species, both *flora* and *fauna*, can be negatively affected by excess algal productivity, and the ecosystem as a whole is often damaged as a result of these bloom events. For example, the large bloom masses shade-out aquatic plants and cause depleted levels of dissolved oxygen, especially when the bacterial decomposition of a dying bloom occurs; this loss of dissolved oxygen leads to fish kills and the suppression of other aquatic animals (Paerl & Otten 2013). Ultimately, frequent blooms of cyanobacteria can lead to loss of species diversity, the closures of water bodies, and the overall impairment of the ecosystem in which they occur.

Over the years, a multitude of technologies and solutions to the problem of these bloom events has been proposed and tested, however, no one solution stands out as an effective permanent solution to nutrient reduction and the harmful blooms. Many states, including North Carolina and Florida, have legislation in place focused on the reduction of nutrient runoff entering the states' watersheds as a preventative measure against excessive cyanobacterial activity. These types of legislation have not had enough of an effect on the reduction of harmful algal blooms, so new technologies for the control of cyanobacteria have been developed. Solar-powered lake mixers (Solarbees) have been developed to churn the water column in order to break-up masses of cyanobacteria, inhibiting their potential for bloom formation (Upadhyay 2013). Another technique is the use of constructed wetlands that use aquatic plants to remove excess amounts of nutrients from the water, thereby inhibiting algal growth in the nearby lake. This study focused on three bodies of water that are currently in use as municipal drinking water reservoirs in the southeast United States: Falls Lake, NC, Jordan Lake, NC, and Lake Okeechobee, FL. These three specific lakes were chosen because they are drinking water reservoirs that are eutrophic and often experience harmful algal bloom events.

They were also chosen because of their differences such as different treatment approaches, the fact that Lake Okeechobee is a natural lake and Falls Lake and Jordan Lake are man-made, and their different geographical locations.

Both Falls Lake and Jordan Lake are run-of-river impoundments located in central North Carolina; this type of reservoir is the predominant lake type in the SE United States (Touchette *et al.* 2007). Both lakes are known to have had multiple cyanobacterial blooms since their creation, and are known to have high percentages (up to 95%) of phytoplankton biomass belonging to genera such as *Aphanizomenon* (Touchette *et al*. 2007). Both Jordan and Falls Lake are relatively young lakes, having both been created in the early 1980s, and both lakes have preventive nutrient control strategies in place. Since 2013, Jordan Lake has been the site of testing for a study on the effectiveness of solar-powered lake mixers called Solarbees for the reduction of cyanobacterial blooms (NC DENR 2013).

Lake Okeechobee, FL is a large natural lake that is used for recreation and public drinking water supply, and is also affected by blooms of cyanobacteria due to eutrophication from both point and non-point sources. Lake Okeechobee is part of an extensive hydrologic system that includes the Everglades and most of southern Florida. A large portion of the Okeechobee watershed, approximately 50 percent, is used for agriculture which is a key source of excess nutrients; some of that load comes from the agricultural area known as the Everglades Agricultural Area, which is owned in part by the United States Sugar Corporation (FDEP 2012). While Lake Okeechobee is far greater in size compared to the two lakes in North Carolina, levels of N and P, and chlorophyll-a are similar, however Lake Okeechobee has different legislation and approaches to the remediation of its water issues, which is one reason it was chosen for comparison of remediation techniques in this study. Since 2006, Lake Okeechobee has been using 45,000 acres of constructed wetlands as a method of removing excess nutrients from the water in an effort to prevent the formation of harmful algal blooms (FDEP 2013).

The fact that these bodies of water are often impacted by algal blooms and have been the testing ground for several remediation approaches including; nutrient load reduction, solar lake mixers, and treatment of storm-water runoff by man-made wetlands, made them ideal candidates for analysis and comparison in this study. While these waters have seen temporary improvement from some treatments, they are poised for future algal bloom events, especially with urbanization and runoff on the rise. Currently, governmental protocol is most focused on prevention of nutrient loading, and less on the rehabilitation of polluted waters. This study was designed to examine the current legislation and treatment strategies regarding levels of N and P, and determine whether-or-not significant decreases in nutrient loads, meant to reduce the cyanobacteria bloom events, have occurred. Chlorophyll-a levels will be used as a measure of algal productivity. It is expected that with increasing urbanization and land development, an increase in eutrophication is approaching, and with it an increase in cyanobacteria events. Due to differences in geographic location, morphology, age, etc., it is expected that these bodies of water will exhibit different genera and activity of cyanobacteria, therefore different remediation approaches may be more effective in one body over another. This study will attempt to identify which remediation techniques are most effective in these types of reservoirs, and if any current approach is sufficient to protect the water supply in a long-term, sustainable capacity.

## Methods

This was a two-semester project begun by Ian Olson (a graduate student) in August, 2015, through the Environmental Assessment Program at North Carolina State University, under the guidance of Dr. Harry Daniels of NCSU. During the Fall semester of 2015, the conceptualization and framework of the project was organized and background research on the topics of cyanobacteria, water quality, nutrient loading, and remediation approaches was begun. Many remediation techniques were reviewed including solar lake mixers (Solarbees), the use of constructed wetlands, herbicides, biological control measures such as grass carp, and storm-water treatment. Ultimately, the findings from the Fall, 2015 semester were presented as a formal study plan and outline in December, 2015. The result of the study plan was that three lakes would be studied for their respective approaches at remediating harmful blooms of cyanobacteria.

In January, 2015 site-specific research was begun on each of the three lakes chosen for the project: Lake Okeechobee, FL, Falls Lake, NC, and Jordan Lake, NC. Important observations and findings were recorded and discussed at two-week intervals during the Spring, 2015 semester. Each water body of interest was reviewed in terms of historical and current water quality, attempted remediation and/or prevention techniques, and overall health of the ecosystem. The lakes were compared and evaluated on levels over a fifteen year period (2000 – 2015) of chlorophyll *a*, dissolved oxygen, total phosphorus (TP), total nitrogen (TN), and presence of known harmful species of cyanobacteria such as *Anabaena*, *Aphanizomenon*, and *Microcystis*. After a comprehensive evaluation of each body of water (Jordan Lake, Falls Lake, and Lake Okeechobee) was performed, comparisons were made from the collected data in order to evaluate the effectiveness of potential solutions to the cyanobacterial blooms. The history and legislative actions regarding each of the study lakes were synthesized into timelines for each lake as a method of comparison. Analysis of these materials was compiled into a comprehensive report/presentation including all relevant data and findings. Data retrieved during the research portion of the project was used to make graphical figures and tables for inclusion in the final report. The project was presented to the Faculty of the Environmental Assessment at North Carolina State University on April 27, 2016.

This project was predominately a review of current peer-reviewed literature from online databases, peer-reviewed and published water quality journals, as well as water quality records, and information from sources such as the NCSU Center for Applied Aquatic Ecology. Many documents were provided by state agencies, such as the North Carolina Department of Environment and Natural Resources (NCDENR) and the Florida Department of Environmental Protection (FDEP). National standards for water quality and nutrient criteria were retrieved from the United States Environmental Protection Agency.

The lakes chosen for this project were carefully selected based on characteristics that are representative of many of the lakes in the SE United States. Lake Okeechobee, FL was chosen for this project because of its unique characteristics that show some similarity to the central North Carolina lakes such as a shallow average depth (Table 1) and large littoral zone, and also differences such as Lake Okeechobee being very large and the only natural lake in the study, and also as the only lake in the study not surrounded by a large urban area. These similarities and differences were examined as part of the analysis and provide an interesting basis for the comparison of remediation techniques between the three bodies of water.

Both Jordan Lake and Falls Lake are river impoundment drinking water reservoirs located in central North Carolina that are classified as Nutrient Sensitive Waters and considered eutrophic. Both Jordan and Falls Lake were constructed and filled in the early 1980's and have both struggled with water quality issues since their creation. Falls Lake is located in an urban area close to Durham, NC and experiences high levels of nutrient loading in the form of runoff from residential areas. Jordan Lake is located in Chatham County, NC in a more rural setting than Falls Lake, however Jordan Lake also experiences nutrient loading in the form of agricultural runoff, residential runoff from large housing developments, and runoff from several large golf courses. The nutrient enrichment of these two lakes has caused an increase in cyanobacterial activity, signified by excessive amounts of chlorophyll-a. Concern over drinking water quality as a result of the algal activity has prompted the introduction of preventative legislation (the primary means of nutrient management in North Carolina) and the implementation of novel remediation efforts such as solar-powered lake mixers.

Lake Okeechobee is a large natural lake that is very shallow (average depth 9 ft) for a lake of is size. Lake Okeechobee is used as a drinking water supply for most of urban, southern Florida. The shallow nature of the lake allows for a large littoral zone which is similar to the impounded lakes of NC. Lake Okeechobee is also considered a eutrophic lake that frequently experiences algal blooms that require closure of recreation areas and extensive water quality monitoring. Unlike the two lakes located in central NC, Lake Okeechobee is located in a fairly rural area and is connected to a large hydrologic network that extends to the tip of Florida, through the Everglades National Park. Lake Okeechobee is subject to large-scale nutrient loading events generally from hurricane activity that cause spikes in TP levels and overall nutrient content. The geographic location of Lake Okeechobee has allowed for the use of man-made wetlands to be constructed and used for phosphorus removal, providing a different means of water quality management than has been used in North Carolina.

## Results/Discussion

An important part of the analysis was the comparison between the physical characteristics of the three lakes in the study (Table 1). While Lake Okeechobee is by far the largest of the three lakes, approximately thirty-seven times larger in surface area than Falls Lake (the smallest lake in the study), it is the shallowest of the three lakes with an average depth of only nine feet. Lake Okeechobee also has a far greater volume than the other study lakes, approximately thirty-two times more water volume than Falls Lake. Jordan Lake has the greatest average depth, at 14 feet, however there is only a five-foot range in depth between all three lakes. The shallow average depth of these lakes is an important factor in their eutrophication, and a common trait amongst drinking water reservoirs in the SE US. The shallow depth of these lakes allows for an expansive littoral zone, Lake Okeechobee for example has a littoral zone that is roughly twenty-five percent of its total area at about 150 square miles (FDEP 2013).

| **Lake Measurements** | | | |
|---|---|---|---|
| | Average Depth | Lake Area | Lake Volume |
| Lake Okeechobee | 9 ft | 467,200 acres | 4,216,000 acre-feet |
| Falls Lake | 12 ft | 12,410 acres | 131,395 acre-feet |
| Jordan Lake | 14 ft | 13,900 acres | 140,400 acre-feet |

**Table 1.** Table showing physical characteristics of the three study lakes. Data provided by the NCDENR and the FDEP.

### Nutrient Analysis:

The US EPA has set forth recommendations for nutrient levels in surface water, but left it up to individual states to create their own nutrient management strategies. Table 2 shows the EPA's recommended nutrient levels based on large, aggregate ecoregions.

"*The EPA's recommended ecoregional nutrient criteria represent conditions of surface waters that have minimal impacts caused by human activities* (US EPA 2002)."

The recommended nutrient criteria values set forth by the EPA are quite stringent, and meant as a "best case scenario" that the states should work towards as a goal, the lakes in this study all fall short of these recommendations due to their connection to human activity. The recommended nutrient criteria are meant to inspire state governments to return impaired waters back to a natural state (or as close as can be achieved) through legislation, the development of nutrient management strategies, BMPs, etc. At the time of this report North Carolina (ecoregion IX) has not set any N or P criteria for surface waters (NCDENR 2015). Florida (ecoregion XIII) has set its criteria for N and P in surface waters to a non-specific level of "not to interfere with native flora and fauna" (FDEP 2014). Both NC and FL adhere to the national criteria of chlorophyll-a in drinking water of 40µg/L, however levels in surface water reservoirs frequently exceed this amount (US EPA 2013). There is expected to be some natural fluctuation in the concentration of nutrients contained in surface waters due to differences in the amount of rainfall, amount of evaporation, and amount of effluent discharged into the water body or watershed (Pfeifle, Giorgino, & Rasmussen 2014). The lakes in this study show some of this normal-type fluctuation, however (with the exception of phosphorus in Lake Okeechobee), nutrient levels in all three lakes have trended upward between 2000 and 2015 despite legislation and remediation efforts.

| **EPA Recommendations for State Nutrient Criteria Based on Aggregate Ecoregions** | | | |
|---|---|---|---|
| | Chlorophyll-a | Total Nitrogen | Total Phosphorus |
| North Carolina (IX) | 4.93 µg/L | 0.36 mg/L | 20.00 µg/L |
| Florida (XIII) | 12.35 µg/L | 1.27 mg/L | 17.50 µg/L |

**Table 2.** EPA recommendations for nutrient levels in surface waters (US EPA 2013).

Phosphorus is the primary limiting nutrient in freshwater aquatic ecosystems, and as a result, primary productivity (including algal growth) increases with phosphorus levels (Paerl & Otten 2013). Cyanobacteria are capable of sequestering phosphorus for later use when it is plentiful, and some also have the ability to fix nitrogen when phosphorus is limited. For this reason it is imperative to reduce phosphorus (and other nutrients like N) loads to water reservoirs in order to reduce the frequency of harmful blooms (Paerl & Otten 2013). Figure 1 shows the trends in total phosphorus for all three studied lakes for the years 2000 - 2015. The large peak in phosphorus for Lake Okeechobee, highest in 2005 at 233 µg/L, is due to several years of high hurricane and tropical storm activity that greatly increased runoff amounts (FDEP 2014). The drop in phosphorus in Lake Okeechobee beginning in 2005-2006 is likely due to the implementation of constructed wetlands and the adoption of Best Management Practices by farmers in the watershed that occurred at that time. The peak in TP for Falls Lake in 2011 had no single identifiable cause other than the general increase in urban development of Durham, NC (NCDENR 2013). TP levels for all three lakes fluctuated during the 15 year period represented by the figure, however, for none of the lakes did TP levels ever come close to the EPA recommendations for TP. This activity suggests that current preventative measures and remediation efforts may be sufficient to bring the total phosphorus level back to a base line amount of 100 – 150 µg/L after a higher period or peak, however they do not seem to be effective at the further reduction of the total phosphorus in the water body. For this reason, many states including North Carolina and Florida, are taking a multi-faceted approach to the overall reduction of TP in the water supply that includes preventative legislation, chemical treatments, and even mechanical means, however, no "silver-bullet" has been found to bring phosphorus down to criteria levels.

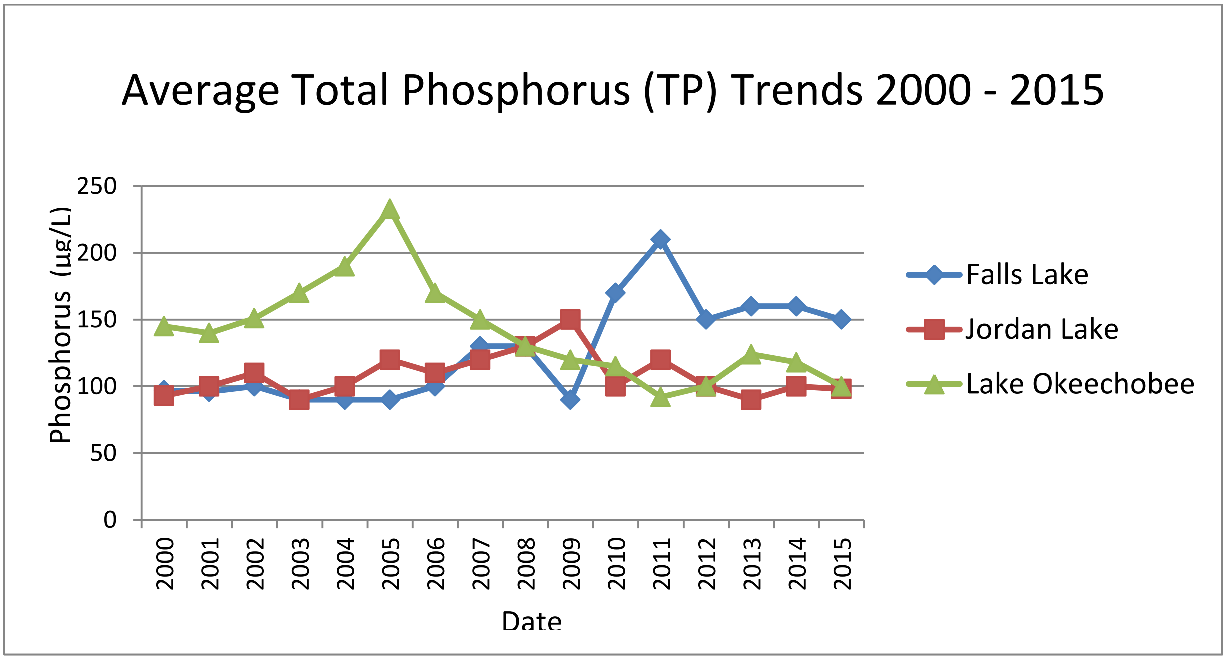


**Figure 1.** Graph representing the average TP level at each of the three study lakes for years 2000 through 2015. (Numerical data provided by the FDEP and NCDENR)

Nitrogen levels are an important indicator of the potential for cyanobacterial activity, because many genera of cyanobacteria (including *Anabaena* and *Cylindrospermopsis*) can fix nitrogen, giving them a competitive advantage in ecosystems where there is a high P to N ratio (Paerl & Otten 2013). In addition, non-nitrogen fixing genera like *Microcystis* can exhibit bloom formations in high N:P environments (Paerl & Otten 2013). Figure 2 shows the average trends in total nitrogen for all three lakes in the study. While there has been some fluctuation in TN levels throughout the 2000-2015 period of time, levels have never decreased significantly below historic levels. Lake Okeechobee consistently has the highest TN of the three lakes studied with most sample readings falling between 1.5 and 2.0 mg/L, and TN for Falls Lake and Jordan Lake has an upward trend, in both cases, from less than 1 mg/L to over 1 mg/L. The high amount of TN in Lake Okeechobee can be attributed to its relationship with the high amount of agriculture in its watershed. Nitrogen is found in animal (and human) waste which can be discharged into the watershed, and ultimately makes its way to the Lake. Such discharges occur frequently along the Kissimmee River, which is the main source of surface water to Lake Okeechobee (31% of total incoming water) (FDEP 2001). The three studied lakes are still in exceedance of the EPA recommendations for total nitrogen and levels are continuing to increase despite BMP's and legislation aimed at the reduction of eutrophication and excessive algal growth.

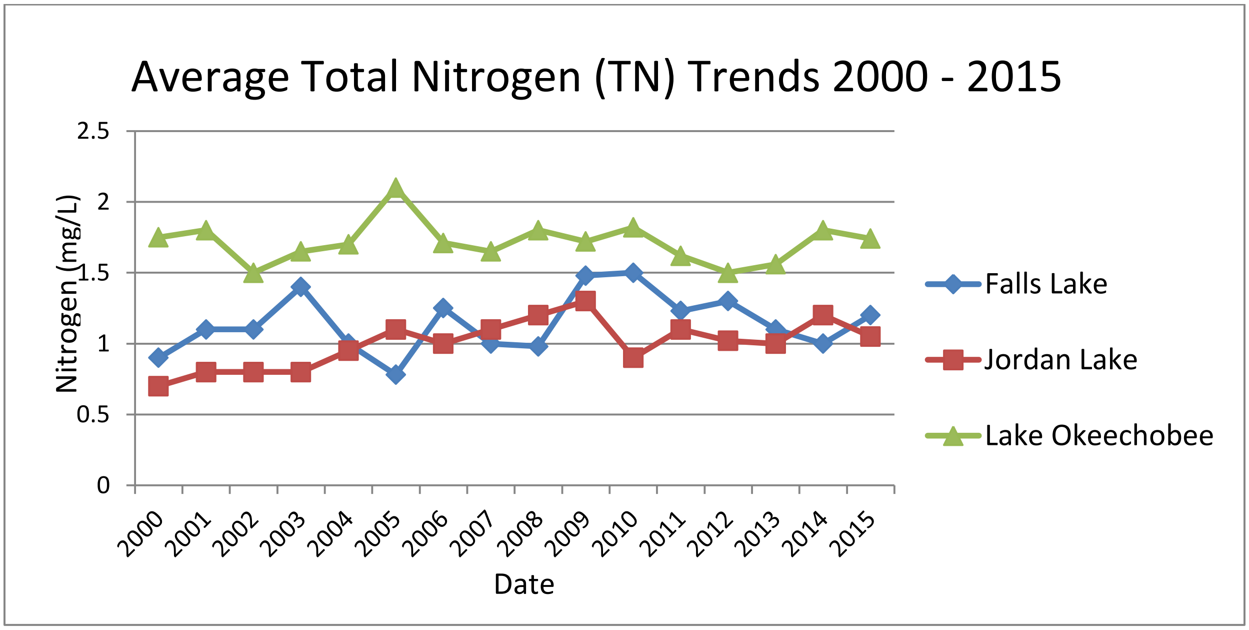


**Figure 2.** Graph representing the average TN at each of the three study lakes for years 2000 through 2015. (Numerical data provided by the NCDENR and the FDEP)

An important indicator of a water body's primary productivity is the concentration of chlorophyll-a; high levels can mean that a large mass of cyanobacteria and other algae has formed and may have ecological implications such as low dissolved oxygen levels which can cause fish kills (Burkholder 2010). The nationally accepted standard for chlorophyll-a in drinking water is 40 µg/L, however the EPA's recommended ecoregional nutrient criteria limits for surface waters are more stringent with 4.93 µg/L recommended for NC and 12.93 µg/L for surface waters in the southern part of FL (US EPA 2013). Falls Lake and Lake Okeechobee are regularly below 40 µg/L on average for the total lake, however there is a fluctuation that occurs year-to-year. Some specific sites in these lakes, for example the Haw River arm of Falls Lake, regularly test above 40 µg/L (NCDENR 2013). In addition to increased chlorophyll-a levels from anthropogenic nutrient loading, there is some natural fluctuation due to temperature changes (cyanobacteria thrive in warmer waters), hydrological events such as precipitation and evaporation, and changes in water chemistry (Paerl & Otten 2013). Figure 3 shows the trends in chlorophyll-a concentrations for all three study lakes for the years 2000 through 2015. All three of the lakes had a rise in chlorophyll-a in the years 2006 – 2008, then values began to return to that of previous years, however, the values for chlorophyll-a in all three lakes during successive years are generally greater than the values from the previous year which promotes the notion that an upward trend in algal productivity is continuing in these lakes despite current remediation/preventive practices. The average chlorophyll-a concentrations are higher in all three lakes in 2015 than they were in 2000; 25 to 27 µg/L in Falls Lake, 38 to 43.5 µg/L in Jordan Lake, and 21 to 26 µg/L in Lake Okeechobee. As the nutrient levels have continued to trend upward so has algal growth, and with it, levels of chlorophyll-a have increased.

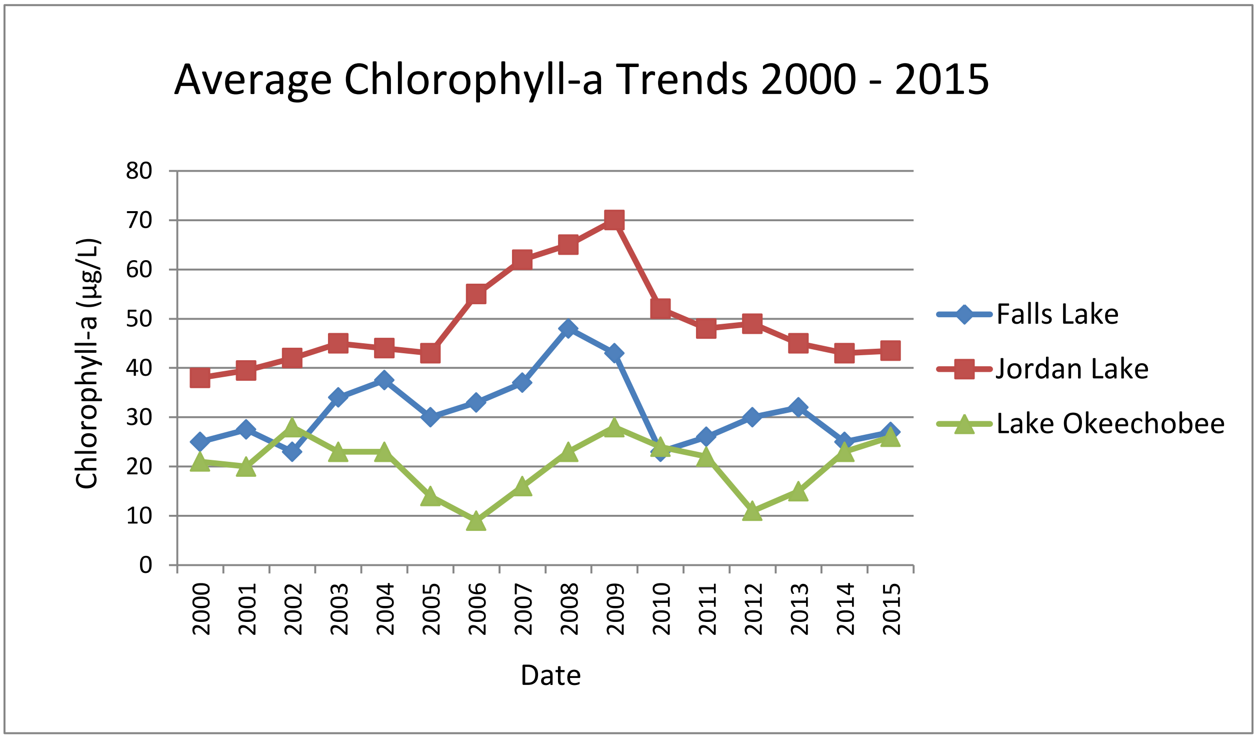


**Figure 3.** Graph representing the average chlorophyll-a concentrations at each of the three study lakes for years 2000 through 2015. (Numerical data provided by the NCDENR and the FDEP)

## History of Legislation and Remediation Efforts:

An important part of the analysis of these lakes was an examination of the lakes' histories regarding legislation and any remediation efforts that have been put into place. Legislative documents, water quality reports, management strategies, incident reports, and other documents were reviewed and compiled into the timelines that follow. These timelines give a "snapshot" of the issues that the lakes have had over the years and the efforts of the state/federal government to correct them. Both Falls Lake and Jordan Lake were classified as eutrophic very soon after their creation in the early 1980s, and remediation efforts along with statewide legislative actions aimed at reducing nutrient loading were implemented several years later. While Lake Okeechobee is considerably older than Falls Lake and Jordan Lake, and has had water quality issues since the 1940s, there was no legislation specifically designed for the nutrient problems in Lake Okeechobee until the year 2000. One emergent trend in all lakes is a period of legislation followed by being classified as impaired or eutrophic, more legislation then still classified as impaired or eutrophic, and so on. This trend highlights the need for more intensive actions to take control of the nutrient/algal problems in these lakes. The need for more intensive measures has prompted the use of novel technologies like Solarbees, in hopes that this new technology will be able to achieve what has so far been unachievable, the reduction of nutrients back to levels that mimic pristine natural waters.

## Falls Lake Timeline

- 1981 – Construction of Falls Lake Dam is completed
- 1983 – Falls Lake finishes filling, and immediately is classified as a Nutrient Sensitive Water.
- 1988 – Due to a rise in phosphorus levels, a statewide phosphate detergent ban is enacted by the NC General Assembly.
- 1992 – NC DENR releases the Lakes Assessment Report, which classifies Falls Lake as eutrophic.
- 1996 – The City of Durham and others form the Upper Neuse River Basin Association (UNRBA).
- 1997 – The North Carolina General Assembly enacts S.L. 1997-458, the Clean Water Responsibility and Environmentally Sound Policy Act, aimed at reducing runoff and restoring waters in the state.
- 1997 – The North Carolina Environmental Management Commission (EMC) adopts the Neuse River Nutrient Sensitive Waters Management Strategy.
- March 2001 – The City of Durham implements new development standards which attempt to regulate runoff from new construction in the area.
- November 2001 – NC DENR releases the Neuse River Basinwide Assessment Report in which Falls Lake is once again classified as eutrophic.
- 2003 – The UNRBA releases the Upper Neuse Watershed Management Plan which covers the entire watershed draining into Falls Lake.
- March 2005 – Rising nitrogen levels in waters downstream from the Butner wastewater treatment plant cause the Division of Water Quality to increase monitoring of Falls Lake.
- July 2005 – NC General Assembly passes the Drinking Water Supply Reservoir Act (Senate Bill 981/S.L. 2005-190) which requires that the EMC develop and adopt a nutrient management strategy for Falls Lake.
- 2006 – NC DENR releases the Neuse River Basinwide Assessment Report in which Falls Lake remains classified as eutrophic.
- 2007 – Increased monitoring by the DWQ of Falls Lake (begun in March 2005) is completed: findings include high levels of chlorophyll-a, high turbidity, and excessive levels of nitrogen and phosphorus.
- January 2008 – Falls Lake is listed on the 2008 impaired waters list for chlorophyll-a.

- June 2008 – Fish kill of 600+ catfish is reported by recreational fisherman, and confirmed by DWQ.
- August 2009 – NC General Assembly approves Senate Bill 1020/S.L. 2009-486 which allows an extension until January, 2010 for the EMC to implement more nutrient management strategies in the Neuse River Basin.
- November 2009 – The DWQ releases the Falls Lake Nutrient Response Model Final Report and presents to the EMC.
- 2010 – The EMC adopts the Falls Lake Nutrient Management Strategy; detailing efforts to enhance and improve water quality.
- 2011 – The NC DENR releases the Neuse River Lake and Reservoir Assessment which again classifies Falls Lake as eutrophic.

<u>Jordan Lake Timeline</u>

- 1963 - U.S. Congress authorized New Hope dam; litigation and impact studies delayed construction.
- 1983 - Jordan Lake impounded and classified as a nutrient sensitive water. From this point on, Jordan Lake is almost always listed as eutrophic or hyper-eutrophic.
- 1997 - NC General Assembly enacts Clean Water Responsibility Act (CWRA), S.L. 1997-458. According to this timetable, rules to limit nitrogen and phosphorous inflows to Jordan Lake, and upgrades to wastewater treatment plants, should be finalized by 2003.
- 1999 - Several Haw River municipalities sought and received a 'compliance extension' to model the lake and build rules based on that model.
- 2002 - Upper New Hope arm of lake listed as impaired for chlorophyll-a (algae). Environmental Management Commission (EMC) approved model for lake which showed that tighter restrictions on pollution were needed.
- 2003 - Department of Environment & Natural Resources (DENR) begins first stakeholder process to develop rules. Town of Cary receives extensive taste and odor complaints about water drawn from Jordan Lake.
- 2005 - EMC's Water Quality Committee votes to send draft rules to public comment, but in response to concern from stakeholders (organized by Greensboro and Burlington), EMC delays for more discussions. Clean Lakes Act, S.L. 2005-190, directs EMC to adopt permanent rules to protect reservoirs. In July and August 2005, DWQ finds elevated pH (9.5) in Haw River and New Hope arms of lake.
- 2006 - Lower New Hope arm and Haw River arm of lake listed as impaired for chlorophyll-a (algae); Haw River arm also listed as impaired for high pH (alkalinity), an effect of the decomposition of algal blooms. Fish kill documented in March 2006 on Upper New Hope arm of lake with approx. 50 fish found in water with DO of 106% and

pH 8.5. Algal sampling at the site revealed a phytoplankton density of 45,000 units/ml with the dominant taxon being Pseudanabaena at 10,000 units/ml. DENR hosts second stakeholder process with 27 meetings.

- 2007 - EMC votes to send draft rules to public comment in March. Comment period runs through August. EMC Commissioners hold series of 14 meetings to incorporate comments and revise rules, ending April 2008.
- 2008 - EMC approves Jordan Lake nutrient rules in June. After series of five meetings, Rules Review Commission finishes approving rules in November.
- 2009 - Disapproval bills introduced at the beginning of session, stakeholder negotiations ensue. S.L. 2009-216 (HB239) contains bulk of compromise, extending a long timeline for compliance and moving compliance date for upgrades to Greensboro's wastewater treatment plant from 2014 to 2016. Negotiated timeline projects new development standards being adopted by local governments by ordinance in 2012. S.L. 2009-484 (SB838) makes change sought by development interests to new development rule, to provide more flexibility in meeting load reduction targets, including buying offsets elsewhere in the watershed.
- 2011 - S.L. 2011-394, Amend Environmental Laws 2011 (HB 119), Section 10, pushes back the deadline for Greensboro to upgrade its wastewater treatment plant from 2016 to 2018, if by the end of 2016 the city obtains a permit to build the upgrade.
- 2012 - S.L. 2012-200, Amend Environmental Laws 2012 (SB 229), Section 9, pushes back the deadline for local governments to adopt ordinances requiring control of stormwater from new development from 2012 to 2014. Roughly half the jurisdictions in the watershed have already adopted new development ordinances, most in the last two years.
- 2013 - S.L. 2013-360, Section 14.3A requires the DENR to establish a 24 – month water quality demonstration project (Solarbee) on Jordan Lake. The department of water quality will contract with a third party to provide, operate, monitor, evaluate, and report on the performance of lake circulators in reducing the adverse harmful effects of algal blooms and excessive chlorophyll in the lake.
- 2013 - S.L. 2013-395 is signed on August 23, 2013 which delays any future rule implementation by three years, pending the results of the water quality demonstration outlined in S.L. 2013-360.

Lake Okeechobee/Everglades Timeline:

Due to its connection to an extensive hydrologic network that includes the Everglades and the Kissimmee River and its watershed, the Lake Okeechobee timeline includes information pertaining to the Everglades as well. The Everglades were the focus of protective acts and legislation beginning in the late 1980s/early 1990s; these acts, due to their hydrologic connection, affected Lake Okeechobee.

- Approximately 6000 years ago Lake Okeechobee is formed in a depression created by the recession of ocean waters.
- 1988 – A settlement agreement is reached between the Federal and Florida state government regarding water quality standards in Everglades National Park and submitted to the state legislature for review.
- 1991 – The Florida Legislature passes the Marjory Stoneman Douglas Everglades Protection Act (MSDEPA) to restore the Everglades.
- 1992 – Approval of the MSDEPA allows Florida and the South Florida Water Management District (SFWMD) to construct 32,000 acres of Stormwater Treatment Areas, including monitoring stations and formulas for evaluating phosphorus levels at discharge of 50 ppb.
- 1994 – The Florida State Legislature passes the Everglades Protection Act directing the state to develop criteria for phosphorus level in the Everglades Protection Area and to implement a best management practices program.
- 1996 – Farmers in the affected area begin to implement the approved best management practices in hopes of controlling phosphorus loading into the watershed.
- 1997 – The SFWMD finishes construction of the first of six Stormwater Treatment Areas, manufactured wetlands that will act to remove excess phosphorus through biological means.
- May 2000 – The Florida Legislature passes the Everglades Restoration Investment Act which allows funding in conjunction with the federal government for the implementation of the Comprehensive Everglades Restoration Plan (CERP).
- June 2000 – The Florida Legislature passes the Lake Okeechobee Protection Act, the first piece of legislation aimed specifically at the protection and restoration of the lake.
- December 2000 – President Clinton authorizes the Water Resources Development Act which allows $11 billion for implementation of the CERP.

- 2002 – President Bush and Florida Governor Jeb Bush sign an agreement that protects impaired waters in Florida under state law as a condition of receiving federal funding.
- January 2004 – The Lake Okeechobee Protection Plan is presented to the Governor and Legislature. The plan contains a schedule for the implementation of varying degrees of load reduction needed to achieve the Lake Okeechobee Phosphorus Maximum Daily Load.
- June 2004 – US Army Corps of Engineers breaks ground on approximately 1000 acres of treatment marshes designed to clean water entering Lake Okeechobee.
- 2005 – Florida Governor Jeb Bush presents the Lake Okeechobee and Estuary Recovery Plan to accelerate the recovery of Lake Okeechobee.
- April 2006 – Construction is completed on several projects aimed at the reduction of phosphorus loading into Lake Okeechobee including the Taylor Creek Stormwater Treatment Area, and the Lake Okeechobee Water Retention and Phosphorus Removal Center.
- June 2006 – The US Army Corps of Engineers breaks ground on the Lake Okeechobee Aquifer Storage and Recovery Project under the CERP.
- October 2006 – Farmers in the Okeechobee watershed adopt Best Management Practices aimed at reducing nutrient runoff.
- May 2007 – The Florida State Legislature passes Senate Bill 392, the Northern Everglades and Estuaries Protection Program (NEEPP) which expands the Lake Okeechobee Protection Act to include protection and restoration of the Lake Okeechobee Watershed including the Caloosahatchee and St. Lucie rivers.
- October 2007 – Construction is completed on the 6 man-made wetlands covering 45,000 acres of land south of Lake Okeechobee that are responsible for removing phosphorus from waters flowing into the lake.
- 2008 - The SFWMD begins negotiations to purchase 187,000 acres of agricultural land owned by the United States Sugar Corporation to begin the remediation of land and waterways between Lake Okeechobee and the Everglades.
- 2009 – The SFWMD approves the negotiations to purchase 73,000 acres of land in the Everglades Agricultural Area from the United States Sugar Corporation for $540 million dollars.
- 2015 – A large algal bloom causes water quality issues, shuts down beaches, and forces the SFWMD to stop all flow from the lake to the east coast.

# Conclusion

The ability of municipalities to regulate the nutrient levels of water sources is a key component in the quest to reduce the harmful effects associated with blooms of cyanobacteria. While both Florida and North Carolina have BMP's and legislation in place aimed at the reduction of nutrients in runoff, nutrient levels have continued to rise over the years keeping those water bodies at risk for future algal events. Current measures seem sufficient to reduce spikes in nutrient loads back to a historic mean, but insufficient at reducing these loads to the EPA's recommended levels and in to a state that will inhibit the growth of cyanobacteria. Florida has shown some success with the reduction of total phosphorus in Lake Okeechobee, most likely due to the use of many acres of constructed wetlands. Unfortunately, geographic location is prohibitive of the use of these wetlands in the NC reservoirs as urban areas are often located adjacent to the water source. Stricter BMP's or legislation will most likely be required to achieve the reduction in TP and TN that is sought by authorities in order to reduce the occurrence of cyanobacteria bloom events. Unfortunately, mechanical means of disrupting the algal masses by means of solar lake mixers (i.e. Solarbees) has been shown to be very poor at the overall reduction of cyanobacteria in the water column and "are unable to adequately mix lakes and reservoirs to effectively control cyanobacterial blooms" (Upadhyay *et al.* 2013). With urbanization and runoff on the rise, more effective measures must be created to deal with the continuing problem of eutrophication and harmful algal blooms in drinking water reservoirs in the US, current measures are simply not enough.

With nutrient levels continuing to climb in the municipal waters of the SE United States, and indeed nationwide, there is certainly more room and need for additional study on this problem. The development of new farming techniques and fertilizers could be a key to nutrient reduction, as could the implementation of novel remediation technologies for waters that are already considered impaired. Lawmakers and politicians can play a role in the achievement of nutrient criteria goals with the passage of new legislation aimed at further reductions in nutrient loads. The future of these waters is uncertain at the current time with an ongoing struggle between continuing development and economic growth, and the public desire for clean, potable water.

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