Assessing the Relative Importance of White Lake's Nutrient Sources

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Summary

The most significant phosphorus sources are rainfall and the sediments, while the most significant nitrogen source is rainfall. The sediments contain relatively high aluminum and iron concentrations (which bind with phosphorus) so sediment phosphorus inactivation as a mitigation tool does not appear to be warranted. However, there are conditions in which sediment phosphorus can become bioavailable (high pH, sediment resuspension). High pH conditions result from cyanobacterial blooms, so having an action plan to mitigate any future blooms (and high water- column phosphorus levels) would be prudent.

Looking back at nutrient data collected in 1974, White Lake water column phosphorus levels have not changed much over time, but nitrogen levels have changed considerably, so that N:P ratios now are different from the past.

The significant influences of rainfall chemistry on White Lake have been unrecognized previously. This may be because the changes in chemistry (less acidity, more nutrients) have happened incrementally, although it also appears that the longstanding assumption that groundwater/springs were the primary source of water to the lake (and therefore the primary source of nutrient enrichment/lake changes) limited our viewpoint.

In North Carolina agricultural influences on the atmosphere and on rainfall nitrogen in particular are well-known, as the well-studied Neuse River Estuary is nitrogen-sensitive. Incorporating more granular weather data with lake monitoring data, and monitoring rainfall nutrients (both nitrogen and phosphorus) on a sustained basis will help us better understand how the lake is responding to changes triggered by weather and climate change.

Lake monitoring indicates that there is some variability in nutrient levels, phytoplankton biomass, and amount of aquatic vegetation and bottom algae mats from year to year, which is to be expected, as no lake is a static system. It seems that 2020 so far is an outlier (much like 2013), with big rains resulting in pulses of nutrients entering the lake: from runoff, from groundwater (when the water table is high), and particularly from the rain itself. These nutrients are what the phytoplankton—the algae suspended in the water column--are responding to, so lake clarity changes as a result.

Helping White Lake to be as clear and healthy as possible requires an acknowledgement that the lake has been affected by and changed by human actions. Increased nutrients, coming in from the air and the rain, coming in from the very altered landscape around the lake, and coming in from the groundwater, are consequences of human activities and alterations that cannot be ignored in any search for "lake clarity".

White Lake should not be a stormwater pond. We know how to manage land development so that lake water quality is protected. While the focus of the stormwater assessment project was nutrients, we know that there are other contaminants in stormwater, so implementing a comprehensive stormwater management program will provide multiple benefits. The relatively high aluminum concentrations in stormwater indicates that acquiring wetlands to provide natural treatment (as well as recharge of the groundwater) would be a good option to pursue.

We know that old leaky wastewater pipes and manholes have the potential to enrich the groundwater that eventually makes its way to the lake, and when condition assessments find problems, they can be (and are being) addressed—but it is hugely expensive, and takes a long time to actually get to the construction phase. Better communications as to what is being done and where should be possible.

We know that there are huge numbers of seagulls roosting in the lake in winter months, but the impact on nutrients is difficult to distinguish from other sources. It is not realistic to expect seagull control over the long term. We might find more success with controlling geese, as they spend a significant portion of time on the shore.

We know that stirring up the lake bottom has a negative impact on the health of the lake, and we know how to distinguish good boating practices from harmful ones. Much better communication with this topic can result in behavior change that will be meaningful for the lake, and ultimately the community that depends on it.

<u>Introduction</u>

White Lake has long been celebrated for the clarity of its water, and as a result, the community consists of dense development around its nearly five-mile lakeshore. It has often been described as a spring-fed lake, and recent hydrological work has found that groundwater from the surficial aquifer enters the lake when the water table is high, contributing a maximum of 6% of lake volume. Groundwater flow generally moves from east to west, towards the Cape Fear River (Shank and Zamora 2019). Limited groundwater level monitoring by NC DEQ also noted the association between levels in a shallow onshore well and a shallow in-lake well (NC DEQ 2017). Rainfall onto the lake surface is the primary source water, as there is no defined inlet to the lake (the watershed is small) and surface runoff is relatively low by comparison.

White Lake's productivity has been variable over time, and most of the primary productivity has been associated with the lake bottom (benthic filamentous green algae and aquatic vegetation such as the low-growing spikerush; e.g., NC DWR 1979). Phytoplankton (algae suspended in the water column) abundance has generally been moderate to low (below 10 µg/L chlorophyll *a*) although there have been brief periods in which clarity (as measured by Secchi depth) has been reduced (July 1998 for example; NCDENR 2014, NC DEQ 2017).

Substantially higher phytoplankton abundance was first seen in the summer of 2013, and this was the first time in which the pH of the lake water was above 6 (but no measurements were done over the period 2009-2012;NCDENR 2014). What was not recognized at the time was the substantial change in the pH of rainfall that had occurred, from 4.5 up to 5.8, with the changes being most rapid during the period 2008-2013 (NADP 2019). As the buffering capacity of the lake water is relatively low, higher algal photosynthesis removes carbon dioxide (which serves as an acid) from the water, and lake pH levels can increase as a result.

An assessment of all potential nutrient sources and their relative importance is the first step in understanding a lake's productivity, but at White Lake, this must be done in the context of understanding the lake's hydrology and the change in the lake's pH—it had been an acid-rain influenced lake, and had undergone change relatively rapidly.

Special projects and monitoring activities at White Lake in recent years have provided more information as to the relative importance of the internal and external nutrient sources: sediments (internal source), groundwater, surface runoff and stormwater, rainfall, and birds (all of these are external sources), and how conditions related to inputs have changed over time. The different sources are considered separately in the following sections of this report; supporting data from lake monitoring, rainfall sampling, stormwater sampling and sediment sampling are also included. The conclusions section includes a brief discussion of management options.

I. Nutrients Already in the Lake

The once-living material in lakes (such aquatic vegetation and algae) either stays within the system, settling out to the bottom sediments, or is exported (washing up onto the lake shore or flushed out through a lake outlet). Lake sediments can therefore be considered as a storehouse for decomposing organic matter and nutrients, particularly for the nutrient phosphorus.

It is generally recognized that sediments play a very important role in phosphorus cycling within shallow lakes, as there is less volume of water overlying the sediment surface, and the processes that regulate P cycling, such as interactions among dissolved oxygen, pH, temperature, and microbial activity, can exert more influence (e.g., Forsberg 1985).

Two of the Bay Lakes, White Lake and Lake Waccamaw, were sampled in February 2019 in order to assess similarities and differences in sediment phosphorus between the two systems. While White Lake is a rainfall-fed seepage lake (no significant inlet) and Lake Waccamaw is a blackwater drainage lake (a relatively large inlet, Big Creek), both lakes have experienced years in which productivity has been relatively high (large amounts of aquatic vegetation or filamentous algae mats). In recent years there have been significant changes in each lake with respect to the types of algae and aquatic vegetation found: the aquatic invasive weed *Hydrilla* has been found in both lakes, and at Waccamaw herbicide treatments were made from 2013-2019, while at White Lake a low-dose alum treatment was done in May of 2018 to mitigate a water-column cyanobacterial bloom.

There are several naturally occurring elements, such as iron, aluminum and calcium, that can serve as adsorbents of phosphorus; in the muddy sediments of both Lake Waccamaw and White Lake, aluminum concentrations were high (and very similar), while iron concentrations in Lake Waccamaw were higher than in White Lake.

Total Phosphorus (TP) levels were higher in Lake Waccamaw sediments, while in each lake TP concentrations diminished with sediment depth. In both lakes the relative importance of the different sediment P fractions was the same:

Al-Bound P >Biogenic P >Fe-Bound P >Ca-Bound P >Loosely-Bound P

Additionally, intact cores from both lakes were incubated under anoxic conditions over a 14-day period with results from both lakes indicating no significant P release, likely due to the adsorptive capacity of the relatively abundant aluminum in sediments of each lake. This means that phosphorus inactivation of the sediments, a common lake management tool, is not needed at either lake.

Nutrients sequestered within living algae, plants and animals are recycled through the process of microbial decomposition, which is influenced by temperature, so that recycling can be rapid during the summer months when water temperatures are highest. The relatively high proportion of biogenic phosphorus in both lakes—which is not bound but rather readily available to fuel algal and plant growth--indicates that internal recycling plays an important role in both systems. See the White Lake Watch web site (www.whitelakewatch.com) for the study description and results.

Sediment resuspension, induced by wind-driven surface waves as well as boat traffic can cause substantial increases in water column concentrations of suspended solids and nutrients (e.g., Anthony and Downing 2003). As White Lake is very shallow (average depth 6.4 feet or less depending on lake level) there have been long-standing concerns about the increased turbidity and filamentous algae collecting in nearshore areas with summer boating activity (Fig. N1).

Figure N1. White Lake shoreline near Nathan's Cove (southwestern shoreline) with muddy sediments creating a visible dark zone over the white sand.

Additionally, boating activity can readily dislodge vegetation such as the low-growing but abundant spikerush (*Eleocharis baldwinii*) and mats of filamentous algae; all of this material eventually moves into shallow areas where wave action causes it to collect along seawalls and sandy shoreline areas, where it decomposes (releasing nutrients that can be recycled readily). Changing boating practices to reduce impacts to the lake has no significant costs to implement, but requires behavior change by a relatively large group, as skiing, tubing, and wave boarding are very popular in this shallow lake.

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II. Nutrients in Groundwater

There have been two recent studies of groundwater at White Lake: one undertaken in 2017 by NC DEQ, and one done for the Town in 2018-2019 by the Bald Head Island Conservancy/UNC-Wilmington.

Groundwater sampling wells were installed at two locations in 2017—one site along the eastern shore, and one site on the western shore of the lake (NC DEQ 2017). At each site, a shallow well and a deep well (25 ft. depth) was located on shore, while a shallow well was also located in the lake. A summary of the data in the 2017 NC DEQ report:

- shallow on-shore wells had higher nutrient levels compared to the deeper wells
- total phosphorus levels in shallow wells averaged 0.50 mg/L compared to the deep wells with a mean of 0.12 mg/L.
- ammonium concentrations were higher on the eastern side of the lake (mean 3.0 mg/L for eastern and 1.77 mg/L for western).
- organic nitrogen concentrations were higher on the eastern side of the lake (mean 2.2 mg/L for eastern and 1.2 mg/L for western), and this trend was also observed in the deeper wells (0.59 mg/L for eastern and 0.19 mg/L for western).
- the in-lake well reflected conditions in White Lake, (with comparable pH, dissolved oxygen, and conductivity measured in the June sampling event; these parameters were not measured on subsequent sample dates) with total phosphorus and total nitrogen values equivalent to lake values. In-lake well inorganic nitrogen was below detection level for each of three sample dates, as it was in lake samples (NC DEQ 2017).

The groundwater sampling by Shank and Zamora (2019) was done over the period February 2018 to January 2019, with a series of wells installed at five locations around the lakeshore. There had been some concern expressed that the wells that had been installed had not been sealed with bentonite clay, so that surface contamination (such as pet waste) may have occurred (which would have affected nutrient concentrations). Two hotspots were noted in their report: a site near the lake on Timberlodge Village Drive (the well was located in a vegetated island that was observed to be popular with pets [left photo in Fig. N2]), and a site near the lake edge at the end of Godwin Road (in which the well was located close to a residence, and the sewer cleanout for the residence [right photo in Fig. N2]).

Figure N2. Top photo: groundwater well at Timberlodge Lane, located in a landscaped island that is popular with dogs—the fencing was added by Town staff when they rehabbed the well. Bottom photo: groundwater well at Godwin Road that was also rehabbed by Town staff. The top pipe is a wastewater line cleanout. Recent attempts to collect well water from these sites have been unsuccessful (Bill Stafford, Town of White Lake, personal communication).

Phosphorus levels in the shallow groundwater may be expected to reflect a combination of factors, including soil organic matter content and pH (e.g., Cheesman et al. 2014), microbial communities present (as they influence biogeochemistry), aluminum content (e.g., Richardson 1985), and any enrichment from fertilizers and wastewater exfiltration. The studies that have been done to date (NC DEQ 2018, Shank and Zamora 2019) were not designed to distinguish between naturally-occurring nutrients and contamination sources; a larger-scale and more detailed assessment would be needed in order to accurately quantify groundwater nutrient sources, and the variability in seasonal water table levels and seasonal wastewater flows suggests that the study would need to be lengthy in order to provide reliable data.

Groundwater nutrient inputs to lakes are typically measured by use of seepage meters placed in the lake to capture groundwater seeping in from the lake bottom (e.g., Lee 1977). At White Lake, this would best be done when the water table levels are high, which is often during the winter months. As noted in Shank and Zamora (2019), the white sand depressions visible along the eastern side of the lake may represent preferential groundwater flow paths that terminate in the lake to produce freshwater springs, and these sites would be expected to have the chemical signature of the surficial aquifer groundwater—including the nutrient concentrations—so they would be the ideal place to locate seepage meters. Previous efforts to detect temperature/pH changes in lake water at these sites, going back as far as the late 1940's, when David Frey was investigating the lake have not been successful in detecting any variations (Frey 1949, NC DEQ 2017), which is another indication that flow rates are variable and associated with water table level, which also varies.

Section References

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III. Nutrients Entering the Lake in Surface Runoff and Stormwater

Most of the existing stormwater infrastructure around White Lake is associated with the roads (US Hwy 701, SR 1515/White Lake Drive, Hwy. 53), which are located on higher ground; this infrastructure directs stormwater away from the lake. Two NC Department of Transportation culverts under White Lake Drive direct surface water towards the lake, via drainage ditches. As these ditches drain an area of approximately 50 acres, the flow rates are relatively high (compared to other runoff situations) after significant rainfall.

Many of the outfalls to the lake are draining relatively small areas such as lawns, while there are several locations where larger areas, including parking lots and streets are draining directly into the lake. A total of 57 pipes and ditches drain to the lake, and the Lumber River COG has put all of these into a GIS map (along with all of the other Town/DOT infrastructure) by the as part of a 205 (j) Water Quality Planning Grant awarded in 2019.

Stormwater water quality testing (primarily for phosphorus and nitrogen compounds) of outfalls, ditches and other areas where runoff was observed was conducted from January to April 2020. Rainfall during this period was above average, and the highest rainfall, 3 inches, occurred February 6-7.

Higher rainfall amounts, particularly in the winter when the water table is higher, can result in more runoff entering the lake. Of the locations sampled for the stormwater project, the highest phosphorus concentration (0.113 mg P/L) was found in (unpaved) street runoff at the lakeshore end of Woodbury Road (on the western side of the lake) on February 7, 2020:

Figure N3. Standing water after a three-inch rain, running along Woodbury Road and into the lake. The volume of water entering the lake here, relative to other runoff situations, was low.

Another hotspot was found on the northeastern side of the lake: the drainage ditch behind the Bladen Medical Center (off White Lake Drive/Lennondale Road; Fig. N4), which drains a commercial and residential area, with the water eventually entering the lake at the two DOT ditches along White Lake Drive (Fig. N5, N6).

Figure N4. Stormwater ditch behind Bladen Medical Center at White Lake Drive and Lennondale Road, after the same three-inch rain, February 7, 2020. Note the cloudy appearance of the water.

Figure N5. Views of the NC DOT drainage ditch at 408 White Lake Drive on February 7, 2020. Residents on either side of the ditch are also draining their yards into the ditch (photo on right). This ditch is closer to (and connected to) the drainage area behind the Bladen Medical Center.

Each DOT drainage ditch on the west side of White Lake Drive connects a ditch on the east side by way of a culvert under White Lake Drive at each location. The force main for the Town's wastewater collection system runs along the western side of White Lake Drive, and this line can be seen by looking into the stormwater box at 408 White Lake Drive.

The ditch channel at 580 White Lake Drive is confined by railroad ties for about half of its length, and it appears to be better maintained (Fig. N6).

Figure N6. Top photo is the drainage ditch at 580 White Lake Drive, and bottom photo is a view of the lakeshore, showing the influence of the highly-colored ditch water on the lake. Photos taken February 7, 2020.

There has been a consistent difference in nutrient concentrations between the two DOT ditches (which was also seen in the 2017 sampling by NC DEQ): nutrient levels at 408 White Lake Drive are higher than levels at 580 White Lake Drive (and the pH levels are higher compared to 580 WLD); there is also variability in nutrient concentration over the duration of a rainfall/runoff event (the highest concentrations are generally found in the first portion of a runoff event and slowly decline with time), which suggests that there could be a benefit to having a natural wetland retention basin in the area to mitigate nutrients. It might also serve to enhance groundwater recharge, particularly as this portion of the lakeshore is more densely developed, with more impervious surfaces (more runoff, less infiltration).

Total Aluminum was relatively high in the drainage ditches (ranging from 0.89 to 1.23 mg/L) and also the outfall from Camp Clearwater (1.75 mg/L), and Dissolved Organic Carbon levels were also relatively high in the ditches (ranging from 65.2 to 79 mg/L)(Appendix N1). Upon entering the higher pH lake, this aluminum can, in essence, create a small-scale natural phosphorus inactivation process, as has been observed elsewhere (e.g., Kopacek et al 2000). Phosphorus removal with alum or similar products is commonly done for stormwater water quality improvement before entering a receiving water body (e.g., Scholz 2016).

Several of the larger pipes which drain into the lake were partially submerged during the period of stormwater sampling, as the winter rainfall had raised lake levels (Fig. N7).

Figure N7. Stormwater pipes under Nathan's Cove pier: left photo taken October 23, 2019 and right photo taken on February 13, 2020. Runoff is from an asphalt street/parking area for the condominiums.

A representative sample of asphalt runoff was taken at the White Lake Marina stormwater grate (located near the boat ramp) on February 14, 2020 (after a 0.25-inch rain the previous night), and phosphorus and nitrogen levels were similar to values found at the other stormwater sites (Appendix N1).

There is a cluster of three culverts just south of Camp Clearwater and one of these runs under White Lake Drive and drains stormwater from Camp Clearwater. As there is constant (but variable) flow from this pipe, it likely draining groundwater as well (Fig. N8). Sampling done in 2018 and 2019 indicates that there is some fecal coliform contamination at times, while Total Nitrogen and Total Phosphorus levels are similar to what has been found in stormwater samples elsewhere around the lake. Inorganic nitrogen in the form of nitrate-nitrite was relatively high on one sampling occasion (January 16, 2020; Appendix N1).

Figure N8. Views of the Camp Clearwater culverts and outfall. The culvert in the center with the chipped upper rim is the one that drains Camp Clearwater. Left photo taken May 22, 2019; middle photo taken January 26, 2020. The photo on the right shows the ditch created by the flows from the culverts (January 26, 2020). The delineation of the watershed (based on elevation) is located in Camp Clearwater, so that flow is directed away from the lake at this location.

The White Lake community has an intimate connection to the lake: each is dependent on the other for its health and viability. Using the lake as a de facto stormwater pond is "passing the buck"— the impacts of development (more contaminated runoff) are borne by the lake, and ultimately the entire community. The Town needs an effective stormwater management plan and a land use plan that makes lake health a priority. As some neighborhoods are not yet built out, it would seem that there are opportunities to include stormwater retention strategies that can benefit water quality, while other situations will require retrofits.

Section References

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Scholz, M. 2016. Wetlands for water pollution control. Second Edition. Elsevier B.V. 524 p.

IV. Nutrients from Birds

The role of birds in phosphorus cycling in lakes is often not considered as it is difficult to quantify, although it may be significant in some situations (e.g., Scherer et al., 1995). Birds that feed in the lake, such as cormorants and dabbling ducks, are recycling phosphorus already in the lake (fish, vegetation) into more readily available forms, while birds that feed outside the lake such as seagulls and geese are importing phosphorus from external sources (bread, insects, etc.). As these birds have relatively high metabolic rates, the time between food ingestion and defecation is relatively short, so that birds that are feeding elsewhere and roosting in a lake overnight would not be expected to contribute significant amounts of fecal material (D. Allen, NC Wildlife Resources Commission, personal communication).

A variety of waterbirds can be found at White Lake in the winter months, including cormorants, coots, a few ducks such as buffleheads, and large numbers of seagulls (primarily ring-billed). Canada geese can be found at the lake year-round; they leave relatively large amounts of droppings, given their large size (e.g., Ayers, et al., 2010). Numbers of geese at the lake in recent years have ranged from 50-75 adults, with no goslings reported.

White Lake bird counts were conducted in January-March 2020; twilight was found to be the best time to make counts, as that was when seagulls were coming in for the night. Estimates ranged from 5,000 to 7,000 birds (primarily seagulls), although these numbers were not seen every night and there were evenings in which counts were not possible (S. Bunn, Town of White Lake, personal communication). At times, hundreds of seagulls remain at the lake during the day, both in the water and on piers and boathouse roofs. Cormorants consistently favor tall posts of piers and no wake buoys, where they can perch to dry their feathers after feeding in the lake (Fig. N9).

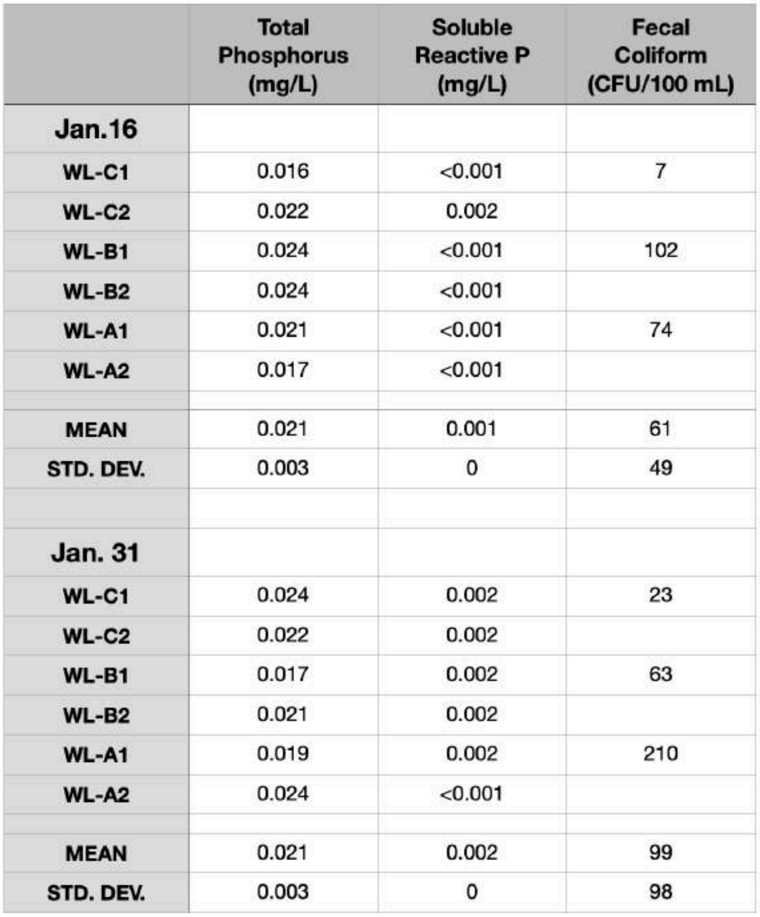
Figure N9. White Lake fish, in another form: cormorant droppings at White Lake Marina pier, February 13, 2020.

Fecal coliform bacteria monitoring in White Lake has shown occasional slight increases in winter months (for example, February 27, 2018 results ranged from 59 to 291 CFU/100 mL; Shank and Zamora, 2019), which may reflect the presence of roosting seagulls.

Water quality sampling in the winter of 2020 included fecal coliform sampling as well as nutrient sampling as the locations of the three long-term monitoring stations (locations established by NC DEQ) which also represent the regions of the lake where seagulls are roosting. Results from January 2020 ranged from 7 to 210 CFU/100 mL (Table N1). If seagulls are presumed to be the contributors to bacterial levels in the middle of the lake, then the relatively low coliform counts suggests that their contribution of phosphorus to the lake would be difficult to discern from other sources, like rainfall.

Water column Total Phosphorus (TP) levels in January 2020 were similar to the annual mean of 0.018 mg P/L seen in 2019, while Soluble Reactive Phosphorus (SRP) levels represented 10% of TP on January 31 (Table N1); SRP levels were at or below detection limits from April-December 2019 (LIMNOSCIENCES 2020).

Table N1. Total Phosphorus and Soluble Reactive Phosphorus, in mg P/L, and Fecal Coliform Bacteria, in CFU/100 mL for White Lake sample stations, sampled on January 16 and January 31, 2020. Samples C1, B1 and A1 were taken at 0.5 m depth while samples C2, B2, and A2 were taken at 2.0 m depth.



	Total Phosphorus (mg/L)	Soluble Reactive P (mg/L)	Fecal Coliform (CFU/100 mL)
Jan.16			
WL-C1	0.016	<0.001	7
WL-C2	0.022	0.002	
WL-B1	0.024	<0.001	102
WL-B2	0.024	<0.001	
WL-A1	0.021	<0.001	74
WL-A2	0.017	<0.001	
MEAN	0.021	0.001	61
STD. DEV.	0.003	0	49
Jan. 31			
WL-C1	0.024	0.002	23
WL-C2	0.022	0.002	
WL-B1	0.017	0.002	63
WL-B2	0.021	0.002	
WL-A1	0.019	0.002	210
WL-A2	0.024	<0.001	
MEAN	0.021	0.002	99
STD. DEV.	0.003	0	98

Seagull estimates from White Lake are similar to roosting seagull counts made at Falls Lake, a large Piedmont reservoir located north of Raleigh (Christmas Bird Count data, National Audubon

Society, 2010, as summarized in Winton and River, 2017). Much larger numbers of roosting seagulls (40,000+) have been reported from Jordan Lake, southwest of Raleigh, since the opening of a nearby landfill, which lead researchers to assess the potential for transport of nutrients from large food sites to nearby roosting sites; Winston and River concluded that seagulls could be one of several external loading sources that could contribute to eutrophication of the water bodies (Winton and River, 2017).

Rainfall in January 2020 totaled 4.5 inches, with a 2.5-inch rainfall on January 14; the water table is generally highest in the winter, so that external sources of phosphorus (rain, groundwater, stormwater) contributes to P loading at the same times that seagulls are roosting in the lake.

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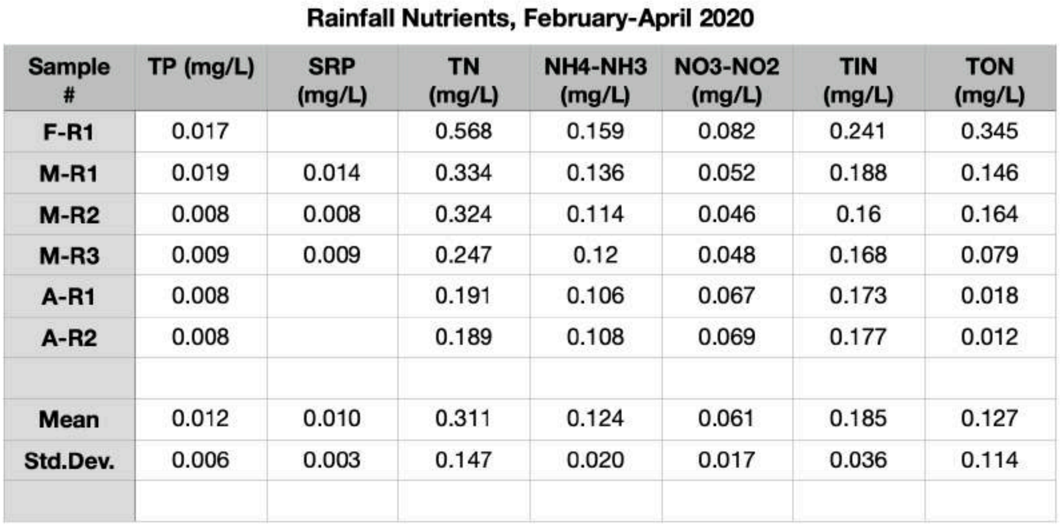
V. Nutrients in Rainfall

Atmospheric deposition consists of both wet deposition (rainfall) and dry deposition (particulate matter such as pollen and dust). Atmospheric contributions to aquatic ecosystems have been recognized as significant external sources of nutrient loading, particularly in lakes that are shallow, and lakes that are situated in agricultural regions (e.g., Ahn and James, 2001, Anderson and Downing, 2006) or urban areas (Grimm and Lynch 2005). As stated in a 1966 report on the chemical composition of rainfall in Eastern NC and Southeastern VA: "study of many of the important geochemical and biological processes affecting water quality must begin with certain assumptions about rainfall composition. Hence, the understanding of these processes is closely tied to our knowledge of rainfall composition. The importance of this fact should not be underestimated." (U.S. Dept. of Interior Geological Survey 1966). Given that rainfall is the primary source of water to White Lake, quantifying nutrient levels in rainfall contributes an important piece to the external nutrient loading puzzle.

Rainfall samples were collected during three rainfall events at White Lake in early 2020: a single sample was collected February 13 (a 0.25-inch rainfall as measured at the Town WWTP), three samples were collected simultaneously on March 5 (a 1.25-inch rainfall) and two samples were collected April 23-24 (a 0.25-inch rainfall). All collection containers as well as the funnel used to transfer collections to sample bottles were rinsed well with deionized water before each use. Rainfall samples (and lake monitoring samples) were placed in coolers with ice packs and express-shipped to IEH Analytical Laboratories in Seattle, WA for analysis (White Lake QAPP 2019). As some particulate matter was observed in the collection containers during the March sampling, SRP was added to the list of parameters analyzed to determine whether particulate deposition might account for a significant portion of TP (Table N2). Pine pollen was observed on the lake surface during that sampling event.

Table N2. Concentrations of Total Phosphorus (TP), Soluble Reactive Phosphorus (SRP), Total Nitrogen (TN), Ammonium-Ammonia (NH_4-NH_3), Nitrate-Nitrite (NO_3-NO_2), and Total Organic Nitrogen (ON) in rainfall samples collected February 13 (F-R1), March 5 (M-R1—M-R3) , and April 23-24 (A-R1—A-R2), 2020). Total Inorganic Nitrogen (TIN) equals NH_4 + NO_3-NO_2, while TON was calculated by subtracting TIN from TN. All units are in milligrams per liter (mg/L).



Rainfall Nutrients, February-April 2020

Sample #	TP (mg/L)	SRP (mg/L)	TN (mg/L)	NH4-NH3 (mg/L)	NO3-NO2 (mg/L)	TIN (mg/L)	TON (mg/L)
F-R1	0.017		0.568	0.159	0.082	0.241	0.345
M-R1	0.019	0.014	0.334	0.136	0.052	0.188	0.146
M-R2	0.008	0.008	0.324	0.114	0.046	0.16	0.164
M-R3	0.009	0.009	0.247	0.12	0.048	0.168	0.079
A-R1	0.008		0.191	0.106	0.067	0.173	0.018
A-R2	0.008		0.189	0.108	0.069	0.177	0.012
Mean	0.012	0.010	0.311	0.124	0.061	0.185	0.127
Std.Dev.	0.006	0.003	0.147	0.020	0.017	0.036	0.114

Rainfall sampling results indicate the following:

- Ammonium and organic nitrogen constitute the majority of total nitrogen in White Lake rainfall for the period sampled
- Inorganic nitrogen, considered to be more readily available for algal growth constitutes 59% of total nitrogen for the period sampled
- Phosphorus, primarily in a form that is readily available for algal growth, is also found in White Lake rainfall
- Replicate collections may help to discern temporal trends

Rainfall at White Lake for the first four months of 2020 totaled 20 inches (4.5 inches in Jan., 6.7 inches in Feb., 3.7 inches in March, and 5.1 inches in April; Appendix N1).

Figure N10. Atmospheric influence on a shallow lake: a view of the sky over White Lake after the 3-inch rain of February 6-7, 2020.

In-Lake Sampling Results

The winter of 2020 was wet, stormy, and at times relatively warm; substantial changes in water temperature from one sample period to the next were seen (for example, a >5-degree Centigrade difference between January 31[mean temp 9.9° C] and February 14 [mean temp 15.5° C] LIMNOSCIENCES lake monitoring field data 2020).

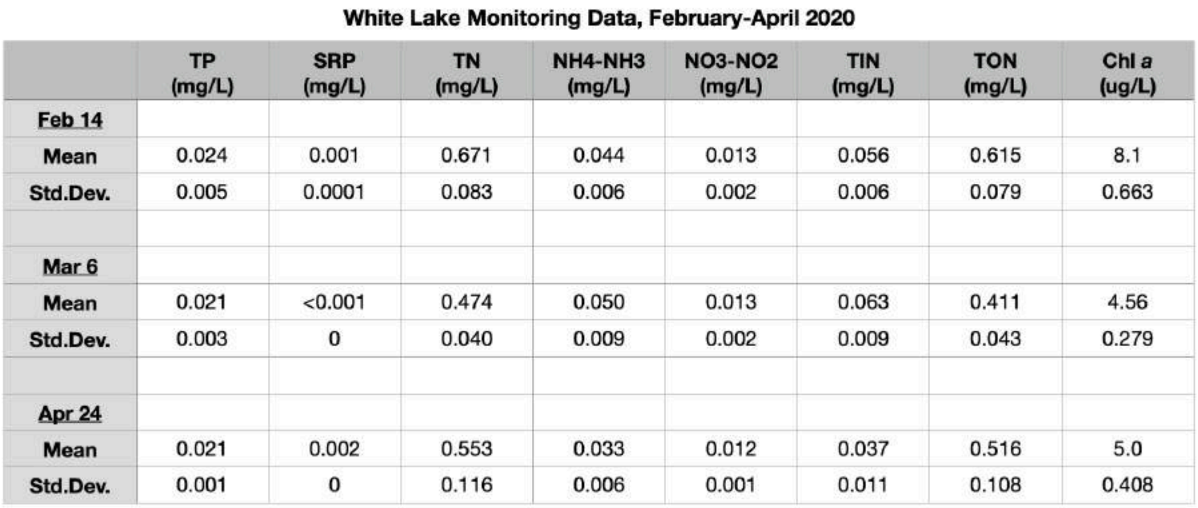
Lake sampling was conducted on February 14, March 6, and April 24 at the three established monitoring stations (located along the midline of the lake) as part of the monthly monitoring of the lake, with two samples collected at each station (one at 0.5 m depth and one at 2.0 m depth). The means and standard deviations for this monthly lake monitoring nutrient data and chlorophyll *a* data are provided in Table N3 for comparison with the rainfall data.

Lake nutrient monitoring results in Table N3 indicate the following:

- White Lake inorganic N as a percentage of total N varied over the three sample events: 8% in February, 13% in March, and 7% in April 2020
- Mean nitrate-nitrite levels were very similar over the 3-month period
- Mean ammonium levels were highest in March
- Mean organic N was highest in February, when phytoplankton biomass (=chlorophyll *a*) was highest
- Soluble P values of 0.002 mg/L (about 10% of total P) were found in one or more samples from Jan. 16, Jan. 31 (5 of 6 samples), Feb. 14 and Apr. 24 (LIMNOSCIENCES lake monitoring data, 2020)
- Mean total P was highest in February, when phytoplankton biomass was highest

Mean turbidity values (expressed as NTU) for sample periods were: 0.79 for Jan. 16; 2.35 for Jan. 31; 2.53 for Feb. 14; 1.80 for Mar. 6; and 1.47 for Apr. 24, and Secchi depths reflected the same trends (LIMNOSCIENCES lake monitoring data, 2020).

Table N3. Means and standard deviations for lake chlorophyll *a* and nutrient samples (n=6) collected February 14, March 6, and April 24, 2020: Total Phosphorus (TP), Soluble Reactive Phosphorus (SRP), Total Nitrogen (TN), Ammonium-Ammonia (NH_4-NH_3), Nitrate-Nitrite (NO_3-NO_2), and Total Organic Nitrogen (ON). Total Inorganic Nitrogen (TIN) equals NH_4 -NH_3 + NO_3 -NO_2, while TON was calculated by subtracting TIN from TN. All units are in milligrams per liter (mg/L) with the exception of chlorophyll *a*, (a measure of phytoplankton biomass), which is expressed in µg/L.



White Lake Monitoring Data, February-April 2020

	TP (mg/L)	SRP (mg/L)	TN (mg/L)	NH4-NH3 (mg/L)	NO3-NO2 (mg/L)	TIN (mg/L)	TON (mg/L)	Chl *a* (ug/L)
Feb 14								
Mean	0.024	0.001	0.671	0.044	0.013	0.056	0.615	8.1
Std.Dev.	0.005	0.0001	0.083	0.006	0.002	0.006	0.079	0.663
Mar 6								
Mean	0.021	<0.001	0.474	0.050	0.013	0.063	0.411	4.56
Std.Dev.	0.003	0	0.040	0.009	0.002	0.009	0.043	0.279
Apr 24								
Mean	0.021	0.002	0.553	0.033	0.012	0.037	0.516	5.0
Std.Dev.	0.001	0	0.116	0.006	0.001	0.011	0.108	0.408

The National Atmospheric Deposition monitoring station at Clinton, NC (http://nadp.slh.wisc.edu/NTN/maps.aspx) has tracked deposition of inorganic N since 1976; while emissions of NO_x have declined in recent decades, the inverse trend has been seen for ammonium concentrations in rainfall (Fig. N11). Over the period 1976-2018 atmospheric deposition of inorganic N (which includes nitrate-nitrite and ammonia-ammonium) has doubled. Modeling work by Walker et al. (2000) related the increases in ammonium concentration at the Clinton station to emissions from intensively managed agricultural operations (CAFOs), as this region (including Duplin, Sampson and Bladen Counties) has seen a very dramatic increase in their abundance since 1990. There appears to be seasonal variability in the volatization of ammonia, and the greatest influence of this source appears to be found in the spring (Occhipinti et al. 2008).

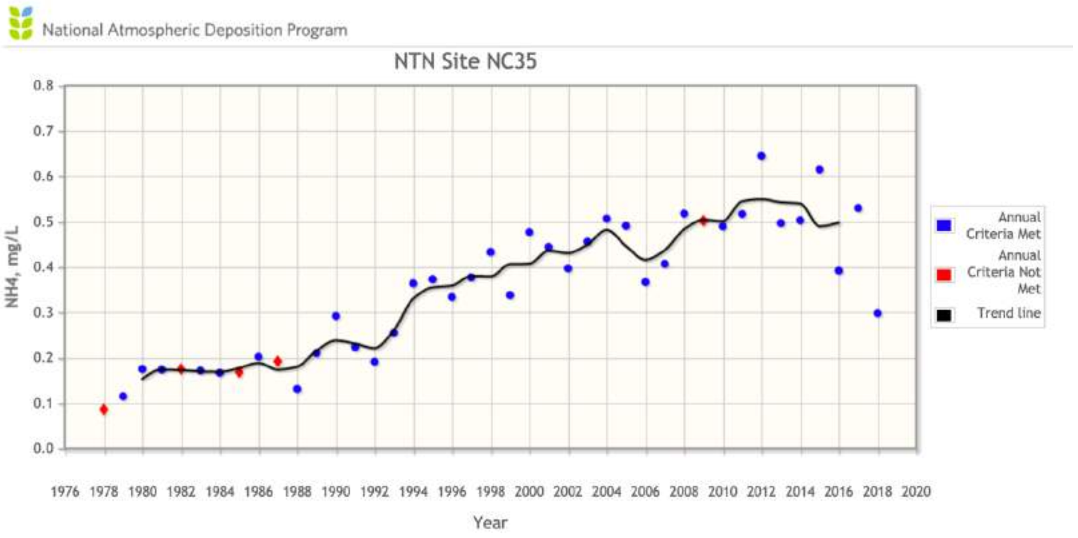


Figure N11. National Atmospheric Deposition Program trend plot for ammonium ion concentration at Clinton monitoring station http://nadp.slh.wisc.edu/data/ntn/plots/ntntrends.html?siteID=NC35

Organic N can include a variety of compounds, such as amino acids and urea, and this form of N has also been found to be an important component of rainfall in other systems (e.g., Timperley et al. 1985, Whitall and Paerl 2008). Organic N is less readily available for phytoplankton by comparison to inorganic N but is still considered to be part of the biologically reactive N pool (e.g., Osburn et al. 2016). At White Lake, organic N is also introduced via stormwater runoff and groundwater inputs (NCDEQ 2017, Shank and Zamora 2019, LIMNOSCIENCES 2020).

The Clinton monitoring station does not measure phosphorus concentrations in rainfall; one study which did monitor monthly phosphorus deposition at nearby Juniper Bay (Robeson County) over the period 2005-2012 measured an average of 0.11 mg P/L of rainfall (standard error = 0.02 mg/L; Vepraskas et al. 2016). The P concentrations from rainfall monitoring at White Lake were an order of magnitude lower (mean of 0.012 mg P/L) but given the large volume of water contributed to the lake by rain falling on the lake surface itself, the 1.25-inch rainfall on March 5, adding about 109.8 million liters of water, would have supplied:

1.78 kg of P to the lake.

The residents of the Town of White Lake still recall the summer of 2013, when it rained and rained (17 inches in June, 11.25 inches in July, 8.25 inches in August; Appendix N1), as the time in which the appearance and clarity of the lake changed noticeably. There were two big rains in June—one at 3.5 inches, and one at 4 inches—and one 4-inch rain in July (Bill Stafford, Town of White Lake, personal communication). The pH of rainfall had changed by that point (from 4.5 to 5.8) and the flush of nutrients entering the lake in the rain and runoff was sufficient to stimulate higher productivity which would further elevate pH (algal biomass in July 2013 averaged 27.7 µg chlorophyll *a*/L, and pH ranged from 8 to 8.3 standard units; it was noted in the 2014 report that the field crew had observed the water as being clear but green [Appendix N2, DENR 2014)]).

Variability in weather (including hurricanes) is due to the ENSO—El Niño Southern Oscillation—and increasingly, by the influences of climate change (e.g., Jeppesen et al. 2017). Rainfall patterns are changing, with more big rains and more severe droughts and rapid-onset droughts. Ongoing monitoring of rainfall nutrients at White Lake may show that there are trends related to season and also with extreme rainfall events associated with hurricanes, as has been seen in rainfall monitoring in Raleigh (Occhipinti et al. 2008).

White Lake is very shallow, and its large lake surface area relative to its volume indicates that large rainfall events can add a substantial volume of water to the lake—much greater than the volume of water entering the lake as surface runoff/stormwater and groundwater inputs. However, large rains can directly influence the volume of stormwater and groundwater seepage into the lake (both of which are variable and hard to quantify accurately), so that the cumulative impact of these larger rainfalls is even greater. The evidence to date indicates that phytoplankton dynamics in this well-mixed lake can be influenced more by large rainfall events/storms than by lengthening lake residence time and any lack of flushing action.

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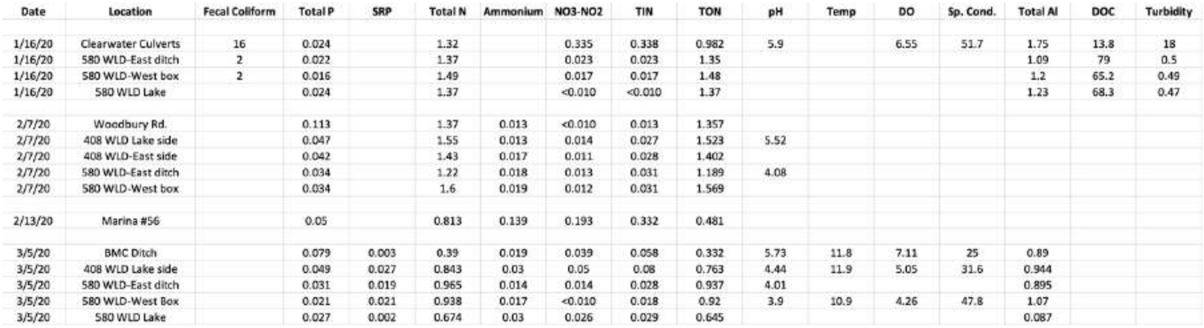
Appendix N1. White Lake stormwater sample data, 2019 and 2020. Several points to note:

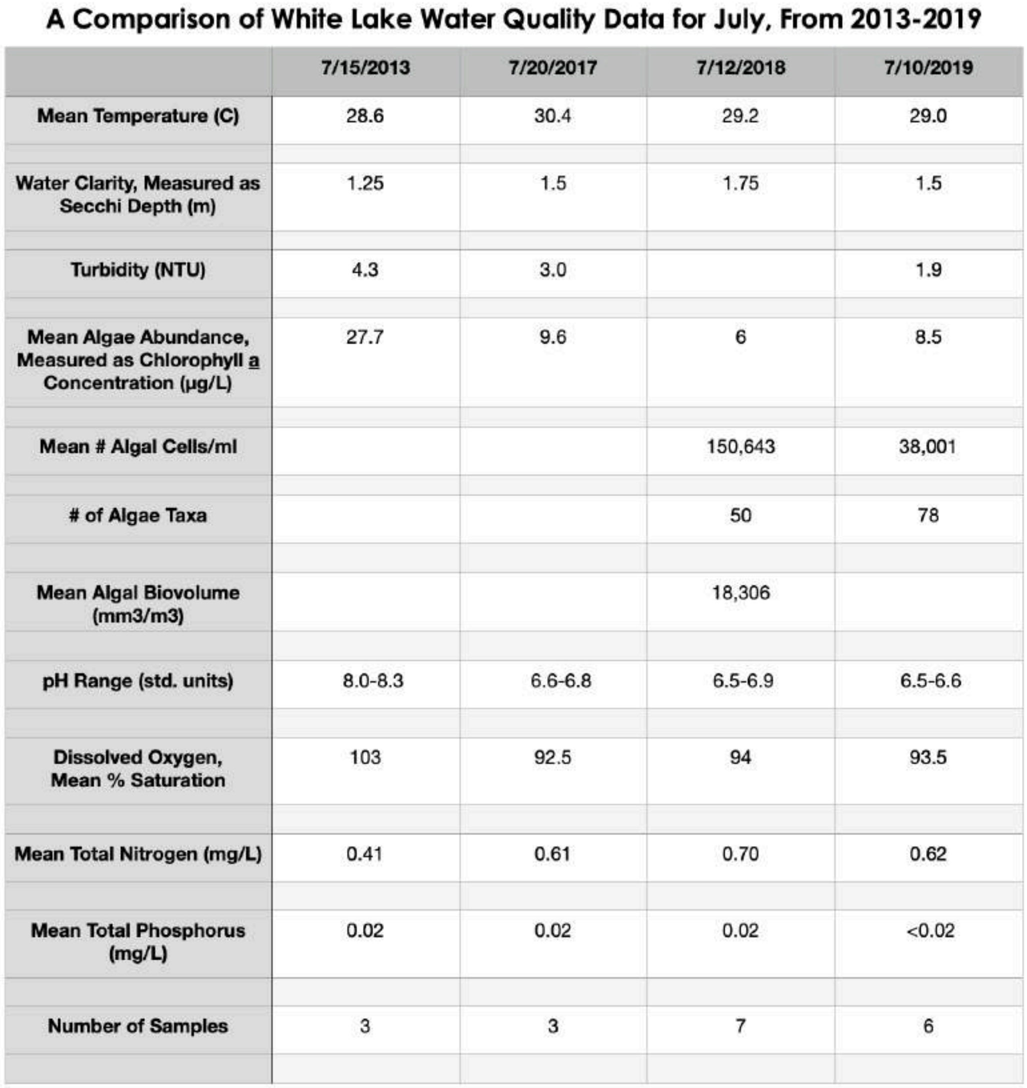
- Total Phosphorus may contain organic/particulate sources in addition to soluble sources
- Organic Nitrogen was the highest component of Total Nitrogen
- Organic Nitrogen was lower in the sample from the paved area at the marina
- There is a consistent difference in nitrogen and phosphorus concentrations between the two DOT drainage ditches, with the one at 580 White Lake Drive having lower values (and there is a difference in pH between the two ditches—580 is lower)
- Dissolved Organic Carbon concentrations in the drainage ditches is high
- Total Aluminum concentrations in the drainage ditches and groundwater is relatively high

At the two drainage ditches sampling was done on the east side of White Lake Drive, and the west side, and the 580 WLD Lake samples were taken at a point where the ditch meets the lake, to determine whether the flow through the ditch vegetation may have had a beneficial effect. SRP was an order of magnitude lower at this point compared to the other two ditch samples (580 WLD East and 580 WLD West-box) in March sampling.



Date	Location	Fecal Coliform	Total P	SRP	Total N	Ammonium	NO3-NO2	TIN	TON	pH	Temp	DO	Sp. Cond.	Total Al	DOC	Turbidity
1/16/20	Clearwater Culverts	16	0.024		1.32		0.335	0.338	0.982	5.9		6.55	51.7	1.75	13.8	18
1/16/20	580 WLD-East ditch	2	0.022		1.37		0.023	0.023	1.35					1.09	79	0.5
1/16/20	580 WLD-West box	2	0.016		1.49		0.017	0.017	1.48					1.2	65.2	0.49
1/16/20	580 WLD Lake		0.024		1.37		<0.010	<0.010	1.37					1.23	68.3	0.47
2/7/20	Woodbury Rd.		0.113		1.37	0.013	<0.010	0.013	1.357							
2/7/20	408 WLD Lake side		0.047		1.55	0.013	0.014	0.027	1.523	5.52						
2/7/20	408 WLD-East side		0.042		1.43	0.017	0.011	0.028	1.402							
2/7/20	580 WLD-East ditch		0.034		1.22	0.018	0.013	0.031	1.189	4.08						
2/7/20	580 WLD-West box		0.034		1.6	0.019	0.012	0.031	1.569							
2/13/20	Marina #56		0.05		0.813	0.139	0.193	0.332	0.481							
3/5/20	BMC Ditch		0.079	0.003	0.39	0.019	0.039	0.058	0.332	5.73	11.8	7.11	25	0.89		
3/5/20	408 WLD Lake side		0.049	0.027	0.843	0.03	0.05	0.08	0.763	4.44	11.9	5.05	31.6	0.944		
3/5/20	580 WLD-East ditch		0.031	0.019	0.965	0.014	0.014	0.028	0.937	4.01				0.895		
3/5/20	580 WLD-West Box		0.021	0.021	0.938	0.017	<0.010	0.018	0.92	3.9	10.9	4.26	47.8	1.07		
3/5/20	580 WLD Lake		0.027	0.002	0.674	0.03	0.026	0.029	0.645					0.087		

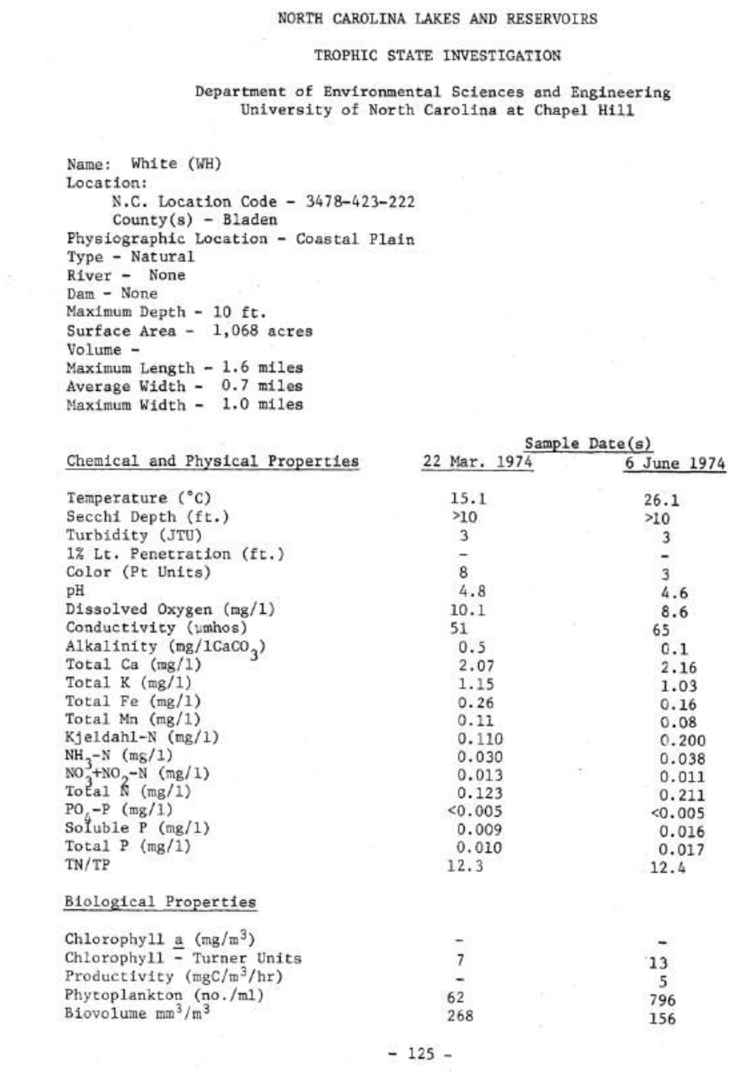
Appendix N2. A comparison of White Lake physio-chemical and algae data for the month of July, from 2013-2019. Data from 2013 and 2017 from NC DEQ reports, and 2018-2019 data from LIMNOSCIENCES reports.



A Comparison of White Lake Water Quality Data for July, From 2013-2019

	7/15/2013	7/20/2017	7/12/2018	7/10/2019
Mean Temperature (C)	28.6	30.4	29.2	29.0
Water Clarity, Measured as Secchi Depth (m)	1.25	1.5	1.75	1.5
Turbidity (NTU)	4.3	3.0		1.9
Mean Algae Abundance, Measured as Chlorophyll a Concentration (µg/L)	27.7	9.6	6	8.5
Mean # Algal Cells/ml			150,643	38,001
# of Algae Taxa			50	78
Mean Algal Biovolume (mm3/m3)			18,306	
pH Range (std. units)	8.0-8.3	6.6-6.8	6.5-6.9	6.5-6.6
Dissolved Oxygen, Mean % Saturation	103	92.5	94	93.5
Mean Total Nitrogen (mg/L)	0.41	0.61	0.70	0.62
Mean Total Phosphorus (mg/L)	0.02	0.02	0.02	<0.02
Number of Samples	3	3	7	6

Appendix N3. Chemical and physical data for White Lake, sampled March 22 and June 6, 1974, from: Weiss, C.M., and E. J. Kuenzler. 1976. The Trophic State of North Carolina Lakes. Water Resources Research Institute of the University of North Carolina Report No. 119.



NORTH CAROLINA LAKES AND RESERVOIRS

TROPHIC STATE INVESTIGATION

Department of Environmental Sciences and Engineering
University of North Carolina at Chapel Hill

Name: White (WH)
Location:
    N.C. Location Code - 3478-423-222
    County(s) - Bladen
Physiographic Location - Coastal Plain
Type - Natural
River - None
Dam - None
Maximum Depth - 10 ft.
Surface Area - 1,068 acres
Volume -
Maximum Length - 1.6 miles
Average Width - 0.7 miles
Maximum Width - 1.0 miles

	Sample Date(s)	
Chemical and Physical Properties	22 Mar. 1974	6 June 1974
Temperature (°C)	15.1	26.1
Secchi Depth (ft.)	>10	>10
Turbidity (JTU)	3	3
1% Lt. Penetration (ft.)	-	-
Color (Pt Units)	8	3
pH	4.8	4.6
Dissolved Oxygen (mg/l)	10.1	8.6
Conductivity (μmhos)	51	65
Alkalinity (mg/l $CaCO_3$)	0.5	0.1
Total Ca (mg/l)	2.07	2.16
Total K (mg/l)	1.15	1.03
Total Fe (mg/l)	0.26	0.16
Total Mn (mg/l)	0.11	0.08
Kjeldahl-N (mg/l)	0.110	0.200
NH_3-N (mg/l)	0.030	0.038
NO_3+NO_2-N (mg/l)	0.013	0.011
Total N (mg/l)	0.123	0.211
PO_4-P (mg/l)	<0.005	<0.005
Soluble P (mg/l)	0.009	0.016
Total P (mg/l)	0.010	0.017
TN/TP	12.3	12.4
Biological Properties		
Chlorophyll a (mg/m^3)	-	-
Chlorophyll - Turner Units	7	13
Productivity ($mgC/m^3/hr$)	-	5
Phytoplankton (no./ml)	62	796
Biovolume mm^3/m^3	268	156

- 125 -
