White Lake, Bladen County, NC
Lake Monitoring Results 2020

Report Prepared by LIMNOSCIENCES
June 14, 2021

This report summarizes 2020 monitoring data for water quality (including nutrients), algae, aquatic vegetation, lake levels, and rainfall. Appendices include water quality data from 2017 (NC DEQ), 2018 and 2019 (LIMNOSCIENCES) for reference purposes.

Sampling Schedules

Monthly sampling was conducted from January-December at three established monitoring stations (Fig. 1). Grab samples for nutrients and chlorophyll a were taken at 0.5 and 2.0 m depths, so that a total of 6 samples were taken for each sample date. Algae samples were taken at 0.5 m depths. Sampling and analysis details are provided in the White Lake Quality Assurance Program Plan (QAPP) (available at www.whitelakewatch.com).

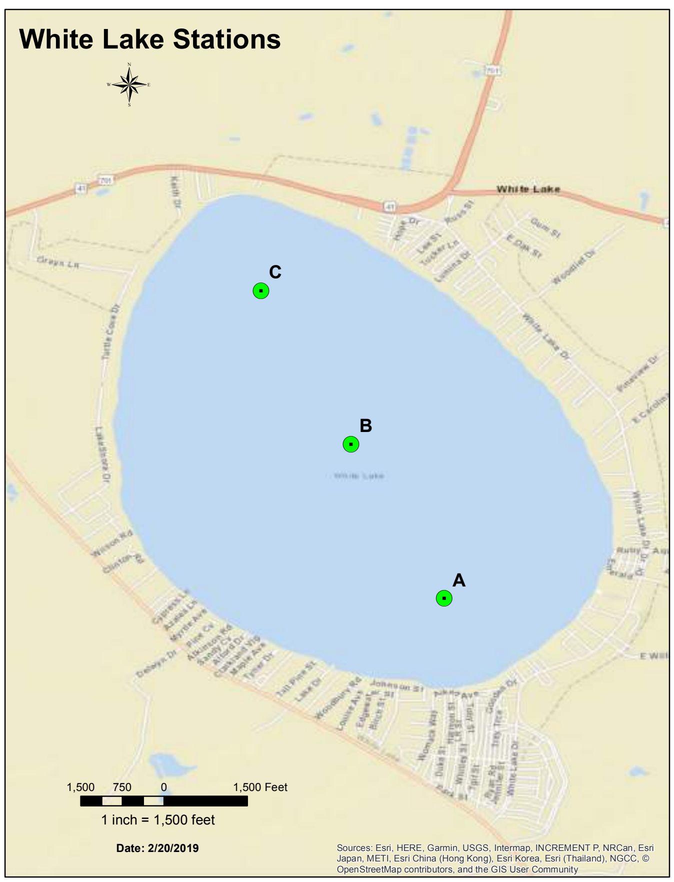


Figure 1. Monitoring stations for White Lake, which correspond to NC DEQ stations (CPF155C, CPF155B, and CPF155A).

A whole-lake aquatic vegetation survey was conducted on October 13, 2020, utilizing a protocol developed by North Carolina State University. Additional monitoring of submerged aquatic vegetation was done in June, July and August by NCSU and/or the NC Aquatic Weed Program (AWCP).

Figure 2. Pre-determined sample points (a total of 202) for aquatic vegetation annual survey in October. All 202 stations were also sampled in June, a subset of 101 stations were sampled in July, and all 202 stations were sampled in August.

Results

Rainfall in 2020 was 1.4 times higher than 2019 rainfall, with the highest monthly amount (12.25 inches) measured in May; as a result, the highest lake levels were observed in June—the opposite pattern of what is seen in most years, when lake levels are lower in summer months. However, even with the large difference in rainfall between years, the lake level variation was very similar between 2019 (12.7 inches) and 2020 (10.3 inches), with a higher difference (19.9 inches) over the two-year period. The lake level at the end of 2020 was six inches higher than at the start of 2020, and four inches below the highest level for the year (Table 1).

Over the monitoring period, water-column algal biomass (measured as chlorophyll *a*) was lowest in March, April, and December and highest in the month of May, with a trend of higher winter phytoplankton biomass compared to 2019, while summer levels were similar between the two years. (Figure 3).

The pH range in 2020 (6.4-7.2 standard units) was very similar to what was observed in 2019 (Figure 3).

Water clarity measured as Secchi depth ranged from 2 meters in January to 1 meter in July (Figure 3, which reports data in feet). There was a notable reduction in clarity between December 2019 (when the disk was visible on the lake bottom) and January 2020.

Table 1. Monthly rainfall at White Lake Wastewater Treatment Plant, and lake level ranges for 2019 and 2020.

White Lake: Monthly Rainfall (in inches)

Month	2020	2019	2018	2017	2016	2015	2014	2013	2012	Monthly Average for Region
January	4.5	2.75	4.20	7.0	3.0	2.5	2.0	1.75	2.75	3.81
February	6.7	2.25	2.00	1.5	10.7	5.5	1.5	2.5	4.0	3.44
March	3.7	3.25	3.95	3.7	1.55	4.15	ND	1.0	7.0	3.91
April	5.1	7.25	6.75	6.75	6.75	4.55	ND	1.75	2.25	3.12
May	12.25	1.20	7.70	2.7	4.5	4.20	ND	2.25	9.25	3.67
June	7.15	5.25	10.00	4.5	3.65	8.70	3.0	17.0	2.0	4.70
July	6.85	6.00	4.75	6.75	3.75	3.0	4.65	11.25	8.6	5.75
August	7.55	5.35	6.25	5.6	4.12	9.4	9.75	8.25	9.75	5.95
September	5.95	5.00	29.45	5.2	15.0	4.7	7.0	1.0	5.0	5.29
October	3.35	3.60	2.25	2.95	14.25	9.75	1.7	1.75	2.25	3.38
November	7.5	4.90	4.25	1.0	0.50	7.25	4.15	0	2.25	3.16
December	4.25	6.00	7.5	5.45	5.1	6.5	3.7	5.75	4.25	3.14
Total	74.85	52.80	89.05	53.1	72.87	70.20		54.25	59.35	49.32
% of Lake Volume	97	69	116	69	95	91		70	77	64

(Volume of Total Rainfall on Lake Surface/Total Lake Volume) x 100 Gives an Estimate of Volume of Rainfall as % of Lake Volume)

White Lake: Annual Lake Elevations, High and Low

2019 High (January 25): 64.6 Feet NAVD 88

2019 Low (July 9): 63.54 Feet NAVD 88

2020 High (June 16): 65.2 Feet NAVD 88

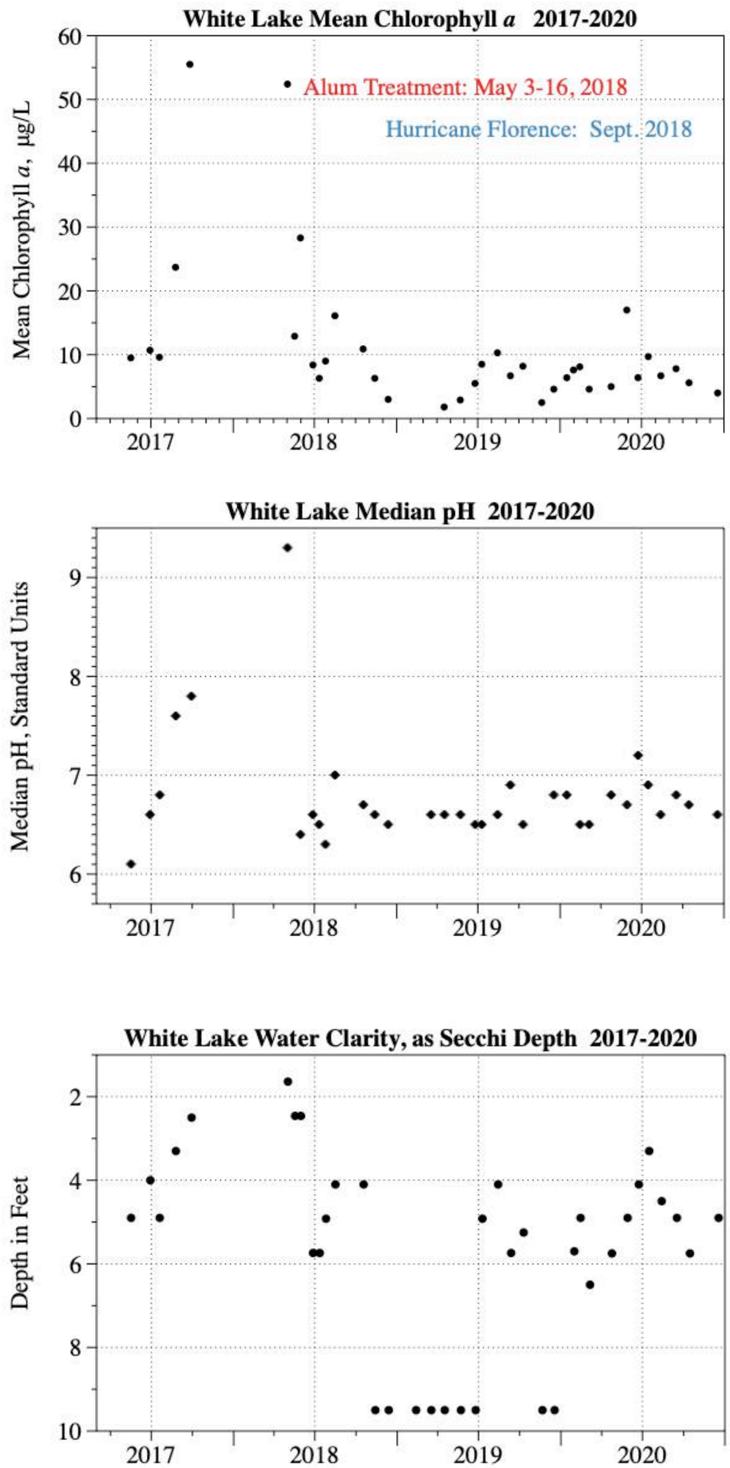
2020 Low (January 1): 64.34 Feet NAVD 88

2019 Lake Level Variation: 12.7 Inches
2020 Lake Level Variation: 10.3 Inches

Variation Over the Two-Year Period 2019-2020: 19.9 Inches

Figure 3. Monthly mean chlorophyll a levels in µg/L, monthly median pH levels in standard units, and monthly mean Secchi depths in feet, from 2017-2020.

White Lake: Algae Biomass (chlorophyll a), pH and Clarity (Secchi Depth)



Determinations of phytoplankton biovolume in 2020 indicated a general trend of higher biovolume in summer months, with the highest mean biovolume in the month of July (Figure 4). Chlorophyll *a*, phaeophytin *a*, turbidity, Secchi depths, algal biovolumes and algal abundance data for 2020 are provided in Appendix 1.

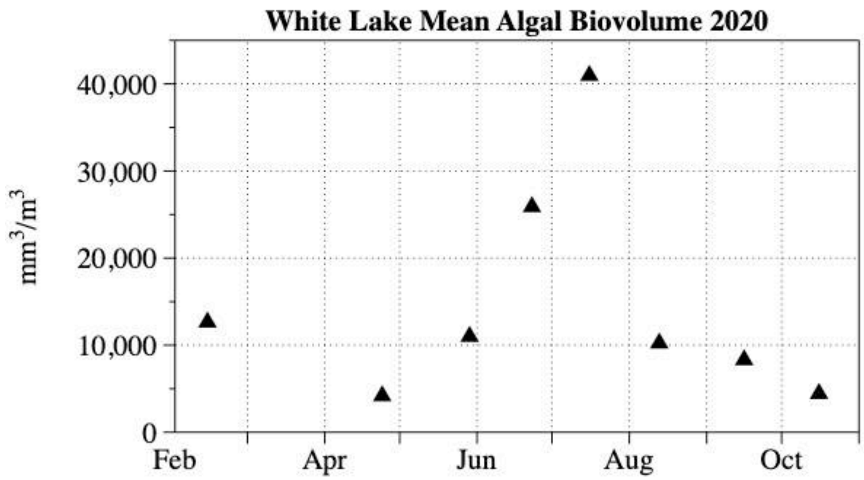


Figure 4. White Lake mean phytoplankton biovolume (mm^3/m^3) in 2020. A grab sample was collected at 0.5 m at each of the three stations on each date, so n=3 for each, with the exception of July, when n=2 due to the loss of one sample during transport to the algal taxonomist.

<u>White Lake Phytoplankton Trends</u>

The first documented phytoplankton bloom occurred in July 2013, after extreme precipitation events in June of that year (Table 2). That bloom was dominated by a unicellular desmid, *Cosmarium* sp. (NC DEQ unpublished data). Desmids have tended to dominate the phytoplankton community in summer months, although a filamentous cyanobacterium (*Planktolyngbya sp.*) had an increased presence in summer 2016, and 2017 (Table 2). This species developed into a full bloom in late summer 2017 (NC DEQ 2017).

White Lake phytoplankton diversity has increased in the past two years (2019-2020), particularly in green algal taxa and desmids (LIMNOSCIENCES 2020, Spirogyra Diversified unpublished data).

Algal blooms with high photosynthetic activity can result in a 2-unit increase in pH because of the low alkalinity of the lake water (3-4 mg $CaCO_3$/L; Weiss and Kuenzler 1976, LIMNOSCIENCES unpublished data).

White Lake is a very dynamic system, and conditions such as temperature can change relatively quickly, which influences the phytoplankton growth (e.g., Paerl and Otten 2013).

Table 2. White Lake data 2013-2017 collected and analyzed by NC DEQ; data reported in NC DEQ (2017). Data from 2018-2020 collected and analyzed by LIMNOSCIENCES and Spirogyra Diversified Environmental Services. ND = no data. One difference between the two data sets appears to be the counting of extremely small picoplankton such as the cyanobacterium *Synechococcus* (which was done by Spirogyra Diversified, from 2018 onwards).

A Comparison of White Lake Algae Data for July, From 2013-2020

	2013	2015	2016	2017	2018	2019	2020
Secchi Depth (m)	1.25	2.6	ND	1.5	1.75	1.5	1.0
Turbidity (NTU)	4.3	1.7	2.0	3.0	1.9	1.9	2.6
Chl a (µg/L)	27.7	16.3	6.2	9.6	6	8.5	9.7
Algal Cells/mL	114,533	2,367	45,433	241,873	150,643	38,033	169,176
Dominant Taxa (#cells/mL)	*Cosmarium* (99%)	*Staurastrum* (35%)	*Planktolyngbya* (95%)	*Planktolyngbya* (79%)	*Synechococcus* (43-71%)	*Synechococcus* (36%) *Staurastrum* (34%)	*Staurodesmus* (43.6%)
Algal Biovolume (mm^3/m^3)	28,400	267	1,400	1,712	18,307	ND	40,965
Dominant Taxa (Biovolume)	*Cosmarium* (100%)	*Oocystis* (40%)	*Planktolyngbya* *Peridinium*	*Gonatozygon* (53%)	*Staurastrum* (79%)	*Staurastrum*	*Staurodesmus* (82%)
pH Range (su)	8.0-8.3	6.0-6.7	6.3-6.7	6.6-6.8	6.5-6.9	6.5-6.6	6.9-7.0

June pH range 6-6.8, mean chl *a* 2.5 µg/L

17" of rain in June, 11.25" in July

There were more cyanobacterial taxa found in 2020 (19) compared to 2019 (14), with a single cyanobacterial taxon, *Synechococcus*, found in February (Appendix 2). Picoplankton-sized cyanobacteria such as *Synechococcus* are often important in oligotrophic waters and occasionally in more productive systems, and some species are "superior competitors for phosphorus" (Wehr and Sheath 2003).

Phytoplankton sampling in White Lake was infrequent prior to 2013, but other small cyanobacterial taxa, such as *Chroococcus* sp. [seen in 2003], and *Aphanocapsa* sp. [seen in Sept. 2013] had a minor presence while small amounts of larger filamentous cyanobacteria (*Anabaena* sp. and *Cylindrospermopsis raciborskii*) were seen in June 2012. The filamentous form *Planktolyngbya sp.* was the most abundant (in both cell density and biovolume) cyanobacterial species in 2016, although it did not dominate the phytoplankton community (NC DEQ unpublished data).

Filamentous cyanobacteria (*Planktolyngbya* and to a lesser degree *Aphanizomenon*) dominated the phytoplankton community prior to the alum treatment in May 2018, constituting 95% of total biovolume (Appendix 3). By July 2018 cyanobacteria biovolume was less than 1% of total biovolume, and it has remained low since, with the highest relative cyanobacterial biovolume in 2020 found in August, at 2% of total biovolume (Appendix 1).

Nutrients

Total Phosphorus (TP) monthly means ranged from 0.019 to 0.025 mg P/L in 2020 (Table 3), which was similar to the range found in 2019 (0.013 to 0.027 mg P/L; Appendix 4).

Soluble Reactive Phosphorus (SRP) levels were low, with no discernable trend of differences between sample depths. Values were often at or below detection limits of 0.001 mg P/L, with the highest values at 0.002 mg P/L (Table 3). In 2019, SRP values were generally below detection limits (Appendix 4).

Table 3. Physical and chemical parameters for White Lake, January-December 2020 (as data was available through April 2021 as of report preparation, it is included as well). Samples were collected at two depths (0.5 and 2.0 m) at each of three stations (equivalent to the monitoring stations used by NC DEQ). A T indicates that chlorophyll a was measured with a Turner hand-held fluorometer, and an asterisk indicates that one measurement was not included in the calculation of the mean for that parameter, as the value was an order of magnitude greater than the other values.

White Lake Monitoring Project 2020-2021

	1/16/20	1/31/20	2/14/20	3/6/20	4/23/20	5/29/20	6/23/20	7/16/20	8/13/20	9/16/2020	10/15/20	12/18/20	2/25/21	3/24/21	4/27/21
Mean Temp (C)	9.8	9.9	15.6	12.6	19.2	25.5	27.5	31.1	30.3	25.2	22.9	10.0	10.6	13.9	19.8
Lake Level (gauge)	1.94	1.95	2.22	2.30	2.00	2.38	2.54	2.5	2.20	1.80	1.95	2.32	2.60	2.20	2.10
Secchi Depth (m) – Visible at Bottom?	2.0	1.75	1.5	1.75	1.75	1.5	1.25	1.0	1.3	1.5	1.75	1.7	1.2	1.0	0.75
Turbidity (NTU)	0.93	2.35	2.50	1.80	1.5	1.6	2.3	2.6	1.9	1.7	1.7		2.0	2.3	3.5
Mean DO (mg/L)	10.0	11.6	9.7	10.6	9.0	8.2	8.6	7.6	7.1	8.2	8.7	11.1	12.2	10.9	10.1
Mean DO % Sat.	102.3	102.5	98.3	100	97	100	109	102	95	99	101	98.4	109	106	110
Mean Sp. Cond. (uS//L)	33	33.8	32.5	32.2	33.3	32.5	32.7	38.8	39.0	39.9	39.5	36.3	32.6	32.5	33.4
Range pH (su)	6.8-6.9	7.0	6.3-6.5	6.5-6.6	6.8-7.0	6.7-6.8	7.1-7.3	6.9-7.0	6.6-6.7	6.7-6.9	6.6-6.8	6.5-6.7	6.5-6.7	6.9-7.0	7.6-8.6
Mean Chlorophyll a (µg/L)	6.4	7.6	8.1	4.6	5.0	17	6.4	9.7	6.7	7.8	5.6	3.1 (T)	11.3	16.3	15.8
Mean DOC (mg/L)	5.8	6.2	5.1	5.1	5.8	5.8	5.3	5.5	5.4	5.3	5.0		5.15	8.26	13.4
Mean Total N (mg/L)	0.718	0.769	0.671	0.474	0.553	0.766	0.757	0.640	0.774	0.768	0.546		0.787	0.577	0.605
NO3-NO2 (mg/L)	0.017	<0.010	0.013	0.013	0.012	0.011	0.013	<0.010	<0.010		0.010		0.015*	<0.010	0.011
NH4-NH3 (mg/L)			0.044	0.050	0.033	0.037	0.006	<0.010	0.010				0.023	0.034	0.011
TDN (mg/L)											0.347		0.478	0.469	0.380
Mean Total P (mg/L)	0.021	0.021	0.024	0.021	0.021	0.019	0.025	0.024	0.021	0.019	0.021		0.025	0.026	0.039
SRP (mg/L)	0.001	0.002	0.001	<0.001	0.001	0.002	<0.001	0.002	0.001		0.001		<0.001	0.001	0.011
TDP (mg/L)													<0.002	0.002	
# of Samples	6/3	6/3	6	6	6	6	6	6	6	3	6	6	3	3	6

Total Nitrogen (TN) levels were generally higher in 2020 compared to 2019, with monthly means ranging from 0.474 to 0.774 mg N/L (Table 3). More winter sampling was done in conjunction with stormwater sampling and rainfall sampling; Table 4 provides means for rainfall nutrients in comparison to means for lake nutrient levels and chlorophyll *a* levels. Organic N and ammonium were the dominant forms of N in rainfall, and Total Nitrogen/Total

Phosphorus ratios (TN/TP [mass]) were similar between lake (mean of 30) and rainfall (mean of 27) samples for the period February to April. The dominant algal taxon in February 2020 was a tiny green, *Nannochloris* sp.

Table 4. Rainfall nutrients and White Lake nutrient and chlorophyll *a* levels, with lake samples collected at the end of rainfall events. Rainfall samples were collected in clean containers that had been rinsed 3x with deionized water. Total Organic Nitrogen (TON) was calculated by subtraction of inorganic nitrogen constituents (NH_4-NH_3 + NO_3-NO_2) from total nitrogen (TN). Lake samples were collected at two depths (0.5 and 2.0 m) at each of three stations (equivalent to the monitoring stations used by NC DEQ).

White Lake Nutrients and Rainfall Nutrients February-April 2020

	TP (mg/L)	TN (mg/L)	NH4-NH3 (mg/L)	NO3-NO2 (mg/L)	TON (mg/L)	Chl *a* (ug/L)
Feb 12						
Lake Mean	0.024	0.671	0.044	0.013	0.615	8.1
Mar 6						
Lake Mean	0.021	0.474	0.050	0.013	0.411	4.56
Apr 24						
Lake Mean	0.021	0.553	0.033	0.012	0.516	5.0
Feb-Apr						
Rainfall Mean	**0.012**	**0.331**	**0.124**	**0.061**	**0.127**	

Dissolved Organic Carbon (DOC) monthly means ranged from 5.04 to 6.20 mg C/L (Table 3) compared to the 2019 range of 4.66 to 7.53, and the 2018 range 13.6 to 7.1 mg C/L [pre-alum treatment DOC data from Shank and Zamora ranged from 16.4 to 20.2 mg/L] (Appendix 4).

Aquatic Vegetation

The 2020 White Lake vegetation survey conducted by NCSU Aquatic Plant Management personnel found a decrease in the percentage occurrence of aquatic vegetation compared to 2019, with 75% of the sample sites having aquatic vegetation (Table 5).

Table 5. Aquatic vegetation found in annual whole-lake surveys of White Lake. Percentage occurrence is determined as the number of survey points in which each vegetation species is found divided by the total number of survey points (202) sampled (Table from 2020 NCSU White Lake Aquatic Vegetation Survey Report).

Species	2014	2017	2018	2019	2020
Hydrilla	0%	84%	0.50%	1.50%	0%
Tuckerman's Pondweed	0%	0%	0%	0%	13%
Spikerush	40%	9%	56%	68%	45%
Bladderwort	14%	0%	0%	0%	0%
Dwarf Milfoil	0%	15%	20%	34%	20%
Low Milfoil	54%	0%	0.50%	0%	0%
Filamentous Algae	0%	0%	0%	0%	49%
Chara	29%	66%	0%	0%	6%
Aquatic Moss	43%	63%	32%	6%	8%
No Vegetation	11%	6%	36%	16%	25%
Vegetation	89%	93%	65%	84%	75%

Filamentous algae was picked up at half of the sample sites, compared to previous surveys in which no filamentous algae was noted in the rake toss collections.

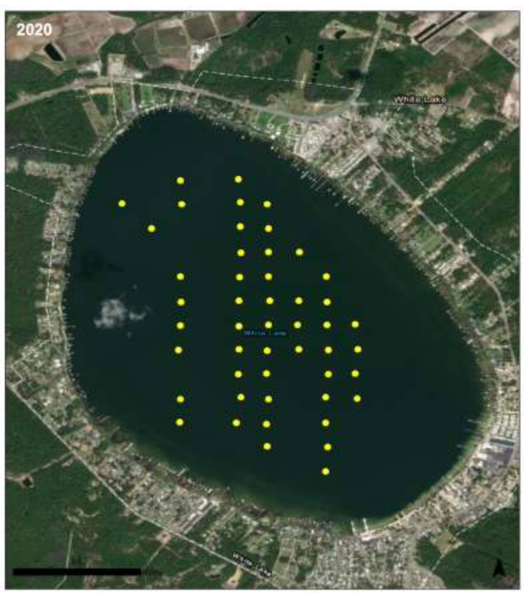


Figure 5. Filamentous algae (*Spirogyra* sp.) was found at 49 sample sites in 2020 (NCSU 2020).

A new aquatic plant, Tuckerman's Pondweed (*Potamogeton confervoides*) was found at 27 sample sites, in both shallow and deeper locations, while no *Hydrilla* (or tubers) was found (NCSU2020).

Spikerush, found at 45% of the sample sites (Figure 6), has been recorded from the lake as far back as vegetation sampling has been conducted (e.g., Tebo 1961).

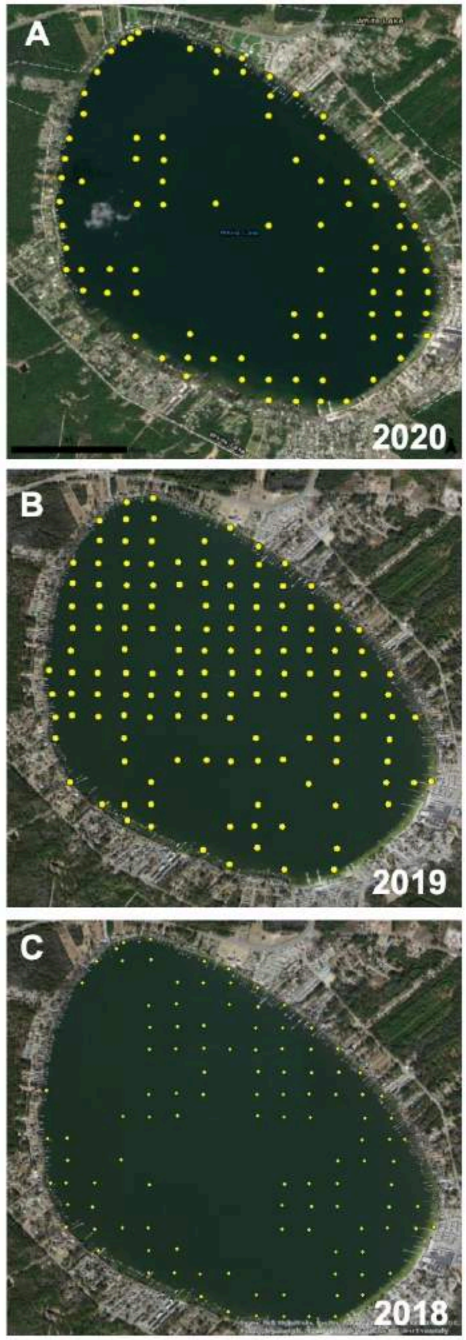


Figure 6. Spikerush (*Eleocharis baldwinii*) was found at 90 sample sites in 2020 (NCSU 2020).

Mid-year monitoring events were conducted in June and August (for hydrilla detection), with results indicating a trend of more vegetation present in early summer (Figure 7; NCSU 2020).

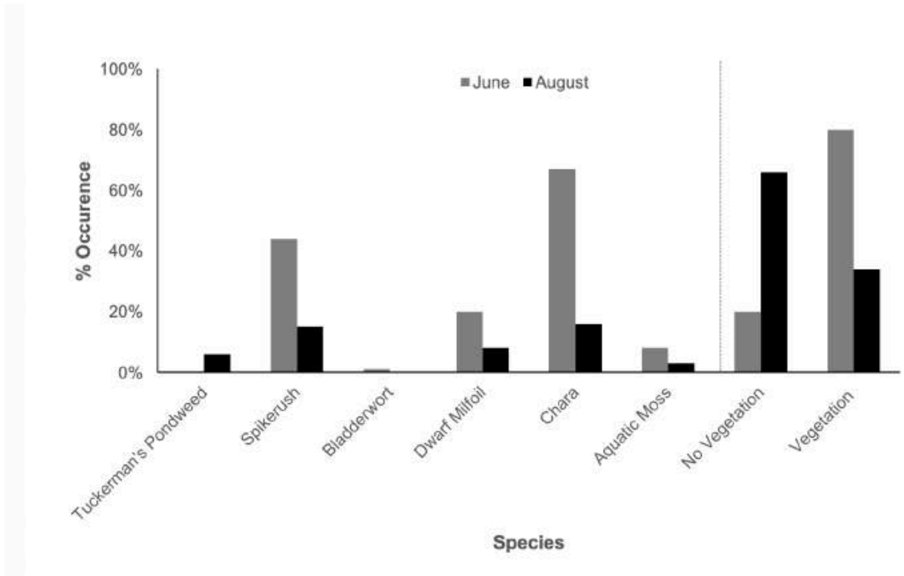


Figure 7. White Lake % occurrence of submerged aquatic vegetation in June and August 2020 (NCSU 2020).

Plant height data was estimated in August 2020 by NCSU personnel, using BioSonics equipment and software. The map generated (Figure 8) indicates that submerged aquatic vegetation in White Lake is primarily 3-12 inches in height, with few observations of emergent vegetation (NCSU 2020).

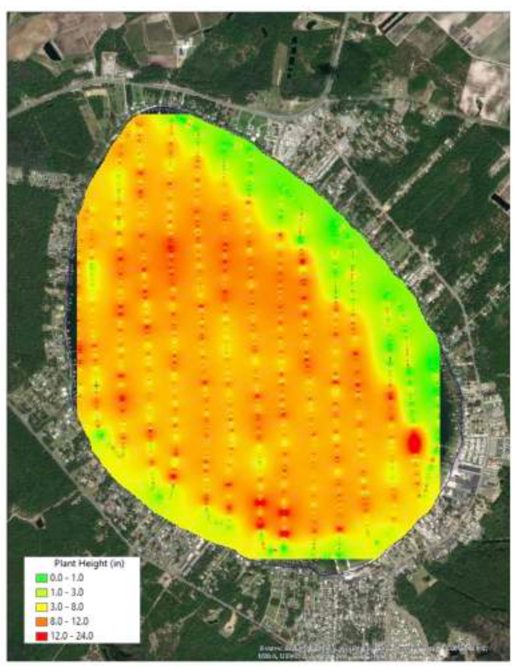


Figure 8. White Lake submerged aquatic vegetation height in August 2020 (NCSU 2020).

Discussion

Sustained, long-term monitoring is critical to understanding lake dynamics, particularly with respect to the development of algae blooms, as variability due to weather can be difficult to distinguish from changes due to human impacts (e.g., Dolulil and Teubner 2000, Paerl and Otten 2013, Paerl 2014, Smol 2009). Climate change-related increases in temperatures and greater hydrologic variability (more big rains and more droughts) can be expected to have significant impacts on a relatively shallow lake such as White Lake (e.g., Havens et al. 2016).

The warmer and wetter winter of 2020 supported more winter phytoplankton biomass relative to 2019, while summer conditions were very similar to those of 2018 and 2019. An increase of 5.5° C in a two-week period in winter (1/31/20 to 2/14/20) indicates how quickly this very shallow lake can change.

Large rainfall events (2-3 inches or more) are becoming more frequent in most of North Carolina, according to the NC Climate Office. Atmospheric deposition of nitrogen, particularly ammonium (Fig. 9) delivered via rainfall, can provide a substantial supply of bioavailable N to White Lake, and its phytoplankton communities can respond quickly to the diffuse source of nutrients in big rains. Long-term monitoring of ammonium concentrations in rainfall at the NADP monitoring station at Clinton, NC show a trend of substantial increases in rainfall ammonium concentrations over time (Fig. 10).

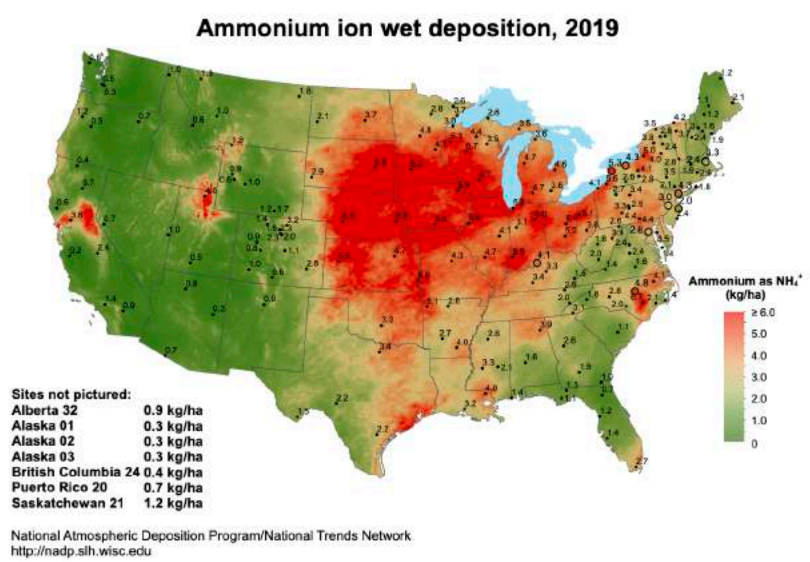


Figure 9. U.S. Environmental Protection Agency National Atmospheric Deposition Program annual data for 2019, for ammonium ion wet deposition (kg/ha). The nearest NADP monitoring station to White Lake is NC35, at Clinton, NC. www.nadp.slh.wisc.edu

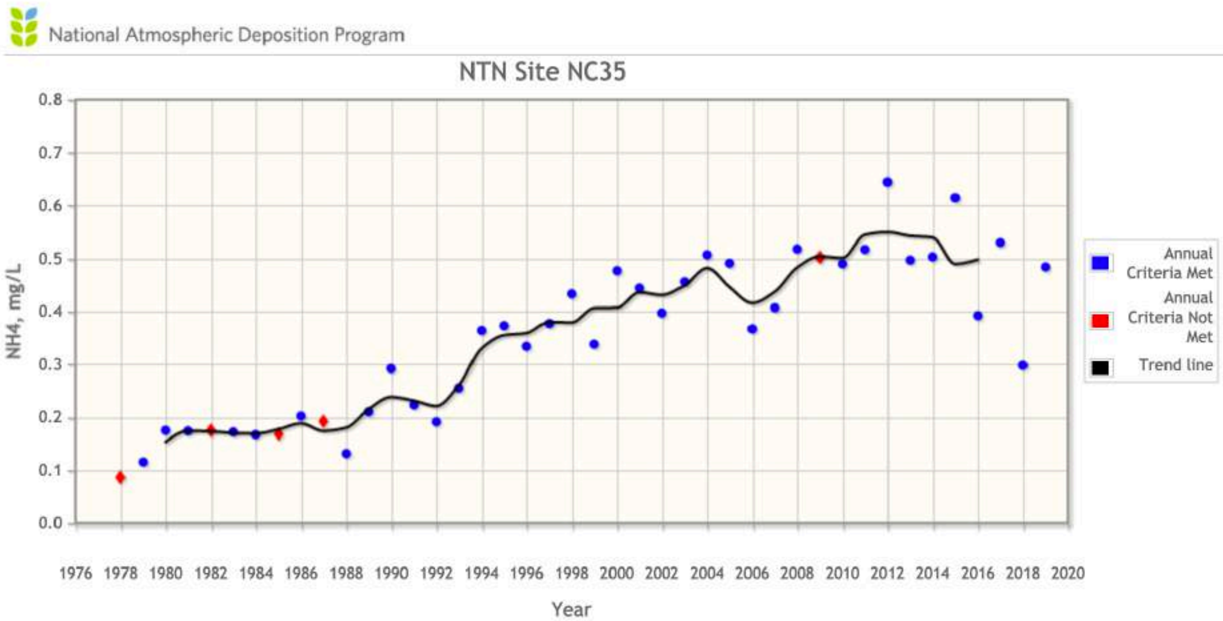


Figure 10. U.S. Environmental Protection Agency National Atmospheric Deposition Program annual mean ammonium ion concentration (mg/L) at Site NC35, located at Clinton, NC. www.nadp.slh.wisc.edu

Nitrogen levels in White Lake are now higher than they were in the past (historical data from Weiss and Kuenzler 1976), and the same holds for other Bay Lakes in the region (LIMNOSCIENCES unpublished data), which suggests the changes are due to changes in common nitrogen sources. White Lake has often been categorized as oligotrophic (low nutrients and productivity); oligotrophic lakes are often the most sensitive to atmospheric deposition of nitrogen (e.g., Elser et al. 2009, Pardo et al. 2011).

Historical ratios of Total Nitrogen to Total Phosphorus (TN:TP) were low (TN:TP [mass] ratios at White Lake were 12 in 1974 [Weiss and Kuenzler 1976]) and are now 2+ times higher, due to the increased nitrogen concentrations.

Another ratio, Dissolved Inorganic Nitrogen (the sum of nitrate-nitrite and ammonium) to Total Phosphorus (DIN:TP) is used as a reliable predictor of nutrient limitation, with mass ratios below 4 indicating nitrogen limitation, and mass ratios above 12 indicating phosphorus limitation (Morris and Lewis 1988, cited in Pardo et al. 2011). Historical DIN:TP mass ratios were 4 and 2.9 in 1974, while ratios in February-April 2020 were 2.4, 3 and 2.1, and the February-April rainfall mean ratio was 15.4. In summer, White Lake DIN levels are often below testing detection limits, so a substantial supply of rainfall DIN can quickly trigger increased phytoplankton productivity in this nitrogen-limited system (as was seen very dramatically in July 2013).

At this point, there is no evidence which would indicate that the filamentous cyanobacteria seen in 2016-2018 are able to outcompete the diversity of "fast responders"—the small, single-celled desmids and green algae--which can rapidly utilize the diffuse nutrient supply entering White Lake during big rains. However, continued monthly monitoring of the phytoplankton community is still warranted as the best means of early detection of a developing cyanobacterial bloom in this important recreational lake.

The annual variability in relative abundance of *Hydrilla* has been pronounced--the lake conditions would seem to favor the robust growth of this aquatic invasive weed, and yet its presence is now below the ability to detect with intensive survey efforts. Further studies are needed to understand the possible growth--limiting factors at play in this lake, but the presence of a second rare aquatic plant in 2020 suggests that this ecosystem is relatively healthy. Continuing the annual whole-lake vegetation survey program will be the best method for early detection of *Hydrilla* or other invasive aquatic weeds in White Lake.

Acknowledgements

The Town of White Lake is to be commended for its support of the ongoing monitoring work, as science-informed management is widely recognized as the most effective.

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Appendix 1. <u>White Lake Data, 2020</u>. Samples taken at three stations along a mid-lake transect, at two depths (#1=0.5 m, and #2 at 2.0 m). Samples for algal analysis were taken at 0.5 m in February, April, May, June, July, August, September, and October, and both algal abundance (cells/mL) and algal biovolumes (mm^3/m^3) were determined. Chlorophyll *a* and phaeophytin *a* were measured as µg/L, turbidity was measured as NTU and Secchi depth was measured in meters.

Date	Sample #	Chl a	Phaeo a	Turbidity	Secchi Depth	Total Algal Biovolume	Cyanobacterial Biovolume	Total Algal Abundance
1/16/20	C-1	7.5	0.7	0.92	2			
1/16/20	C-2			0.94				
1/16/20	B-1	5.3	1.4	0.96	2			
1/16/20	B-2			0.96				
1/16/20	A-1	6.4	0.7	0.9	2			
1/16/20	A-2			0.92				
1/31/20	C-1	6.4	1.4	2.5	1.75			
1/31/20	C-2			2.4				
1/31/20	B-1	8	1.3	2.4	1.75			
1/31/20	B-2			2.6				
1/31/20	A-1	8.5	0.1	1.8	w			
1/31/20	A-2			2.4				
2/14/20	C-1	8.4	2.8	2.9	1.5	11,734	14	94,260
2/14/20	C-2	8.8	2.6	2.6				
2/14/20	B-1	6.9	2	2.4	1.4	14,593	13	106,740
2/14/20	B-2	8	2.1	2.4				
2/14/20	A-1	8	2.5	2.7	1.5	11,605	7	79,524
2/14/20	A-2	8.5	1.9	2.2				
3/6/20	C-1	4.3	0.6	1.7	1.75			
3/6/20	C-2	4.3	0.1	1.5				
3/6/20	B-1	4.8	0.1	1.9	2			
3/6/20	B-2	4.9	0.1	1.9				
3/6/20	A-1		0.1	2	w			
3/6/20	A-2	4.5		1.8				
4/24/20	C-1	4.8	1.9	1.6	w	3,551	5	31,532
4/24/20	C-2	5.3	1.4	1.5				
4/24/20	B-1	5.3	1.4	1.6	1.75	4,804	18	73,048
4/24/20	B-2	5.3	0.6	1.4				
4/24/20	A-1	4.8	0.8	1.4	w	2,967	4	30,200
4/24/20	A-2	4.3	0.6	1.3				
5/29/20	C-1	14	2.6	1.5	1.5	10,505	57	31,816
5/29/20	C-2	17	3	1.6				
5/29/20	B-1	19	2.5	1.5	1.5	11,566	49	36,936
5/29/20	B-2	17	3.6	1.6				
5/29/20	A-1	18	3.4	1.6	1.5	10,191	43	32,160
5/29/20	A-2	19	4.4	1.6				
6/23/20	C-1	6.7	0.1	2.4	1.25	27,160	374	410,608
6/23/20	C-2	6.2	0.8	2.3				
6/23/20	B-1	5.3	2.1	2.2	1.25	24,648	185	228,672
6/23/20	B-2	6.7	1.7	2.4				
6/23/20	A-1	6.7	0.8	2.3	1.25	25,868	504	359,436
6/23/20	A-2	6.7	0.8	2.4				

Appendix 1 (continued).

Date	Sample #	Chl a	Phaeo a	Turbidity	Secchi Depth	Total Algal Biovolume	Cyanobacterial Biovolume	Total Algal Abundance
7/16/20	C-1	8.4	0.1	2.6	1	41,730	180	199,280
7/16/20	C-2	6.7	0.8	2.7				
7/16/20	B-1	12	1.1	2.6	1	40,199	30	82,384
7/16/20	B-2	9.3	0.9	2.6				
7/16/20	A-1	11	0.5	2.5	w			
7/16/20	A-2	11	2.4	2.6				
8/13/20	C-1	6.4	1.8	1.8	1.4	12,660	201	437,872
8/13/20	C-2	6.4	1.4	1.9				
8/13/20	B-1	5.9	1.6	2	1.25	8,855	156	299,752
8/13/20	B-2	6.9	1.7	2				
8/13/20	A-1	7.5	0.4	1.9	1.25	9,323	252	644,884
8/13/20	A-2	6.9	2	1.9				
9/16/20	C-1	8	1.7	1.6	1.4	8,974	124	106,984
9/16/20	B-1	7.5	1.9	1.6	1.5	7,197	81	70,896
9/16/20	A-1	8	1.3	1.9	1.5	8,772	268	139,908
10/15/20	C-1	5.9	2	1.7	1.75	3,962	51	49,584
10/15/20	C-2	7.1	2.8	1.7				
10/15/20	B-1	5.3	1.8	1.6	1.75	3,788	58	66,092
10/15/20	B-2	5.9	1.2	1.7				
10/15/20	A-1	4.8	1.5	1.6	1.75	5,575	531	140,444
10/15/20	A-2	4.8	1.9	1.7				
12/18/20	C-1	3			1.75			
12/18/20	C-2	4						
12/18/20	B-1	3			1.5			
12/18/20	B-2	3						
12/18/20	A-1	3			1.5			
12/18/20	A-2	3						

Notes: December 2020 chlorophyll a was measured as µg/L with a Turner handheld fluorometer. For Secchi depth measurements 'w' indicates that windy field conditions did not allow for an accurate reading.

Appendix 2. White Lake cyanobacterial taxa lists for 2019 and 2020.

White Lake Cyanobacteria Taxa 2019

	4/17/19	5/23/19	7/10/19	9/12/19
Synechococcus	x	x	x	x
Aphanocapsa delicatissima		x		x
Aphanocapsa sp.	x			x
Chroococcus aphanocapsoides				x
Planktolyngbya crassa.				x
Planktolyngbya limnetica	x			x
Planktolyngbya sp.			x	
Cyanoganis ferriginea	x	x		x
Jaaginema sp.			x	
Limnolyngbya circumcreta	x			
Aphanizomenon sp.		x	x	x
Raphidiopsis curvata	x			x
Merismopedia tenuissima	x			
Donichospermum sp.				x
Total # Taxa	**7**	**4**	**4**	**10**
Total Cyanos = 14				

Appendix 2. White Lake cyanobacterial taxa lists for 2019 and 2020 (continued).

White Lake Cyanobacteria Taxa 2020

	2/14/20	4/24/20	5/29/20	6/23/20	7/16/20	8/13/20	9/16/20	10/15/20
Synechococcus	x	x	x	x	x	x	x	x
Aphanocapsa delicatissima		x			x	x	x	x
Aphanocapsa incerta					x		x	x
Aphanocapsa sp.		x	x	x	x	x	x	x
Borzia sp.		x	x	x			x	x
Chroococcus aphanocapsoides		x		x		x	x	x
Lyngbya sp.			x					
Planktolyngbya crassa			x	x	x	x	x	x
Planktolyngbya limnetica				x	x	x	x	x
Limnothrix redekei						x		
Limnothrix sp.			x					
Aphanothece sp.			x	x	x	x	x	x
Cyanoganis ferriginea			x	x		x	x	x
Pseudanabaena limnetica			x	x		x	x	x
Jaaginema sp.			x			x	x	
Planktothrix sp.				x				
Aphanizomenon sp.				x	x	x	x	x
Cylindrospermopsis phillipinensis								x
Cylindrospermopsis raciborskii				x		x		
Komvophoron sp.					x			
Total # Taxa	**1**	**5**	**10**	**12**	**9**	**13**	**13**	**13**
Total Cyanos = 19								

Appendix 3. White Lake Phytoplankton Data, 2018. The first sample date, May 2, was the day before the alum treatment began, and the second date, May 18, was two days after the completion of the treatment. No samples were collected in September due to Hurricane Florence. Seven stations were sampled for the first six sample dates, and three stations were sampled in November and December. The M following the date indicates the means for that date.

Date	Total Biovolume	Total Abundance	Chlorophyll a	Secchi Depth	Turbidity	% CYANO BIOVOL	pH
5/2/18	161,458	16,881,500	47	0.5	5.1	95.8	9.6
	99,916	9,407,250	55	0.5	5.4	95.3	9.66
	170,266	16,995.25	54	0.5	5.4	94.9	9.62
	125,517	11,922,000	48	0.5	4.8	95.9	9.55
	157,750	15,846,750	48	0.5	4.4	95.1	9.12
	177,745	17,803,750	57	0.5	5	95.8	9.58
	168,289	16,447,000	58	0.5	4.2	91.6	9.4
5/2/18 M	151563	12617892	52.4	0.5	4.9	94.8	
5/18/18	109,003	12,283,500	12	0.75	6.2	95.7	5.95
	77,160	8,383,750	13	0.75	6	97.8	5.94
	90,667	9,518,750	14	0.75	6.2	93.5	6.03
	54,681	5,628,750	13	0.75	6.7	92.2	6.04
	65,132	7,261,000	12	0.75	6	93.4	6.11
	24,637	2,617,000	14	0.75	6.3	91.3	6.19
	72,000	7,682,500	12	0.75	6.4	96.7	6.1
5/18/18 M	70468.6	7625035.7	12.9	0.75	6.3	94.9	
5/31/18	107,867	4,396,250	27	0.75	5.2	35.3	6.56
	83,714	2,744,000	24	0.75	5.1	28.3	6.82
	150,771	4,103,000	25	0.75	5.2	23.6	6.6
	80,741	4,281,250	27	0.75	5.2	47.1	6.46
	109,009	4,479,500	28	0.75	5.6	35.9	6.51
	105,915	3,944,750	35	0.75	5.7	30.8	6.55
	82,435	4,669,750	32	0.75	5.4	49.6	6.43
5/31/18 M	102921.7	4088357.1	28.3	0.75	5.3	34.4	
7/12/18	6,374	171,000	5	1.6		0.8	6.54
	8,290	76,500	6	1.6		0.2	6.53
	44,780	105,000	6	1.5		0.3	6.5
	40,573	217,750	5	1.75		0.4	6.58
	9,078	176,000	8	1.75		0.5	6.9
	9,737	161,250	8	1.5		0.4	6.68
	9,393	147,000	6	1.6		0.4	6.76
7/12/18 M	18317.9	150642.9	6.3	1.6		0.4	

Date	Total BV	Total Abundance	Chl a	Secchi	Turbidity	%Cyano Biovol	pH	pH-pm
8/16/18	30,303	74,000	15	1.25	3.2	0.0	6.24	7.34
	20,632	109,750	17	1.25	3.3	0.1	6.39	7.56
	12,876	110,500	16	1.25	3.5	0.2	6.35	7.45
	61,206	173,750	18	1.25	3.8	0.1	6.19	6.81
	45,759	70,750	17	1.25	3.3	0.0	5.83	6.23
	36,395	117,000	15	1.25	3.4	0.1	6.16	6.67
	31,534	87,750	15	1.25	3.6	0.0	6	6.49
8/16/18 M	34100.7	106214.3	16.1	1.3	3.4	0.1		
10/18/18	57,339	162,750	15	1.25	3.4	0.1		
	70,737	116,750	10		3.1	0.3		
	82,934	162,250	11	1.5	3.1	0.0		
	79,601	279,250	12		3.2	0.3		
	41,665	99,550	9		3.1	0.0		
	55,911	112,000	11		3.2	0.0		
	77,526	244,000	8		3.3	0.1		
10/18/18 M	66530.4	168078.6	10.9	1.4	3.2	0.1		
11/13/18	26,563	133,000	9	2.5	1.4	0.1	6.33	
	89,903	180,750	5	2.5	1.4	0.2	6.58	
	19,210	46,000	5	2.5	1.7	0.0	6.63	
11/13/18 M	45225.3	119916.7	6.3	2.5	1.5	0.2		
12/13/18	3,817	6,160	3	B	0.8	0.0	6.25	
	2,148	5,316	3	B	0.8	0.1	6.54	
	2,331	5,776	3	B	1	0.1	6.66	
12/13/18 M	2765.3	5750.7	3	B	0.9	0.0		

Appendix 4. White Lake Monitoring Data 2017-2020.

White Lake Monitoring Data 2017

From NC DEQ (2017) report:

Table 5. Physical and chemical data results for White Lake, 2017

	SURFACE PHYSICAL DATA							PHOTIC ZONE CHEMICAL DATA										
Date	Sampling Station	DO mg/L	Water Temp C	pH s.u.	Cond. µmhos/cm	Secchi Depth meters	Percent SAT	TP mg/L	TKN mg/L	NH3 mg/L	NOx mg/L	TN mg/L	TON mg/L	TIN mg/L	Chla µg/L	Total Solids mg/L	Total Suspended Solids mg/L	Turbidity NTU
September 26, 2017	CPF155A	7.9	25.1	8.1	43	0.8	96.2%	0.05	1.00	<0.02	<0.02	1.01	0.99	0.02	58.0	71	22.0	5.1
September 26, 2017	CPF155B	7.8	25.4	7.8	43	0.8	95.0%	0.04	1.00	<0.02	<0.02	1.01	0.99	0.02	53.0	68		4.1
September 26, 2017	CPF155C	7.7	25.4	7.8	43	0.9	94.5%	0.04	1.00	<0.02	<0.02	1.01	0.99	0.02		70		4.4
August 25, 2017	CPF155A	7.3	29.4	7.6	43	1.0	95.0%	0.04	0.81	<0.02	<0.02	0.82	0.80	0.02	25.0	52		5.4
August 25, 2017	CPF155A1	7.6	30.0	7.6	44	1.0	99.8%	0.03	0.81	<0.02	<0.02	0.82	0.80	0.02	21.0	52		4.8
August 25, 2017	CPF155A2	7.0	29.4	7.1	43	1.0	92.0%	0.04	0.80	<0.02	<0.02	0.81	0.79	0.02	25.0	76		4.8
August 25, 2017	CPF155B	6.6	29.7	6.9	44	1.0	87.0%	0.03	0.82	<0.02	<0.02	0.83	0.81	0.02	25.0	54		3.5
August 25, 2017	CPF155C	6.3	29.9	6.5	44	1.0	83.0%	0.03	0.79	<0.02	<0.02	0.80	0.78	0.02	24.0	109		3.8
August 25, 2017	CPF155C1	6.5	30.1	6.6	44	1.0	87.7%	0.03	0.77	<0.02	<0.02	0.78	0.76	0.02	25.0	48		4.1
August 25, 2017	CPF155C2	6.9	29.9	6.8	44	1.0	90.5%	0.03	0.80	<0.02	<0.02	0.81	0.79	0.02	21.0	80		4.0
July 20, 2017	CPF155A	7.0	30.6	6.8	43	1.3	92.0%	0.02	0.59	<0.02	<0.02	0.60	0.58	0.02	8.9	50	<12.0	3.2
July 20, 2017	CPF155B	6.9	30.7	6.8	44	1.6	92.7%	0.02	0.58	<0.02	<0.02	0.59	0.57	0.02	12.0	64	<6.2	3.2
July 20, 2017	CPF155C	7.0	29.8	6.6	43	1.5	92.7%	0.02	0.62	<0.02	<0.02	0.63	0.61	0.02	7.9	70	<6.2	2.6
June 29, 2017	CPF155A	7.4	28.9	7.4	44	1.2	96.1%	0.02	0.65	<0.02	<0.02	0.66	0.64	0.02	9.5	73	<12.0	4.2
June 29, 2017	CPF155A1	7.4	29.0	6.6	44	1.2	95.1%	0.02	0.68	<0.02	<0.02	0.69	0.67	0.02	10.0	76	<6.2	4.0
June 29, 2017	CPF155A2	7.2	29.1	6.5	44	1.2	94.1%	0.02	0.70	<0.02	<0.02	0.71	0.69	0.02	9.4	74	<6.2	3.6
June 29, 2017	CPF155B	7.3	28.6	6.5	44	1.2	94.0%	0.02	0.66	<0.02	<0.02	0.67	0.65	0.02	12.0	76	6.5	5.8
June 29, 2017	CPF155C	7.2	28.4	6.5	44	1.1	91.7%	0.02	0.69	<0.02	<0.02	0.70	0.68	0.02	11.0	76	10.0	4.7
June 29, 2017	CPF155C1	7.3	28.5	6.6	44	1.2	95.0%	0.02	0.67	<0.02	<0.02	0.68	0.66	0.02	12.0	66	<6.2	4.2
June 29, 2017	CPF155C2	7.2	28.7	6.6	44	1.1	94.0%	0.03	0.63	<0.02	<0.02	0.64	0.62	0.02	11.0	69	<6.2	3.7
May 17, 2017	CPF155A	8.3	25.6	5.9	44	1.5	101.5%	0.02	0.53	<0.02	<0.02	0.54	0.52	0.02	9.2	67	6.5	2.3
May 17, 2017	CPF155B	8.6	24.6	6.1	44	1.5	103.2%	0.03	0.52	<0.02	<0.02	0.53	0.51	0.02	10.0	63	<6.2	2.2
May 17, 2017	CPF155C	8.6	24.7	6.4	44	1.5	103.7%	0.02	0.62	<0.02	<0.02	0.63	0.61	0.02	9.2	59	7.8	2.3

Appendix 4. White Lake Monitoring Data 2017-2020 (continued).

White Lake Summary Data, 2018

Physical and chemical sampling conducted by LIMNOSCIENCES/Envirochem, from May-December 2018. Parameters and sample stations for May established by NC DEQ in conjunction with the low-dose alum treatment (conducted May 3-16), with a single sample taken at 0.5 m at each sample station.

	5/2/18	5/31/18	6/27/18	7/12/18	7/26/18	8/16/18	10/18/18	11/13/18	12/13/18
Mean Temp (C)	23.4	27.4	30.23	29.2	28.1	30.0	22.8	15.4	7.6
Mean DO (mg/L)		8.19	7.61	7.29	7.42	7.56	8.45	9.65	11.81
Range % Sat. DO	121-124	99-107	98-106	88-98	93-97	89-104	96-100	96-97	98-100
Range pH	9.12-9.62	6.31-6.68	6.55-7.29	6.46-6.9	5.53-6.41	6.39-7.56	6.5-7.0	6.33-6.63	6.25-6.66
Mean Cond. (uS/L)	33.31	90.76	95.7	90.6	86.6	88.6	32.3	27.8	22.2
Mean Turbidity (NTU)	4.9	5.3				3.4	3.2	1.5	0.9
Mean Secchi Depth (m)	0.5	0.75	1.75	1.75	1.5	1.25	1.25	2.5	3.0
Mean Chl. a (ug/L)	52	28	8	6	9	16	11	6	3
Mean TOC (mg/L)	23	16.1	13.7	14.5	12.3	11.9	7.8	7.4	7.1
Mean DOC (mg/L)			12.5	13.6	11.2		7.0	6.6	6.7
Mean Total N (mg/L)	1.3	1.8	0.5	0.7	0.7	0.8	0.8	0.5	0.6
Range Ammonia(mg/L)	<0.2	<0.2-0.5	<0.2-1.0	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Range TKN (mg/L)	0.9-1.5	0.8-1.4	<0.5-1.0	0.5-0.7	0.5-0.9	0.5-1.1	0.6-0.9	<0.5-0.6	0.5-0.7
Range NO3-NO2(mg/L)	<0.02-0.36	<0.02-1.06	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Mean Total P (mg/L)	0.15	0.08	0.08	0.08		<0.04	<0.04	<0.04	<0.04
Range Soluble P (mg/L)	0.04-0.13	0.05-0.13	<0.04-0.06	<0.04-0.08		<0.04	<0.04	<0.04	<0.04
# Sample Sites	7	7	13	7	8	7	7	3	3

NC DEQ conducted sampling at three stations from May to September 2018. Their nutrient results were presented in a report (NC DEQ 2019) in graphical form rather than table form, and results were generally quite similar to the results in the table above **with the exception of phosphorus levels**, with considerably higher results reported by Envirochem (Soluble P levels were very high as well, sometimes exceeding TP).

Phosphorus data from NC DEQ (2019) report:

Total Phosphorous (TP)

Total phosphorous is often the limiting nutrient in algal growth (productivity) and was the target of alum treatment. Concentrations of TP have been increasing since 2013 (DWR 2017). TP reached its highest concentration in May of 2018 with a value of 0.06 mg/L before decreasing after the alum treatment (Figure 7) to 0.02 mg/L. TP was below the detection level (0.02 mg/L) in July and August of 2018. Note: The TP measurement includes phosphorus found in phytoplankton.

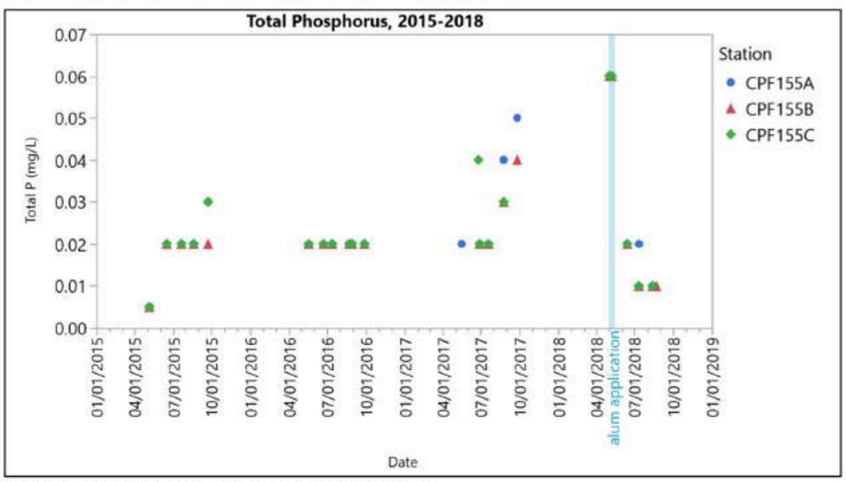

Figure 7 - TP concentrations at White Lake, 2015-2018.

Drs. Chris Shank and Peter Zamora were also sampling White Lake in 2018, starting in February. Their phosphorus data was also analyzed by Envirochem, with high and variable results (for example, Total Dissolved P values were 0.88, 0.01, 0.61, 0.73, 0.68 mg P/L on January 29, 2019). By comparison with 2019 data (in the following table), all of which was analyzed by another laboratory, all values for Soluble Reactive P were at or below the detection limit of 0.001 mg P/L, which suggests that there were significant QC issues with the 2018-9 P data analyzed by Envirochem, and NC DEQ data only should be relied on for 2018 Total P data.

Dissolved Organic Carbon (DOC) was one of the parameters Shank and Zamora measured at 5 lake stations. Mean DOC (mg C/L) from February 27, 2018 was 17.0 (3 stations), April 10 was 18.7, June 5 was 15.8, July 11 was 12.5, August 14 was 10.6, October 17 was 6.2, and December 4 was 7.9.

White Lake Monitoring Data 2019

Physical and chemical monitoring parameters for White Lake, March-December 2019. Samples were collected at two depths (0.5 and 2.0 m) at each of three stations (equivalent to the monitoring stations used by NC DEQ). As the depth of the lake is a function of lake level, which varies, when the Secchi is visible on the lake bottom it is recorded as a "yes" instead of a depth.

	3/18/19	4/17/19	5/23/19	6/25/19	7/10/19	8/14/19	9/12/19	10/10/19	11/21/19	12/18/19
Mean Temp (C)	17.1	20.8	27.0	29.0	29.0	30.3	28.9	21.7	10.1	11.3
Lake Level (gauge)	1.78	1.76	1.42	1.09	1.00	1.38	1.40	1.00	1.3	1.5
Secchi Depth (m)—					1.5	1.25	1.7	1.6		
Visible at Bottom?	Yes	Yes	Yes	Yes					Yes	Yes
Turbidity (NTU)					1.9	2.1	1.4	1.7	0.6	0.7
Mean DO (mg/L)	9.9	8.9	9	7.9	7.2	7.3	7.9	8.5	11.2	10.8
Mean DO % Sat.	103	99	99	103	93.5	97.4	102.8	97.1	99	99
Mean Sp. Cond. (uS//L)	32	31.8	32.6	34.0	34.4	33.1	31.5	33.1	35.5	34.4
Range pH (su)	6.4-6.8	6.3-6.7	6.2-6.6	6.2-6.7	6.5-6.6	6.3-6.6	6.8-7.0	6.3-6.6		6.7-6.9
Mean Chlorophyll a (µg/L)		1.8	2.9	5.5	8.5	10.3	6.7	8.2	2.5	4.6
Mean DOC (mg/L)					4.66	4.91	5.38	5.87	7.53	5.17
Mean Total N (mg/L)		0.304	0.330	0.481	0.616	0.548	0.719	0.613	0.407	0.642
NO3-NO2 (mg/L)		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.010
Mean Total P (mg/L)		0.017	0.014	0.014	0.015	0.027	0.022	0.023	0.013	0.020
SRP (mg/L)		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001
# of Samples	3	6	6	6	6	6	6	6	6	6