2017 White Lake Water Quality Investigation

White Lake, Bladen County (Cape Fear Basin)

December 2017

Prepared by

NORTH CAROLINA DEPARTMENT OF ENVIRONMENTAL QUALITY

Division of Water Resources

Water Resources
ENVIRONMENTAL QUALITY

Executive Summary

White Lake, a Carolina Bay lake located in Bladen County, N.C., is unique in its lack of tannin-colored water typical of these lakes. Instead, White Lake has historically been known for its crystal-clear water and white sand which made it a popular recreation and tourist destination. An increase in the amount of algae found on the lake bottom (benthic algae), along with changes in the water from clear to green-colored, have resulted in a decline in the aesthetics of the lake in recent years. More recently, lake water monitoring by the Division of Water Resources (DWR) has detected a change in the lake pH from acidic to near neutral and an increase in nutrient levels, turbidity and chlorophyll *a* values. In 2014, the Town of White Lake and the N.C. State Parks requested assistance from DWR to determine potential causes for the increasing benthic algae and water quality changes in White Lake. In response to this request, in-lake water quality monitoring was conducted in 2015 through 2017, with the inclusion of groundwater and watershed water quality monitoring in 2017. This report summarizes the conditions of White Lake and nearby water sources in 2017.

The findings from this study were:

- <u>Lake conditions</u> – Evidence of increasing lake productivity (eutrophication) and declining water quality due to:
    - Increasing nutrient concentrations in 2017 as compared with previous 36 years of DWR sampling efforts
    - Increase in chlorophyll *a* values
    - Changes in the algal community from green algae to bluegreen algae dominated

- <u>Groundwater</u> –
    - Elevated Total Kjeldahl nitrogen (TKN) concentrations in shallow well water
    - Low nutrient concentrations in deep well water
    - Low nutrient concentrations in spring water, with no evidence of outflow into the lake

- <u>Watershed</u> –
    - Elevated nutrient concentrations in the two DOT storm drainage ditches on the northeastern side of the lake
    - Both ditches did not flow unless rainfall event was 1.25” or greater

The findings of this study suggest that the shallow groundwater and nonpoint source nutrients are elevated and the volume of artesian spring input to the lake may be decreasing. To identify feasible solutions and management strategies for White Lake’s nutrient enrichment problem, further evaluation of these issues should be conducted to comprehensively characterize nutrients and water volume in and around White Lake.

Background and Purpose

The geographic area of concern for this study is White Lake, the surrounding watershed, neighboring bay lakes and local aquifers. White Lake is a shallow, 1,068-acre Carolina Bay lake located near Elizabethtown, N.C. The maximum depth of this lake is approximately nine feet and estimated residence time is 292 days. Except for a small, 0.12-mile long strip of land along the northern shoreline, the entire 4.8-mile shoreline is developed for residential and some commercial uses. Approximately two-thirds of the lake shoreline is bulk-headed or forested. The remaining one-third of the lake shoreline is gently sloped. As part of the N.C. State Parks Singletary Lake complex, White Lake provides recreational opportunities such as swimming, fishing and boating.

White Lake is an unusual Carolina Bay lake in that the water of this lake is clear rather than colored by tannins (i.e., tea colored). The water clarity has historically been attributed to numerous springs at the bottom of the lake that bring water in such that water input is not dominated by shallow (near surface and organic) groundwater inflow as is the case with other Carolina Bay lakes. The water level of White Lake is determined by the regional water table and, in drought years, will drop in response to the decrease in rainfall and groundwater (springs) input. The outlet channel is in the northwestern section of the lake as opposed to the southeastern section as in other bay lakes (Frey, D.G., June 1949; Wells, B.W. et al., 1953).

Beginning in 1950, various state agencies occasionally received complaints from residents and visitors regarding unwanted aquatic vegetation in White Lake. Over time, these complaints increased and expanded to include sewer spills, fish kills, green water color and reports of skin rashes on swimmers. These types of observations resulting from algae blooms and aquatic weeds are frequently an indication of excessive nutrients in lake water.

In 2014, at the request of the Town of White Lake, N.C. Parks and the DWR Fayetteville Regional Office, the division expanded ambient monitoring efforts on White Lake. Water monitoring efforts, which began in 1981, consisted of lake water sampling during the summer months to evaluate water quality conditions in respect to lake use. Based on evaluation of this historic data, the 2010 trophic state of the lake had shifted from oligotrophic (low productivity) to mesotrophic (moderate productivity). Short periods of eutrophic conditions (high productivity) have also been observed. The most dramatic water quality change has been the lake's pH. The acidic nature of White Lake (~4.5 historic average) has risen to a more neutral average pH value of 6.9 over the last 10 years. This pH increase may be due to the increase in benthic algae in the lake.

The purpose of the 2017 study was to determine potential sources of nutrient loading to White Lake which may be contributing to the increased productivity observed in the lake.

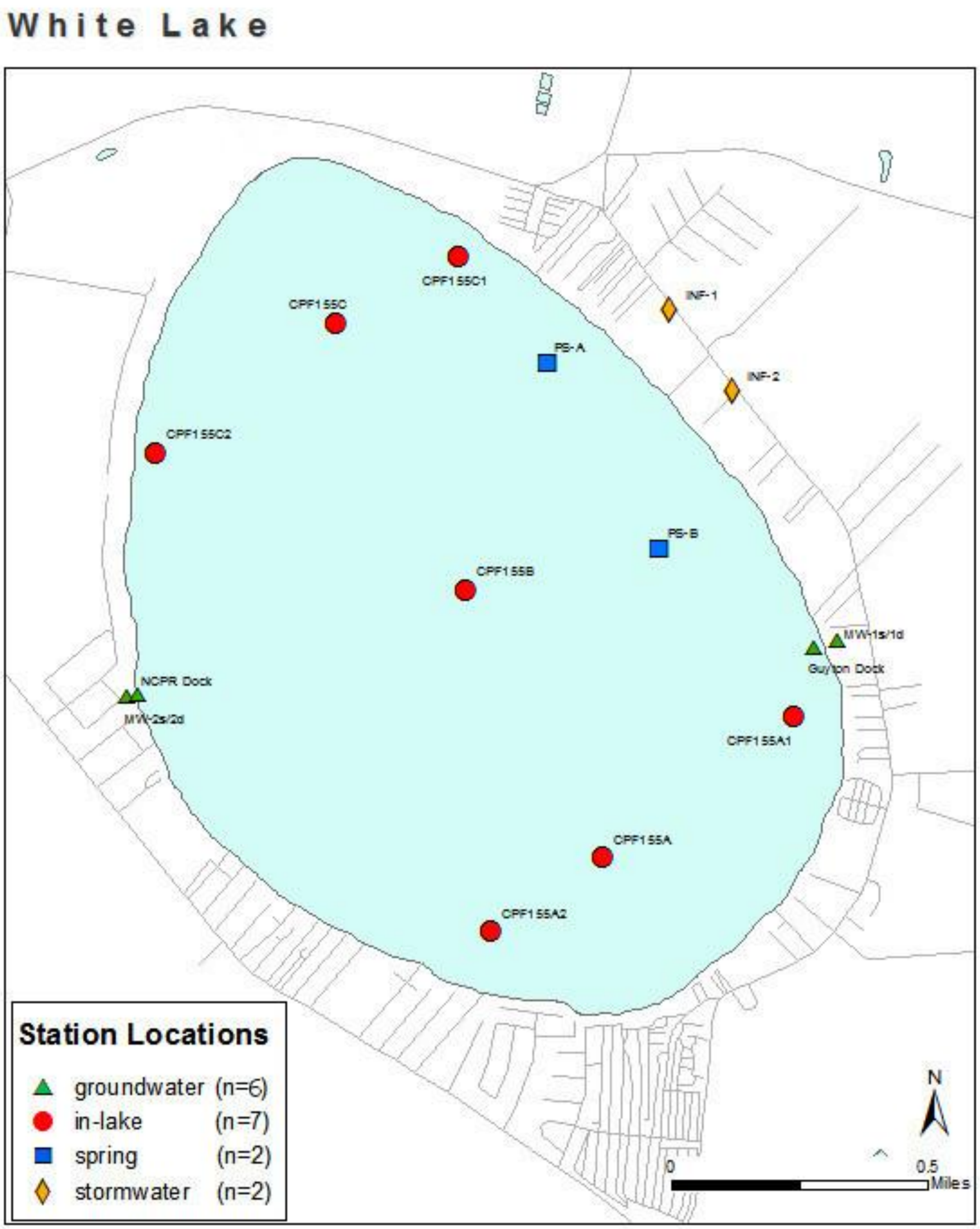

Figure 1. White Lake and sampling site locations.

Methodology

White Lake Monitoring

White Lake was sampled by staff from the DWR Fayetteville Regional Office monthly from May through September 2017. Three historical DWR sampling sites (CPF155A, CPF155B and CPF155C) were sampled each month while four near shore sites (CPF155A1, CPF155A@, CPF155C1 and CPF155C2) were sampled in June and August to provide additional water quality conditions (Figure 1, Table 1). Parameters measured and water chemistry parameters evaluated at each site are presented in Table 2.

Table 1. White Lake sampling sites

Site Name	Coordinates (latitude…longitude)		Physical Parameter	Chemical Parameters Photic Zone
CPF155A	34.635840	-78.493380	X	X
CPF155A1	34.639817	-78.486742	X	X
CPF155A2	34.633747	-78.497204	X	X
CPF155B	34.643460	-78.497990	X	X
CPF155C	34.651020	-78.502440	X	X
CPF155C1	34.652891	-78.498214	X	X
CPF155C2	34.647387	-78.508633	X	X

Table 2. White Lake sampling parameters

Physical Parameters	Chemical Parameters
Temperature (°C) Dissolved Oxygen (mg/L) Dissolved Oxygen (% Sat.) pH (s.u.) Conductivity (µS/cm) Secchi Depth (m)	Chlorophyll *a* (*u*g/L) Turbidity (NTU) Total Solids (mg/L) Total Suspended Solids (mg/L) Nutrients -Total Phosphorus (mg/L) -Total Kjeldahl Nitrogen (mg/L) -Nitrate & Nitrite (mg/L) -Ammonia (mg/L) Phytoplankton

Artesian Aquifer Monitoring

To evaluate the relationship between the artesian aquifer and White Lake, water samples were collected at suspected spring sites located in the lake for physical and chemical analysis (Figure 1, Table 3). With the assistance of local citizens of White Lake, DWR staff examined the lake floor with side scan sonar to find the locations of depressions reported as associated with the spring outlets. Drift scans over these locations with temperature and pH probes, just above the lake floor, were used in attempt to identify noticeable contrasts between spring and lake water. Water samples were collected from two sites and submitted for laboratory analysis for comparison (Table 3).

Water samples were collected from suspected submerged spring sites with a PVC well casing equipped with a 0.010-inch slot screen. These were "washed" or "jetted" into the lake bottom to an approximate depth of ten feet. The naturally occurring sand was used as the gravel pack. The well casing and screen were developed with a peristaltic pump. Sample water was pumped from the well to a collection container and distributed into sample bottles for laboratory water chemistry analysis. Physical water quality parameters were also measured from the sample water.

Table 3. White Lake in-lake spring sampling sites and sampling parameters

Site Name	Coordinates (latitude…longitude)	Physical Parameters	Chemical Parameters
PS-A **PS-B**	34.64988 -78.49521 34.64459 -78.49135	Temperature (°C) Dissolved Oxygen (mg/L) Dissolved Oxygen (% Sat.) pH (s.u.) Conductivity (µS/cm) Depth to Water (feet)	Nutrients* -Total Phosphorus (mg/L) -Total Kjeldahl Nitrogen (mg/L) -Nitrate & Nitrite (mg/L) -Ammonia (mg/L) Select Metals

Groundwater Monitoring

Groundwater samples were obtained from six monitoring wells temporarily installed at various locations around the lake (Table 4). Onshore shallow wells (two) were installed in the first water bearing zone encountered, and were designated with an "s" for "shallow". A second set of onshore wells were installed below the first water bearing zone and were designated with a "d" for "deep". The wells were constructed with PVC well casing and PVC screen (0.010-inch slots). The gravel pack was constructed with No. 2 sand, and the wells sealed with bentonite clay. Additionally, two shallow in-lake groundwater wells (Guyton Dock near wells MW-1s-1d and NCPR Dock near MW-2s-2d) were installed to provide a comparison of lake groundwater chemistry with onshore groundwater chemistry.

The wells were installed based on the location of the first and second water bearing zone, and not necessarily on aquifer conditions. Since the wells were not necessarily constructed in the aquifer conditions required to produce turbid free water, water samples were filtered (0.45 µm) prior to preservation in the field. The wells were developed on the same day they were installed and purged a minimum of three well volumes prior to each sampling event.

Table 4. Groundwater well sampling sites and sampling parameters at White Lake

<table>
<tr><th>Site Name</th><th>Coordinates
(latitude…longitude)</th><th>Physical Parameters</th><th>Chemical Parameters</th></tr>
<tr><td>MW-1S</td><td rowspan="2">34.64193 -78.48525</td><td rowspan="6">Temperature (°C)
Dissolved Oxygen (mg/L)
Dissolved Oxygen (% Sat.)
pH (s.u.)
Conductivity (µS/cm)</td><td rowspan="6">Nutrients *
-Total Phosphorus (mg/L)
-Total Kjeldahl Nitrogen (mg/L)
-Nitrate & Nitrite (mg/L)
-Ammonia (mg/L)</td></tr>
<tr><td>MW-1D</td></tr>
<tr><td>Guyton Dock</td><td>34.64176 -78.48609</td></tr>
<tr><td>MW-2S</td><td rowspan="2">34.64046 -78.50966</td></tr>
<tr><td>MW-2D</td></tr>
<tr><td>NCPR Dock</td><td>34.64053 -78.50927</td></tr>
</table>

Stormwater Drainage Ditch Monitoring

Water samples from two drainage ditches located on the northeastern side of White Lake (Figure 1) which drain directly into the lake were sampled following a major rainfall event (~1.25”) in April. These water samples were analyzed for nutrient concentrations in an effort to determine to what extent these ditches contribute to nutrient-loading of the lake.

Results

(All data tables in this section are available in Appendix C.)

White Lake Water Quality Monitoring Results

Surface dissolved oxygen at the lake sampling sites was greatest in May (range = 8.3 to 8.6 mg/L) and ranged from 6.3 to 7.9 mg/L from June through September (Table 5). Secchi depths, a measurement of lake water clarity and light penetration, ranged from 0.8 to 1.6 meters. The September secchi depths were the lowest measurements recorded for White Lake since 1981 when monitoring of this lake by DWR was initiated.

The lowest surface pH value (5.9 s.u.) was observed in May and the highest value (8.1 s.u.) occurred in September. Both values were measured at site CPF155A. In July 2013, DWR observed surface pH values ranging from 8.0 to 8.3 s.u. in White Lake. Surface conductivity values ranged from 43 to 44 umhos/cm in 2017. These were the lowest surface conductivity values observed by DWR for White Lake since 1981.

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

Overall, nutrient concentrations in White Lake were greatest in September as compared with the previous sampling months in 2017 (Table 5). Both NH_3 and $NO_2 + NO_3$ were below DWR laboratory detection levels. Total phosphorus ranged from 0.02 to 0.05 mg/L and total Kjeldahl nitrogen (TKN) ranged from 0.52 mg/L in May to 1.00 mg/L in September. Total organic nitrogen ranged from 0.53 to 0.99 mg/L. There were little differences in near-shore and mid-lake nutrient concentrations. Chlorophyll *a* values ranged from 7.9 to 58.0 µg/L. The values for chlorophyll *a* in September were greater than the state water quality standard of 40 µg/L. Analysis of phytoplankton samples collected from White Lake in 2017 indicated that the algal community in June and July was dominated by the green alga, *Gonatozygon brebissonii.* In August, the algal community transitioned to *Planktolyngbya limnetica*, a filamentous bluegreen alga that dominated the lake's algal community (North Carolina Department of Environmental Quality, 2017).

Submerged Springs Monitoring Results

Drift scans with temperature and pH probes over suspected artesian spring outlets did not identify any significant changes between lake water and spring water. Water samples were collected in July from two suspected spring sites located at the bottom of White Lake. The depth of the water collection was approximately eight to 11 feet below the lake bed (Figure 1, Table 6).

Table 6. Nutrient concentrations and physical measurements of sample water from submerged springs in White Lake

Location	Date	Water Temperature °C	Dissolved Oxygen mg/L	Conductivity µmhos/cm	pH s.u.	Total Phosphorus mg/L	Total Kjeldahl N mg/L	Ammonia NH_3 mg/L	Nitrite + Nitrate mg/L	Total N mg/L	Total Organic N mg/L	Total Inorganic N mg/L
PS-A	July 1, 2017	27.9	5.4	42	6.0	<0.02	0.42	<0.02	<0.02	0.43	0.41	0.02
PS-B	July 1, 2017	27.2	2.0	42	5.8	0.03	0.51	0.22	<0.02	0.52	0.29	0.23

Groundwater Monitoring Results

Water samples were collected from six wells at two sites from June through August. The physical and chemical data are presented in Table 7 below and site locations are presented in Figure 1. Shallow wells ranged from three to four feet below the land surface, while deep wells extended 20 to 25 feet below the land surface. The greatest differences in physical values between shallow and deep wells were observed at MW-1S and MW 1D (Table 7), where surface conductivity, dissolved oxygen and water temperature were greater in the shallow well compared to the deeper well. The differences between these measurements at MW-2S and MW-2D were not as great. Groundwater physical condition data is limited to this date only.

For both pairs of onshore well sites, nutrient concentrations in the shallow wells were higher than those in deeper well water. Shallow water from MS-1S on the eastern shore of White Lake had higher nutrient concentrations than from the shallow well MW-2S on the western shore. To compare with onshore groundwater chemistry, in-lake groundwater chemistry at the Guyton Dock shallow well near MW-1S/1D wells had higher dissolved oxygen and pH and lower conductivity on June 30th. Chemically, this in-lake well had lower phosphorus and nitrogen values than both the shallow and deep well onshore wells, with the exception of total organic nitrogen. Water samples collected at well locations on July 20th indicate shallow well water was higher in nutrient concentrations when compared to deeper well water, while shallow water from MW-1S was higher in nutrient concentrations compared to samples obtained from well MW-2S. Nutrients remained higher in the shallow well samples collected on August 28th. Shallow well nutrients from MW-1S also remained higher than those in MW-2S.

Table 7. Nutrient data collected from groundwater wells at White Lake, June- August 2017

Date m/d/yr	Sampling Station	Water Temperature °C	Dissolved Oxygen mg/L	pH s.u.	Conductivity umhos/cm	Total Phosphorus mg/L	Total Kjeldahl N mg/L	Ammonia NH3 mg/L	Nitrite + Nitrate mg/L	Total N mg/L	Total Organic N mg/L	Total Inorganic N mg/L
June 30, 2017	MW-1S	27.0	3.0	4.8	242	0.30	4.90	2.90	<0.02	4.91	2.00	2.91
June 30, 2017	MW-1D	19.6	0.8	4.4	56	0.17	1.00	0.30	<0.02	1.01	0.70	0.31
June 30, 2017	Guyton Dock *	31.5	7.4	7.3	44	0.02	0.75	<0.02	<0.02	0.76	0.74	0.02
June 30, 2017	MW-2S	25.9	0.8	5.6	129	0.50	3.40	2.60	<0.02	3.41	0.80	2.61
June 30, 2017	MW-2D	20.9	0.7	5.9	102	0.09	0.59	0.41	<0.02	0.60	0.18	0.42
July 20, 2017	MW-1S					0.61	5.30	3.00	<0.02	5.31	2.30	3.01
July 20, 2017	MW-1D					0.13	0.88	0.35	<0.02	0.89	0.53	0.36
July 20, 2017	Guyton Dock *					<0.02	0.52	<0.02	<0.02	0.53	0.51	0.02
July 20, 2017	MW-2S					0.59	2.60	1.20	0.10	2.70	1.40	1.30
July 20, 2017	MW-2D					0.09	0.58	0.40	<0.02	0.59	0.18	0.41
July 20, 2017	NCPR Dock *					<0.02	0.56	<0.02	<0.02	0.57	0.55	0.02
August 28, 2017	MW-1S					0.52	5.50	3.10	<0.02	5.51	2.40	3.11
August 28, 2017	MW-1D					0.16	0.86	0.33	<0.02	0.87	0.53	0.34
August 28, 2017	Guyton Dock *					<0.02	0.46	<0.02	<0.02	0.47	0.45	0.02
August 28, 2017	MW-2S					0.53	2.80	1.50	<0.02	2.81	1.30	1.51
August 28, 2017	MW-2D					0.10	0.58	0.39			0.19	
August 28, 2017	NCPR Dock *					0.03	0.75	<0.02	<0.02	0.76	0.74	0.02

* In-lake comparison data

Groundwater level data was also collected at designated sites at White Lake. The general trend for groundwater in the immediate vicinity of the lake was reflective of the soil characteristics adjacent to well locations and their respective source of water. The onshore shallow well data exhibits flux at a faster and more responsive rate than soils adjacent to the deeper well at 25 feet below the surface. Shallow in-lake groundwater wells follow the same trend as shallow onshore wells, although to a lesser degree in response to rainfall events. This can be observed in Figure 2 which depicts water level information collected at four-hour intervals during the study period at MW-1S, MW-1D, and the Guyton Dock wells. Changes in lake well levels do correlate to groundwater level flux adjacent to the lake as noted in previous studies (Wells, B.W. and S. G. Boyce, 1953). The understanding submerged artesian springs in the lake is limited due to a limited number of sites and timeframe for study. Thus, the contributions of shallow groundwater and artesian springs to White Lake is not conclusive based on data collected this study.

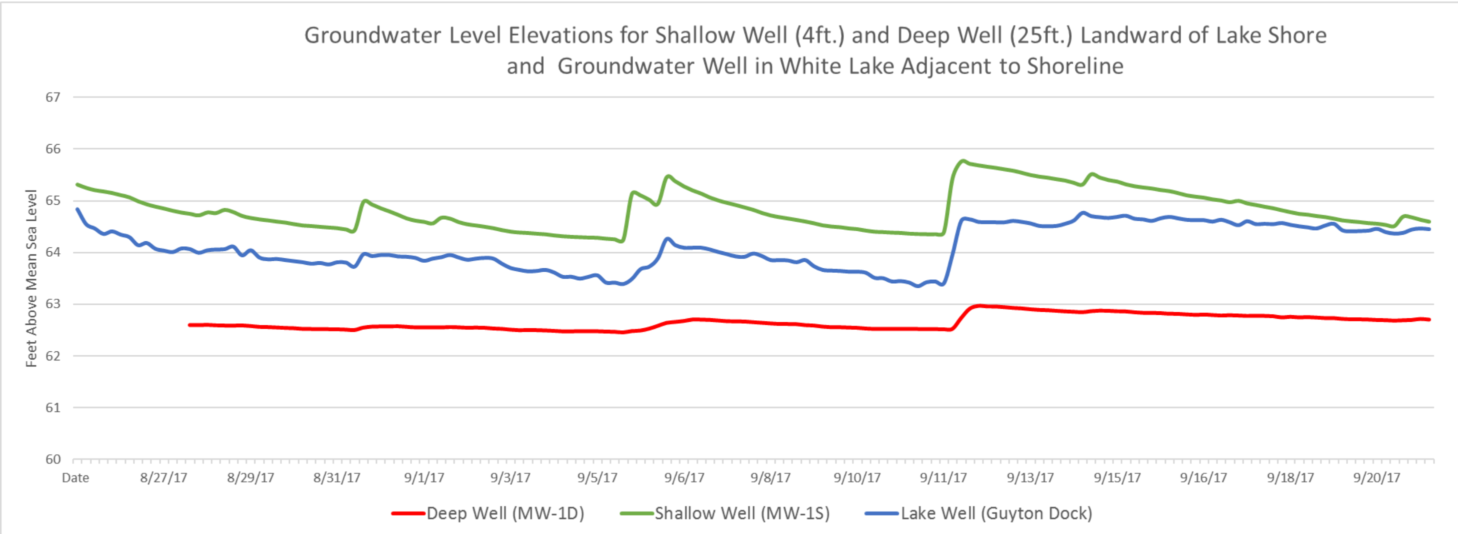

Figure 2. Comparison of shallow and deep well groundwater depths in relation to in-lake groundwater depth

Stormwater Drainage Ditch Monitoring Results

Nutrient water samples were collected twice from stormwater drainage ditch INF-1 in April 2017 and once from drainage ditch INF-2 (Table 8). Total phosphorus concentration in INF-1 was greater in the first storm collection event as compared with the second event. Total Kjeldahl nitrogen was elevated in both drainage ditches as was total organic nitrogen.

Table 8. Nutrient data collected from stormwater ditches.

Date m/d/yr	Sampling Station	Total Phosphorus mg/L	Total Kjeldahl N mg/L	Ammonia NH3 mg/L	Nitrite + Nitrate mg/L	Total N mg/L	Total Organic N mg/L	Total Inorganic N mg/L
4/3/2017	INF-1	0.12	1.2	0.03	0.07	1.27	1.17	0.10
4/6/2017		0.04	1.3	0.02	<0.02	1.31	1.28	0.03
4/6/2017	INF-2	0.04	3.4	0.03	0.02	3.42	3.37	0.05

INF-1 Located at 408 White Lake Dr.

INF-2 Located at 580 White Lake Dr.

Inputs only flowed when rain events exceeded 1.25 inches of rain.

Discussion

An evaluation of the historic DWR lake monitoring data was conducted to identify trends. Based on this evaluation (Appendix A), the trophic state (biological productivity) of White Lake has increased within the past 20 years. A review of chemistry and physical data trends indicate that the productivity of White Lake is increasing. An increase in nutrient levels has supported an increase in both planktonic and benthic algae along with increases in the water column chlorophyll *a* values. Subsequently, these microscopic plants have contributed to an increase in the turbidity and green coloration of the once crystal-clear lake water. The increase in algal growth also contributes to an increase in the pH of the lake from acidic to near neutral conditions.

The shift in the pH of White Lake from approximately 4.0 to 4.7 s.u. to approximately 7.0 s.u., and shift in specific conductivity from approximately 95 µmhos/cm to 45 µmhos/cm in recent years is an indication of an important change in the lake's water quality. In 2015, a study conducted by Dr. Kimberly Jones and students from Brunswick Community College attempted to determine whether changes in the chemistry of spring water entering the lake was contributing to the pH increase (Jones, 2015). If the aquifer had come in contact with a layer of limestone, subsequent buffering of the acidic spring water (i.e. increased pH) might explain in the overall increase in the lake water pH. Spring water samples, however, were found to have a pH of 4.7 s.u. while lake water pH away from the spring site was measured at 6.9 s.u. This result agreed with the pH values obtained by DWR staff in 2017 which indicated that water from the spring sites were lower (5.8 to 6.0 s.u.) compared to the lake water (6.6 to 6.8 s.u.) in July. The change in spring water pH observed in 2015 to 2017 may have been due to difficulty DWR staff had in determining the exact location of the spring outflow sites in 2017, as well as potential (but unmeasured) differences in outflow rates in 2016 as compared with 2017.

Phytoplankton samples collected in 2017 by DWR indicate changes in the composition of the algal community over the past four years. In 2013, this community consisted primarily of desmids such as green algae, and other algal groups such as cryptophytes, chrysophytes and diatoms. These algal groups are typically found in acidic, oligotrophic (low nutrient) waters and are beneficial in supporting a healthy aquatic environment. DWR first identified the presence of bluegreen algae in White Lake in 2015. Since that time, the relative abundance of chrysophytes, cryptomonads and diatoms have decreased, while the abundance of bluegreen algae has increased. This shift in the algal community is an indication of nutrient enrichment, and reflects a change in the trophic state of White Lake from oligotrophic to eutrophic (North Carolina Division of Water Resources, 2017; Appendix B).

Data collected from shallow onshore wells in June and July 2017 suggest that elevated nutrients from groundwater may be a source of nutrient loading in White Lake. Water collected from artesian spring sites below the lake bed was much lower in nutrient levels compared to these shallow groundwater samples. Groundwater level flux between landward and in-lake sites indicates a closely connected system in which the lake receives its source water from surficial (<5') and deep (>5') aquifers. It appears that during the course of this study, the nutrient loading in White Lake is at times dominated by shallow groundwater and to a lesser degree the in-lake spring sources. However, the current volume of groundwater input versus the artesian springs is unknown.

In the early 1950s, Frey and Boyce conducted a simple dye experiment in White Lake that determined the head pressure from the submerged artesian springs was great enough to force fluorescent dye from the lake's shoreline landward into the coarse sand rim of the lake. Using six inch wells perpendicular to the shoreline, dye placed in the well closest to the lake had migrated 10 feet *away* from the lake to the third well over 26 hours. As a comparison, the same experiment was conducted at Jones Lake. The dye in the first well remained in that well without migrating for 14 hours (Wells, B.W. and S. G. Boyce, 1953). If the water pressure from the submerged springs has decreased, the resultant pressure may no longer be sufficient to prevent the movement of shallow groundwater adjacent to the shoreline from flowing *into* the lake. This would likely result in a shift towards a predominantly precipitation and shallow groundwater driven system as opposed to one that is supplied by spring water. This change may have a significant influence on the lake's retention time (the time it takes for new water to enter and move out of the lake). Lake outflow from Turtle Cove was measured at approximately 250 gpm during the months of February and March 2017 by DWR field staff. Flow from the lake ceased in June 2017 and, as of November 2017, had yet to resume. Such a pattern of outflow reduction and water retention correlates with late summer 2017 reduction in water quality conditions, increased nuisance benthic algae and algal blooms.

In summary, internal lake nutrient cycling, coupled with nutrients from shallow groundwater and potential nonpoint sources (i.e., surface water runoff due to storm events), combined with increasing lake residence times appear to be creating in-lake nutrient levels capable of supporting ongoing nuisance levels of algal growth and declining lake aesthetics. Further evaluation of White Lake's hydrology, nutrient sources, and aquatic plant community should be performed to provide better understand the dynamics of White Lake and to develop effective nutrient and aquifer management solutions.

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Appendix A

White Lake Water Quality Trends
and Analysis Report

White Lake Water Quality Data Trends and Analysis

White Lake, Bladen County (Cape Fear Basin)

December 2017

North Carolina Department of Environmental Quality

Division of Water Resources

Water Sciences Section - Intensive Survey Branch

Background and Data Information

White Lake, used extensively for water-based recreational activities, is a Carolina Bay Lake with historically acidic waters and unusually high water clarity. Recently, there have been questions regarding the lake's water quality based on water clarity concerns. The N.C. Division of Water Resources has monitored White Lake since 1981 as part of routine basin-wide assessments, with the last assessment in 2013. Additional data has been collected from the lake from 2015 through 2017 as part of the special study. This report highlights data summaries from this multi-year database, calculated from 126 water quality sampling events from the surface (depth of 0.15 meters) or photic zone (mean 4.4 meters). Samples were collected from three sites across White Lake for all years with the exception of 2017, when additional locations were sampled within and around White Lake: in-lake water column (n=4, total n=7), spring (n=3), groundwater (n=6), and stormwater (n=2) (Figure 1). For more specific yearly information, please review Basin Assessment Reports on the Water Sciences Section website at https://deq.nc.gov/about/divisions/water-resources/water-resources-data/water-sciences-home-page. Data was analyzed by year sampled.

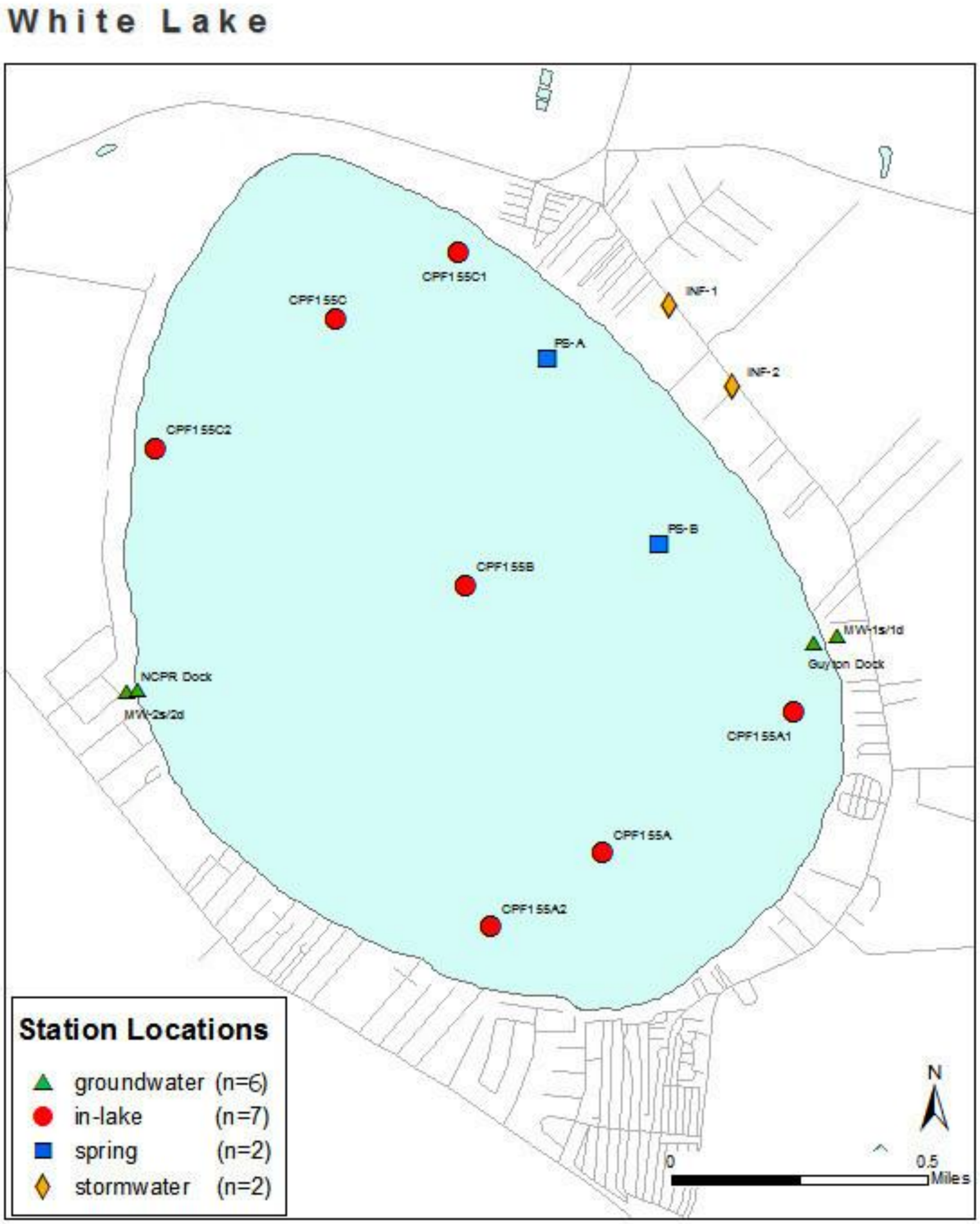


Figure 1. Sampling sites at White Lake, Bladen County

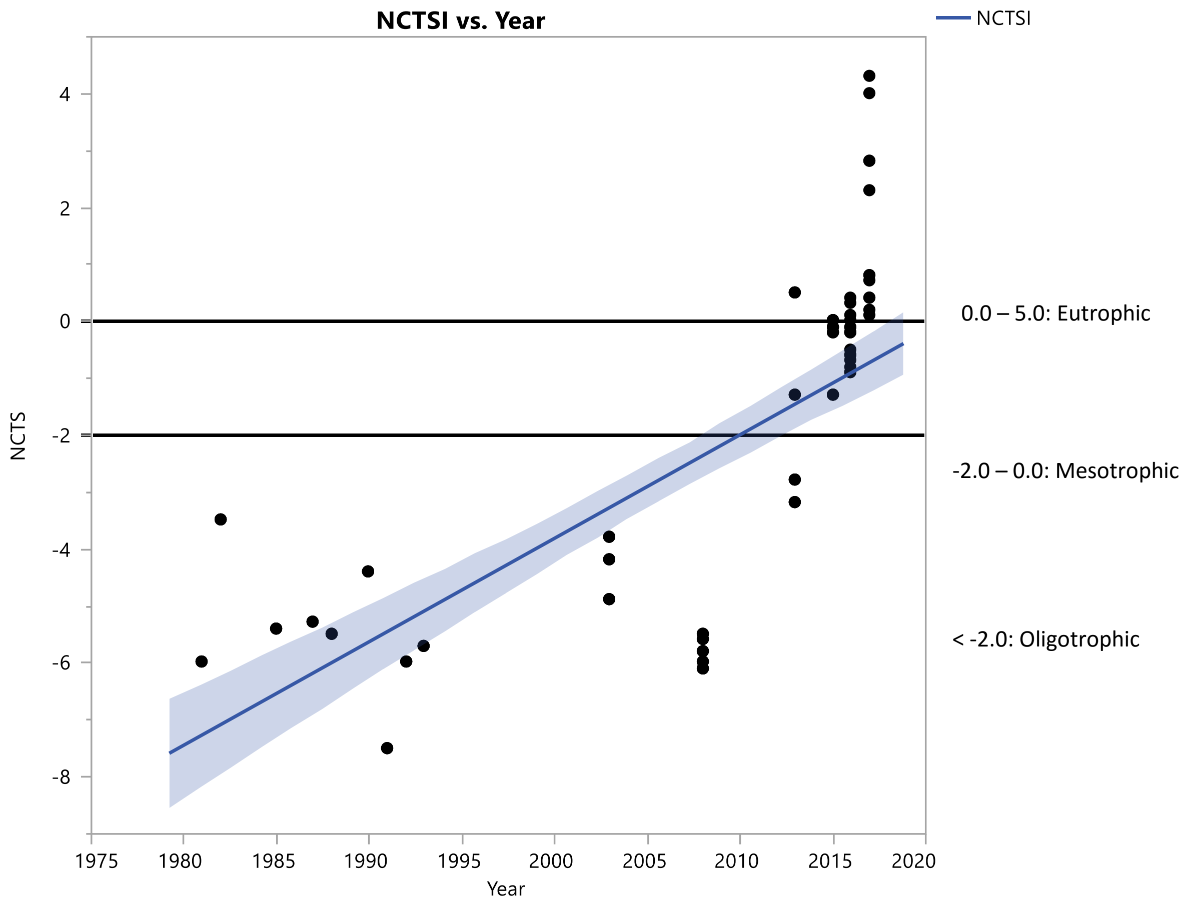
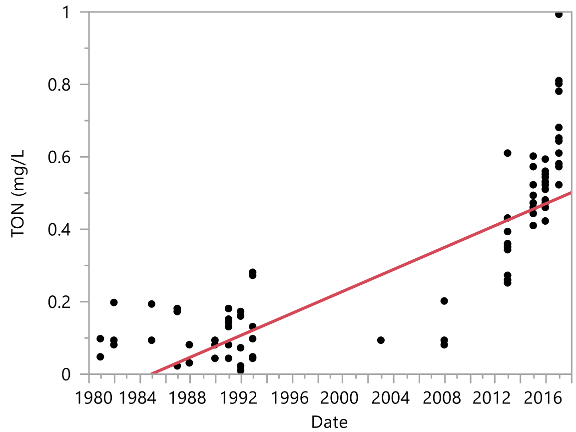
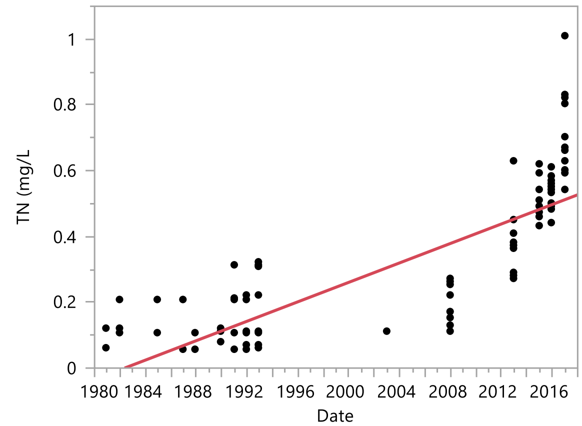


Figure 2. White Lake NCTSI from 1981 to 2017 by monthly site visits and associated regression trend line

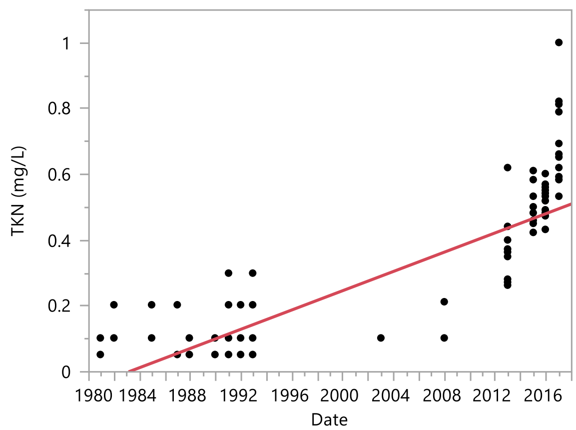
Figure 3. Nutrient values collected from the photic zone and associated regression trend lines
(Data points represent individual site visits.)



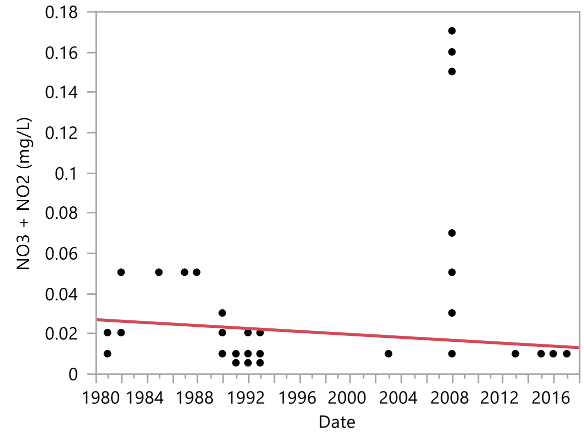
3A. Total Organic Nitrogen: p< .0001, α = 0.05, R^2= 0.568



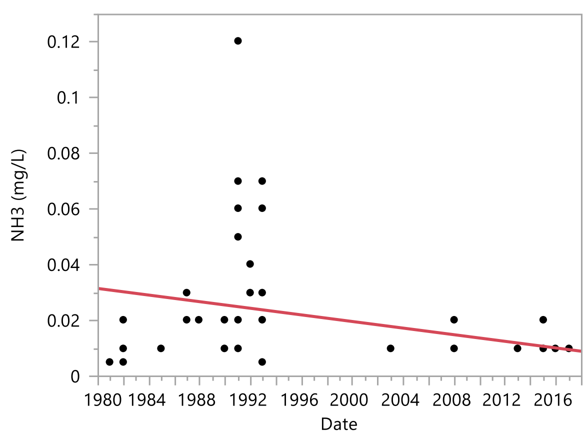
3B. Total Nitrogen: p< .0001, α = 0.05, R^2= 0.571



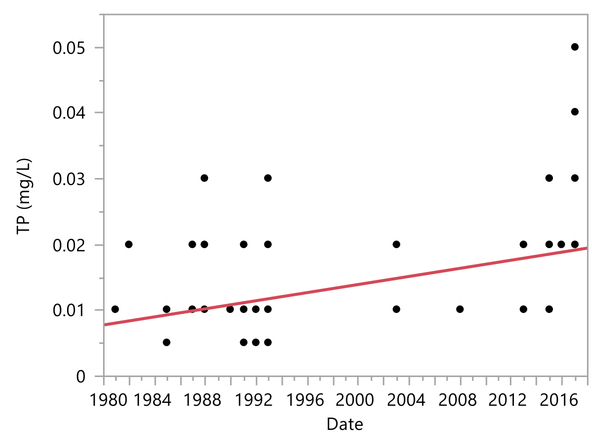
3C. Total Kjeldahl Nitrogen: p< .0001, α = 0.05, R^2= 0.547



3D. Nitrate + Nitrite: p= .057, α = 0.05, R^2= 0.029

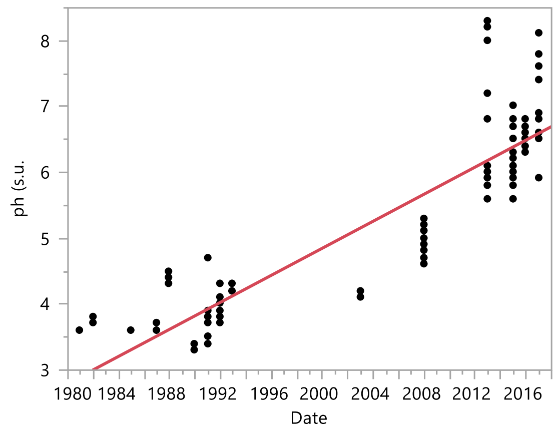


3E. Ammonia: p< .0001, α = 0.05, R^2= 0.184

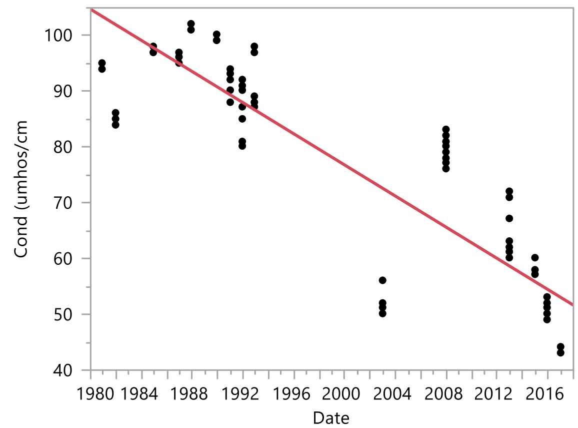


3F. Total Phosphorus: p< .0001, α = 0.05, R^2= 0.201

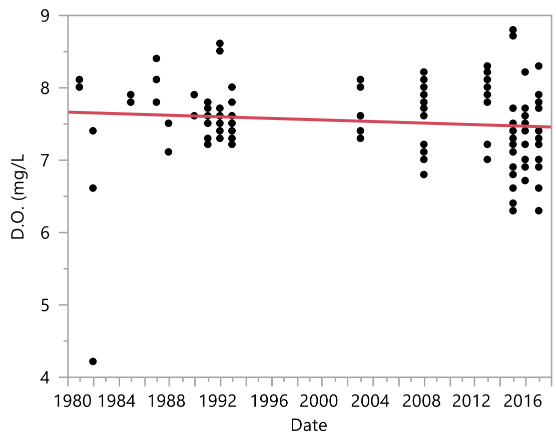
Figure 4. Physical water quality values collected from the surface and associated regression trend lines. Data points represent individual site visits.



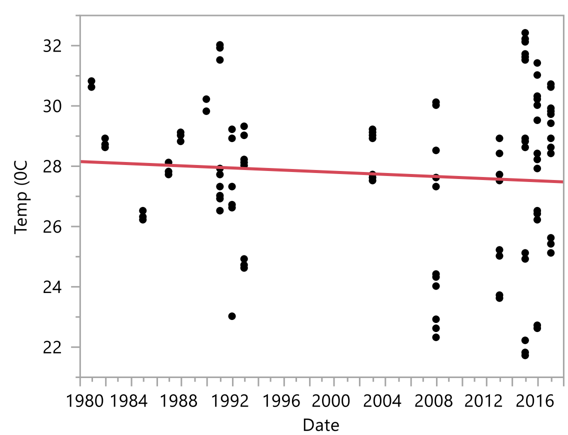
4A. pH: $p < .0001$, $\alpha = 0.05$, $R^2 = 0.779$



4B. Conductivity: $p < .0001$, $\alpha = 0.05$, $R^2 = 0.761$

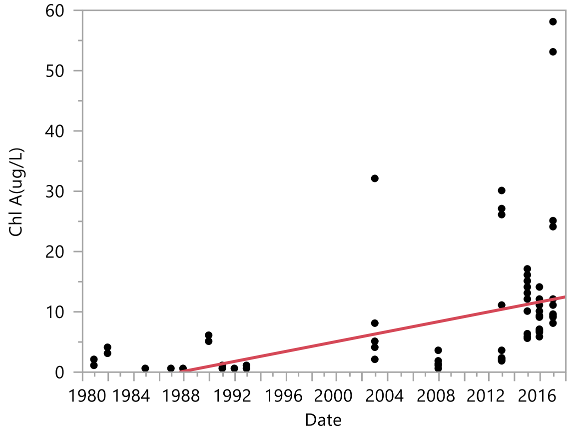


4C. Dissolved Oxygen: $p = 0.209$, $\alpha = 0.05$, $R^2 = 0.013$

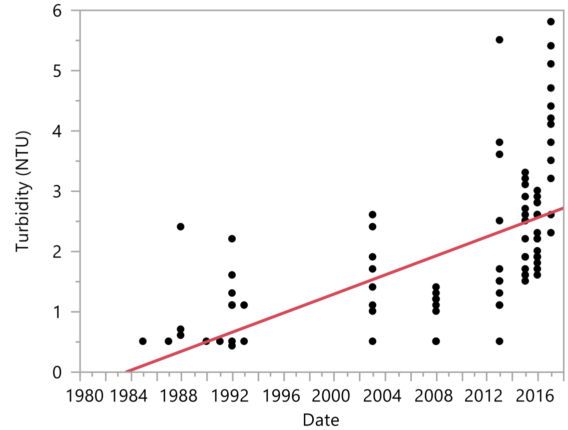


4D. Temperature: $p = 0.368$, $\alpha = 0.05$, $R^2 = 0.006$

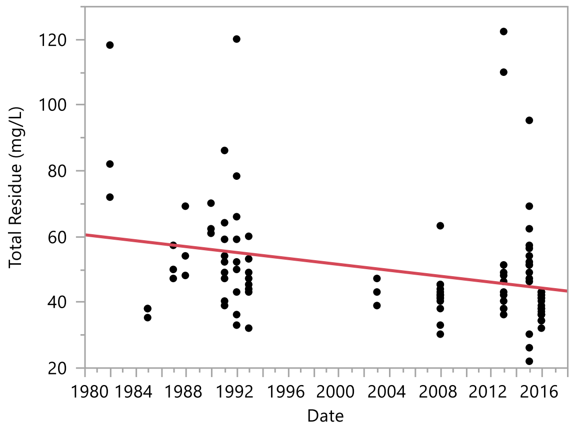
Figure 5. Clarity water quality values collected from the photic zone and associated regression trend lines. Data points represent individual site visits.



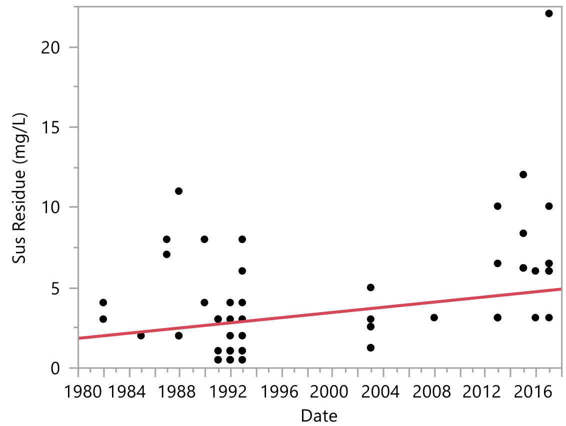
5A. Chlorophyll a: $p < .0001$, $\alpha = 0.05$, $R^2=0.278$



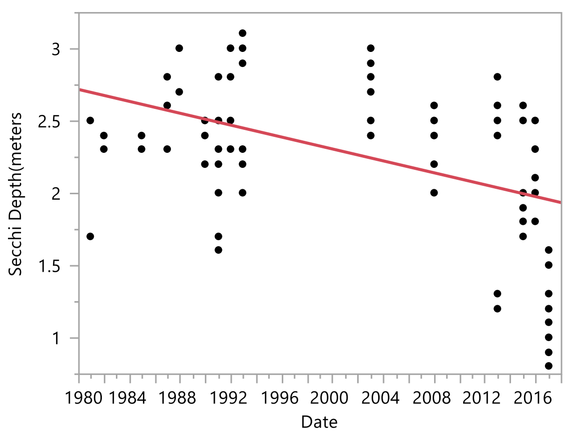
5B. Turbidity: $p < .0001$, $\alpha = 0.05$, $R^2= 0.463$



5C. Total Residue: $p= .003$, $\alpha = 0.05$, $R^2= 0.082$



5D. Suspended Residue: $p= .0004$, $\alpha = 0.05$, $R^2=0.103$



5E. Secchi Depth: $p < .0001$, $\alpha = 0.05$, $R^2= 0.214$

Appendix B

White Lake Algae Report

Phytoplankton Assemblages

in White Lake, Bladen County 2017

December 2017

Prepared by:

NORTH CAROLINA DEPARTMENT OF ENVIRONMENTAL QUALITY

Division of Water Resources

Water Sciences Section

Ecosystems Branch

Water Resources
ENVIRONMENTAL QUALITY

Suggested Citation:

North Carolina Division of Water Resources. 2017. Phytoplankton Assemblages in White Lake, Bladen County, 2017. November 2017.

Report prepared by:

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INTRODUCTION

The North Carolina Department of Environmental Quality (DEQ) Division of Water Resources (DWR) conducted sampling in White Lake as part of the 2013 Basinwide Assessment Monitoring Program. The results of this assessment indicated changes in the lake's chemistry, most notably pH, as well as changes in phytoplankton (free-floating algae) assemblages. As a follow up to the 2013 monitoring, DWR has conducted annual assessments of the chemical, physical, and biological conditions in White Lake beginning in 2015 and concluding with the current study in 2017. The aim of this study is to determine if ecological conditions have been impacted by the observed changes in lake chemistry.

METHODS

Study Area

Monthly monitoring was conducted at three historic Ambient Lake Monitoring Program sites from May to September 2017. Four additional sites were sampled during the June and August site visits in order to identify any alternate physical, chemical, and biological conditions near the shoreline (Figure 1).

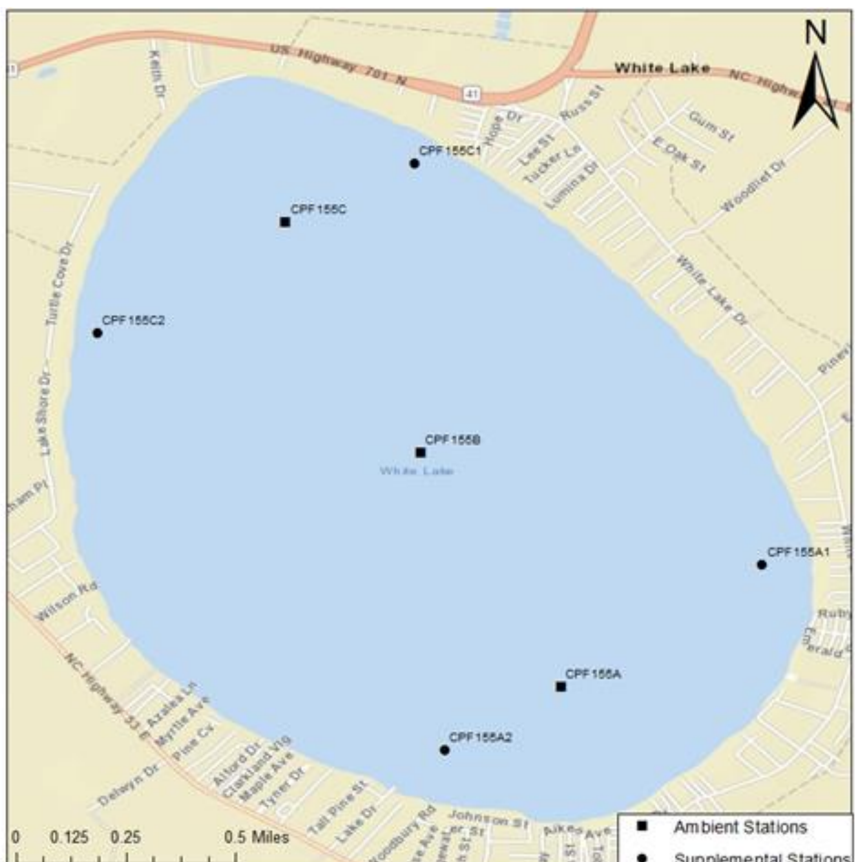


Figure 1. White Lake sampling locations

Sampling Protocols

Phytoplankton samples were collected from the photic zone from June to September concurrently with chemical and physical parameters following Intensive Survey Branch's Standard Operating Procedures (DENR 2013).

Algal Sample Enumeration

Phytoplankton samples were quantitatively evaluated by identifying the algae to the lowest taxonomic level achievable (i.e. genus or species) and counting individual cells and units according to standard operating procedures (NCDWR 2016).

Algal blooms were determined by measure of unit density and/or biovolume. Unit density is a quantitative measure of the number of filaments, colonies or single-celled taxa in a waterbody expressed as units/mL. Because cell size varies significantly between algal species, unit density alone can be misleading when attempting to quantify algal blooms. Biovolume, an estimate of the total volume occupied by the algal assemblage, is used to adjust for the variations in cell size. Analyzing both unit density and biovolume allows for a better understanding of the ecological impact of the phytoplankton assemblage. For the purposes of this report, a unit density ≥ 10,000 units/mL or a biovolume ≥ 5,000 mm^3/m^3 indicate algal bloom activity at the time of sampling.

RESULTS

Phytoplankton densities from June through September 2017 were generally high (>10,000 units/mL) for all sample locations. Monthly samples showed little variance between stations with the exception of August when algal densities at three stations (CPF155A1, CPF155A2 and CPF155C2) were approximately double all other sample locations. Algal densities tended to increase throughout the study period with a slight decrease during the month of July (Table 1, Figure 2). Biovolume showed greater variability between stations each month and did not directly reflect the trends in algal density. Biovolume was greatest during the month of August for all sites except CPF155B, which peaked in September (Table 2, Figure 3).

Phytoplankton community composition showed little variance between sites. During the months of June and July, the algal community was dominated by the green alga, *Gonatozygon brebissonii* (Figure 4). In August, the algal community transitioned to dominance by the bluegreen alga, *Planktolyngbya limnetica* (Figure 5). The decrease in total algal density in July corresponds with the shift in community dominance, indicating the simultaneous collapse of the *Gonatozygon* population and the magnification of the *Planktolyngbya* population (Figure 6).

Measurements of water clarity (secchi depth, chlorophyll-a, total suspended solids (TSS) and turbidity) are listed in Table 3. Secchi depth tended to decrease between the months of May to September, with a slight increase during the month of July. Chlorophyll-a increased throughout the study period, with a slight decrease in July. Trends in algal densities were directly reflected in chlorophyll-a values and indirectly related to secchi depth.

DISCUSSION

With the exception of 2013[1], phytoplankton densities have steadily increased over the last four years (Table 1). All samples collected in 2017 exceeded the algal bloom criteria for unit density, however, the biovolume criteria was only exceeded during the months of August and September. This discrepancy is due to the relatively small cell volume of the dominant algal species *Gonatozygon* and *Planktolyngbya*, causing bloom densities of these algae to have a relatively small impact on the overall algal biomass. Bloom conditions have been documented in White Lake in previous years, but these events typically dissipated before the next month's sampling.

Changes in algal community composition have also been observed over the past four years. In 2013, the algal community was consistently dominated by desmids (green algae), with other algal groups such as cryptophytes, chrysophytes, and diatoms increasing in abundance later in the growing season. These algal groups are characteristic of acidic, oligotrophic waters and considered beneficial to supporting a healthy aquatic environment. Bluegreen algae were not identified in White Lake until 2015. Since that time, the relative abundance of bluegreen algae has increased while the relative abundance of other algal groups such as chrysophytes, cryptomonads, and diatoms has decreased (Figure 7). During the 2017 sampling season, *Planktolyngbya* contributed as high as 90% of the unit density and 87% of the biovolume in White lake (Table 1 and 2). The lack of diversity in the algal assemblage is a potential stress on zooplankton and other aquatic animals, as bluegreen algae are not a desirable food source for planktivores. Bluegreen algae, especially in bloom densities can also be an indication of nutrient enrichment. Their continued dominance in White Lake may reflect a shift from an oligotrophic system to a more eutrophic environment.

Changes in algal community composition throughout the summer of 2017 may indicate the response of algal community structure to changes in aquatic chemistry. In June and July 2017, the algal community was dominated by the desmid, *Gonatozygon brebissonii*. Desmids are common in low pH environments, and have historically been the dominant group within White Lake. Beginning in July, the community began to shift to bluegreen dominance by *Planktolyngbya limnetica*. *Planktolyngbya* is able to tolerate a wide range of environmental conditions and is common in reservoirs throughout the state. *Planktolynbya* blooms remain suspended throughout the water column potentially causing water discoloration, but are not known to form surface scums or mats. Some bluegreen algae have the ability to produce toxins that present a potential health risk to humans and animals. Fortunately, *Planktolyngbya* is not known as a toxin producer.

[1] The elevated algal densities observed in 2013 resulted from the suspension of benthic, green algae into the water column during the months of June and July. (NCDEQ, 2016)

Table 1. Phytoplankton density and dominant taxa in White Lake (2013-2017)

Date	Station	Density (units/ml)	Dominant Group	Group % Dominance	Dominant	Taxa % Dominance
5/21/2013	CPF155A	1,500	Dinoflagellates/ Greens	54/43	Ankistrodesmus/ Peridinium	43/41
5/21/2013	CPF155B	2,400	Dinoflagellates/ Greens	48/39	Peridinium	48
5/21/2013	CPF155C	4,000	Dinoflagellates/ Greens	55/40	Peridinium/ Unidentified green	55/31
6/17/2013	CPF155A	8,600	Greens	98	Unidentified green	94
6/17/2013	CPF155B	8,100	Greens	98	Unidentified green	93
6/17/2013	CPF155C	14,200	Greens	97	Unidentified green	97
7/15/2013	CPF155A	120,300	Greens	100	Unidentified green	99
7/15/2013	CPF155B	126,500	Greens	99	Unidentified green	99
7/15/2013	CPF155C	96,800	Greens	100	Unidentified green	99
8/26/2013	CPF155A	100	Cryptomonads/ Greens	57/42	Komma	57
8/26/2013	CPF155B	60	Chrysophytes	75	Synura	75
8/26/2013	CPF155C	200	Greens	40	no dominant	N/A
9/23/2013	CPF155A	3,200	Greens	84	Ankistrodesmus	43
9/23/2013	CPF155B	2,500	Greens	81	Ankistrodesmus/ Staurastrum	36/33
9/23/2013	CPF155C	3,100	Greens	81	Ankistrodesmus	55
5/7/2015	CPF155A	2,800	Greens	66	Ankistrodesmus	54
5/7/2015	CPF155B	2,800	Greens	60	Ankistrodesmus	48

Date	Station	Density (units/ml)	Dominant Group	Group % Dominance	Dominant	Taxa % Dominance
5/7/2015	CPF155C	4,200	Greens	53	Ankistrodesmus	41
6/17/2015	CPF155A	7,800	Bluegreens	53	Planktolyngbya	50
6/17/2015	CPF155B	7,400	Greens	46	Planktolyngbya/ Staurastrum	31 & 30
6/17/2015	CPF155C	3,700	No dominant	N/A	Planktolyngbya	37
7/22/2015	CPF155A	2,600	Greens	78	Staurastrum	37
7/22/2015	CPF155B	1,800	Greens	88	Staurastrum	34
7/22/2015	CPF155C	2,700	Greens	95	Staurastrum	35
8/20/2015	CPF155A	18,300	Bluegreens	81	Planktolyngbya	81
8/20/2015	CPF155B	15,800	Bluegreens	75	Planktolyngbya	75
8/20/2015	CPF155C	12,600	Bluegreens	76	Planktolyngbya	70
9/23/2015	CPF155A	5,200	Bluegreens	48	Planktolyngbya	48
9/23/2015	CPF155B	5,600	Bluegreens	52	Planktolyngbya	52
9/23/2015	CPF155C	6,000	Bluegreens	45	Planktolyngbya	45
5/19/2016	CPF155A	3200	Greens	71	Ankistrodesmus	37
5/19/2016	CPF155B	2100	Greens	85	Selenastrum	68
5/19/2016	CPF155C	2200	Greens	81	Selenastrum	65
6/23/2016	CPF155A	39700	Bluegreens	97	Planktolyngbya	97
6/23/2016	CPF155B	29600	Bluegreens	89	Planktolyngbya	89
6/23/2016	CPF155C	34800	Bluegreens	95	Planktolyngbya	95
7/16/2016	CPF155A	55500	Bluegreens	97	Planktolyngbya	96
7/16/2016	CPF155B	47800	Bluegreens	96	Planktolyngbya	96
7/16/2016	CPF155C	33000	Bluegreens	93	Planktolyngbya	93
8/23/2016	CPF155A	6000	Bluegreens	62	Planktolyngbya	62
8/23/2016	CPF155B	5000	Bluegreens	67	Planktolyngbya	67
8/23/2016	CPF155C	8000	Bluegreens	53	Planktolyngbya	53
9/28/2016	CPF155A	8800	Bluegreens	71	Planktolyngbya	71

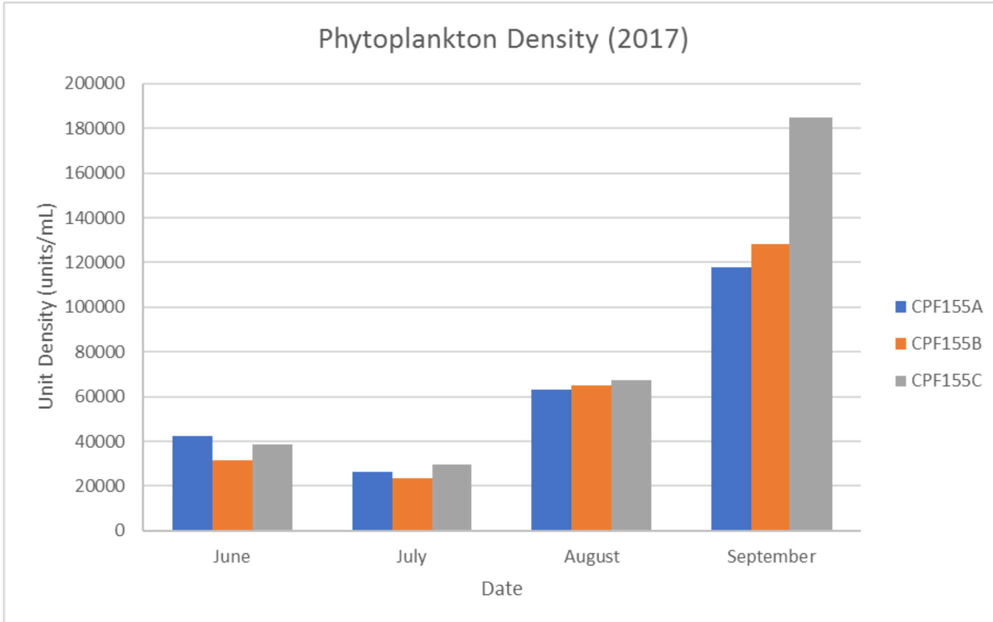
Date	Station	Density (units/ml)	Dominant Group	Group % Dominance	Dominant	Taxa % Dominance
9/28/2016	CPF155B	9800	Bluegreens	62	Planktolyngbya	61
9/28/2016	CPF155C	8000	Bluegreens	56	Planktolyngbya	56
6/29/2017	CPF155A	42400	Greens	63	Gonatozygon	49
6/29/2017	CPF155A1	33200	Greens	65	Gonatozygon	50
6/29/2017	CPF155A2	40500	Greens	66	Gonatozygon	56
6/29/2017	CPF155B	31500	Greens	64	Gonatozygon	53
6/29/2017	CPF155C	38600	Greens	71	Gonatozygon	60
6/29/2017	CPF155C1	40300	Greens	67	Gonatozygon	55
6/29/2017	CPF155C2	47600	Greens	60	Gonatozygon	50
7/20/2017	CPF155A	26200	Greens	63	Gonatozygon	50
7/20/2017	CPF155B	23500	Greens	61	Gonatozygon	47
7/20/2017	CPF155C	29400	Greens/Bluegreens	42/57	Planktolyngbya	49
8/24/2017	CPF155A	63200	Bluegreens	84	Planktolyngbya	78
8/24/2017	CPF155A1	100800	Bluegreens	76	Planktolyngbya	66
8/24/2017	CPF155A2	130200	Bluegreens	86	Planktolyngbya	76
8/24/2017	CPF155B	64800	Bluegreens	77	Planktolyngbya	68
8/24/2017	CPF155C	67300	Bluegreens	81	Planktolyngbya	68
8/24/2017	CPF155C1	67900	Bluegreens	76	Planktolyngbya	70
8/24/2017	CPF155C2	117700	Bluegreens	76	Planktolyngbya	62
9/26/2017	CPF155A	117700	Bluegreens	88	Planktolyngbya	86
9/26/2017	CPF155B	128400	Bluegreens	94	Planktolyngbya	90
9/26/2017	CPF155C	184100	Bluegreens	91	Planktolyngbya	89

Table 2. Phytoplankton biovolume and dominant taxa in White Lake (2013-2017)

Date	Station	Biovolume (mm^3/m^3)	Dominant Group	Group % Dominance	Dominant Taxa	Taxa % Dominance
5/21/2013	CPF155A	2900	Dinoflagellates	99	Peridinium	96
5/21/2013	CPF155B	5500	Dinoflagellates	94	Peridinium	94
5/21/2013	CPF155C	10400	Dinoflagellates	96	Peridinium	96
6/17/2013	CPF155A	2100	Greens	100	Unidentified green	99
6/17/2013	CPF155B	2100	Greens	92	Unidentified green	91
6/17/2013	CPF155C	3800	Greens	94	Unidentified green	92
7/15/2013	CPF155A	29800	Greens	100	Unidentified green	100
7/15/2013	CPF155B	31400	Greens	100	Unidentified green	100
7/15/2013	CPF155C	24000	Greens	100	Unidentified green	100
8/26/2013	CPF155A	30	Greens	81	Oocystis/Closteriopsis	43/38
8/26/2013	CPF155B	20	Chrysophytes	99	Synura	99
8/26/2013	CPF155C	20	Chrysophytes	57	Synura	57
9/23/2013	CPF155A	300	Greens	64	Dictyosphaerium	34
9/23/2013	CPF155B	200	Greens	72	No dominant	n/a
9/23/2013	CPF155C	200	Greens	65	Oocystis	30
5/7/2015	CPF155A	1400	Dinoflagellates	24	Peridinium	84
5/7/2015	CPF155B	2600	Dinoflagellates	95	Peridinium	95
5/7/2015	CPF155C	3000	Dinoflagellates	90	Peridinium	90
6/17/2015	CPF155A	600	No dominant	N/A	No dominant	N/A
6/17/2015	CPF155B	400	Greens	68	Oocystis	38
6/17/2015	CPF155C	400	No dominant	N/A	No dominant	N/A
7/22/2015	CPF155A	300	Greens	67	Oocystis	30
7/22/2015	CPF155B	200	Greens	64	Oocystis/Peridinium	50 & 31

Date	Station	Biovolume (mm^3/m^3)	Dominant Group	Group % Dominance	Dominant Taxa	Taxa % Dominance
7/22/2015	CPF155C	300	Greens	61	Oocystis	41
8/20/2015	CPF155A	400	Greens	78	Scenedesmus	51
8/20/2015	CPF155B	800	No dominant	N/A	No dominant	N/A
8/20/2015	CPF155C	600	Cryptomonads	44	Cryptomonas	37
9/23/2015	CPF155A	1100	Dinoflagellates	66	Peridinium	66
9/23/2015	CPF155B	1100	Dinoflagellates	77	Peridinium	77
9/23/2015	CPF155C	600	No dominant	N/A	Peridinium	38
5/19/2016	CPF155A	100	Greens	65	Ankistrodesmus	50
5/19/2016	CPF155B	100	Pyrrhophyta	48	Peridinium	48
5/19/2016	CPF155C	200	Pyrrhophyta	42	Peridinium	42
6/23/2016	CPF155A	1000	Bluegreens	58	Planktolyngbya	58
6/23/2016	CPF155B	2900	Pyrrhophyta	78	Peridinium	78
6/23/2016	CPF155C	1200	Bluegreens/Euglena	42/40	Planktolyngbya	42
7/16/2016	CPF155A	1100	Bluegreens	75	Planktolyngbya	75
7/16/2016	CPF155B	1300	Bluegreens	70	Planktolyngbya	70
7/16/2016	CPF155C	1800	No dominant	N/A	Peridinium	40
8/23/2016	CPF155A	500	Greens	46	Peridinium	31
8/23/2016	CPF155B	400	Greens	54	Oocystis	32
8/23/2016	CPF155C	800	Greens	49	No dominant	N/A
9/28/2016	CPF155A	400	Greens	43	Dictosphaerium	36
9/28/2016	CPF155B	700	No dominant	N/A	No dominant	N/A
9/28/2016	CPF155C	500	No dominant	N/A	Cryptomonas	32
6/29/2017	CPF155A	4800	Greens	55	Gonatozygon	39
6/29/2017	CPF155A1	2400	Greens	83	Gonatozygon	67
6/29/2017	CPF155A2	3300	Greens	77	Gonatozygon	66
6/29/2017	CPF155B	3100	Greens	64	Gonatozygon	51
6/29/2017	CPF155C	4700	Greens	56	Gonatozygon	45

Date	Station	Biovolume (mm^3/m^3)	Dominant Group	Group % Dominance	Dominant Taxa	Taxa % Dominance
6/29/2017	CPF155C1	3200	Greens	80	Gonatozygon	68
6/29/2017	CPF155C2	4400	Greens	61	Gonatozygon	50
7/20/2017	CPF155A	2100	Greens	72	Gonatozygon	58
7/20/2017	CPF155B	1600	Greens	81	Gonatozygon	68
7/20/2017	CPF155C	2200	Greens	54	Gonatozygon	34
8/24/2017	CPF155A	4800	Greens/Bluegreens	43/44	Gonatozygon	35
8/24/2017	CPF155A1	4400	Bluegreens	73	Gonatozygon	45
8/24/2017	CPF155A2	11700	Bluegreens	56	No dominant	N/A
8/24/2017	CPF155B	4300	Greens/Bluegreens	55/41	Actinastrum	45
8/24/2017	CPF155C	5600	No dominant	47	Actinastrum	31
8/24/2017	CPF155C1	6400	Greens	50	Actinastrum	41
8/24/2017	CPF155C2	10300	Greens	64	Actinastrum	41
9/26/2017	CPF155A	3600	Bluegreens	47	Planktolyngbya	63
9/26/2017	CPF155B	5500	Bluegreens	94	Planktolyngbya	41
9/26/2017	CPF155C	4200	Bluegreens	66	Planktolyngbya	87



Lake

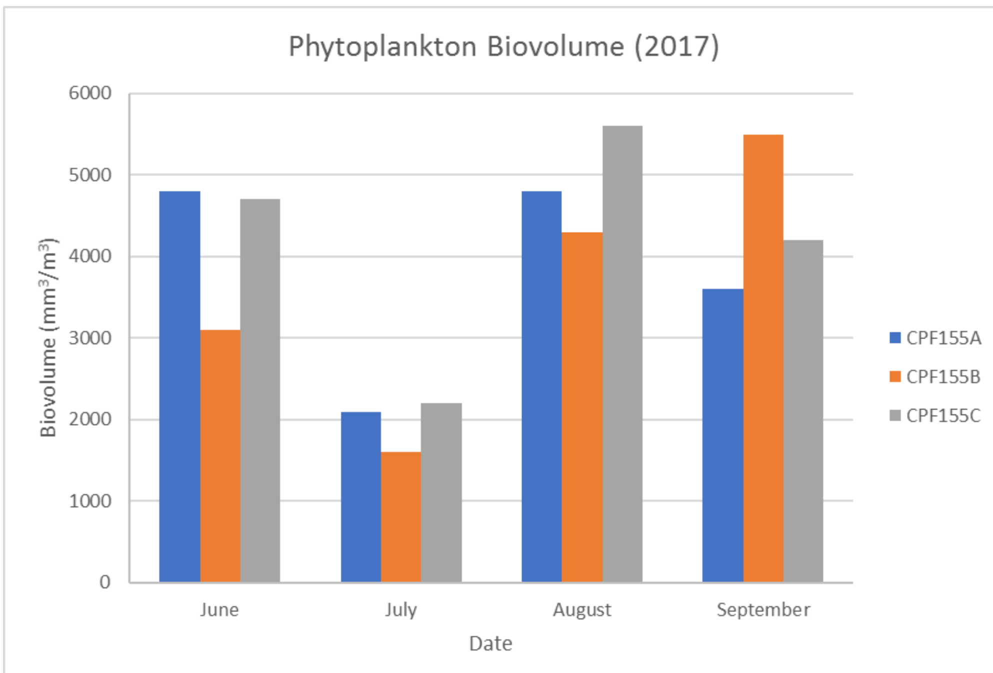


Figure 3. Phytoplankton biovolumes observed at ambient monitoring stations in White Lake from June to September 2017

Figure 4. *Gonatozygon brebissonii* (magnified 200x)

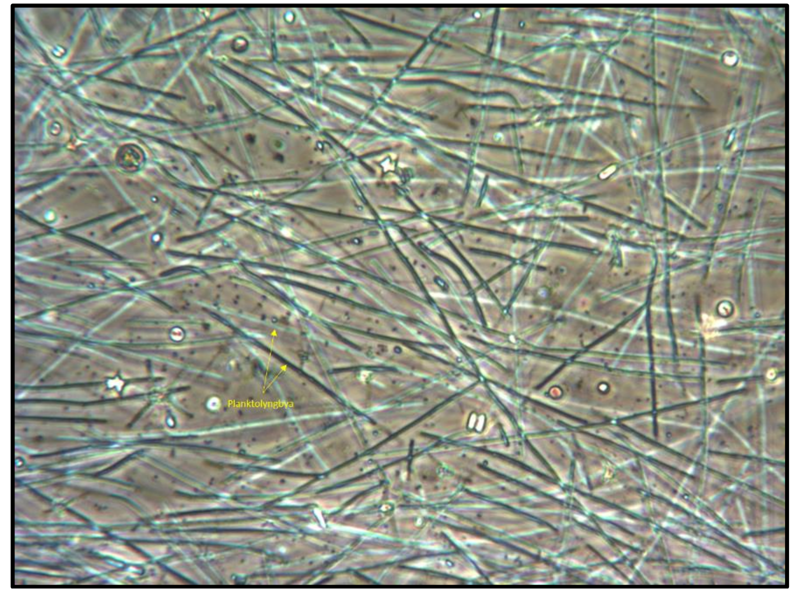


Figure 5. *Planktolyngbya limnetica* (magnified 200x)

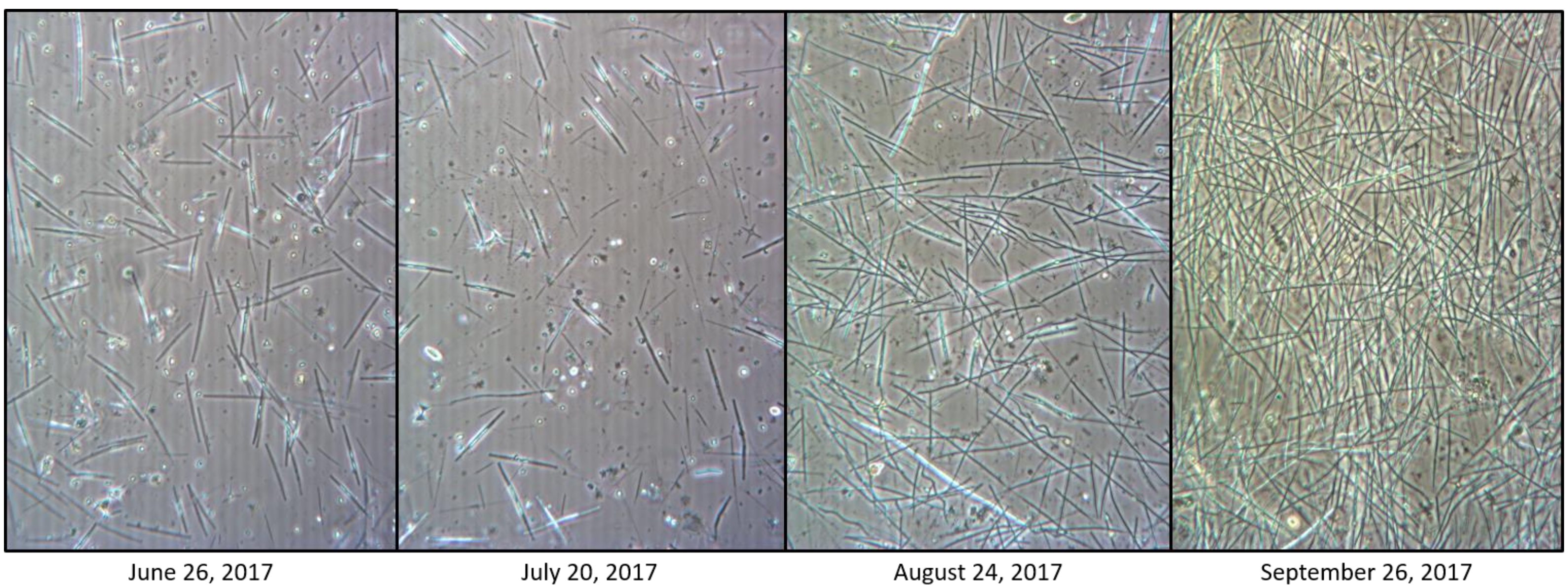


Figure 6. Algal assemblages in White Lake at CPF155C from June to July 2017 (magnified 100x)

Table 3. Measurements of water clarity in White Lake 2017.

Date	Station	Secchi Depth (m)	Chlorophyll-a (µg/L)	Total Suspended Solids (mg/L)	Turbidity(NTU)
5/17/17	CPF155A	1.5	9.2	6.5	2.3
5/17/17	CPF155B	1.5	10.0	<6.2	2.2
5/17/17	CPF155C	1.5	9.2	7.8	2.3
6/29/17	CPF155A	1.2	9.5	<12.0	4.2
6/29/17	CPF155A1	1.2	10.0	<6.2	4.0
6/29/17	CPF155A2	1.2	9.4	<6.2	3.6
6/29/17	CPF155B	1.2	12.0	6.5	5.8
6/29/17	CPF155C	1.1	11.0	10.0	4.7
6/29/17	CPF155C1	1.2	12.0	<6.2	4.2
6/29/17	CPF155C2	1.1	11.0	<6.2	3.7
7/20/17	CPF155A	1.3	8.9	<12.0	3.2
7/20/17	CPF155B	1.6	12.0	<6.2	3.2
7/20/17	CPF155C	1.5	7.9	<6.2	2.6
8/25/17	CPF155A	1.0	25.0	-------	5.4
8/25/17	CPF155A1	1.0	21.0	-------	4.8
8/25/17	CPF155A2	1.0	25.0	-------	4.8
8/25/17	CPF155B	1.0	25.0	-------	3.5
8/25/17	CPF155C	1.0	24.0	-------	3.8
8/25/17	CPF155C1	1.0	25.0	-------	4.1
8/25/17	CPF155C2	1.0	21.0	-------	4.0
9/26/17	CPF155A	0.8	58.0	22.0	5.1
9/26/17	CPF155B	0.8	53.0	-------	4.1
9/26/17	CPF155C	0.9	--------	-------	4.4

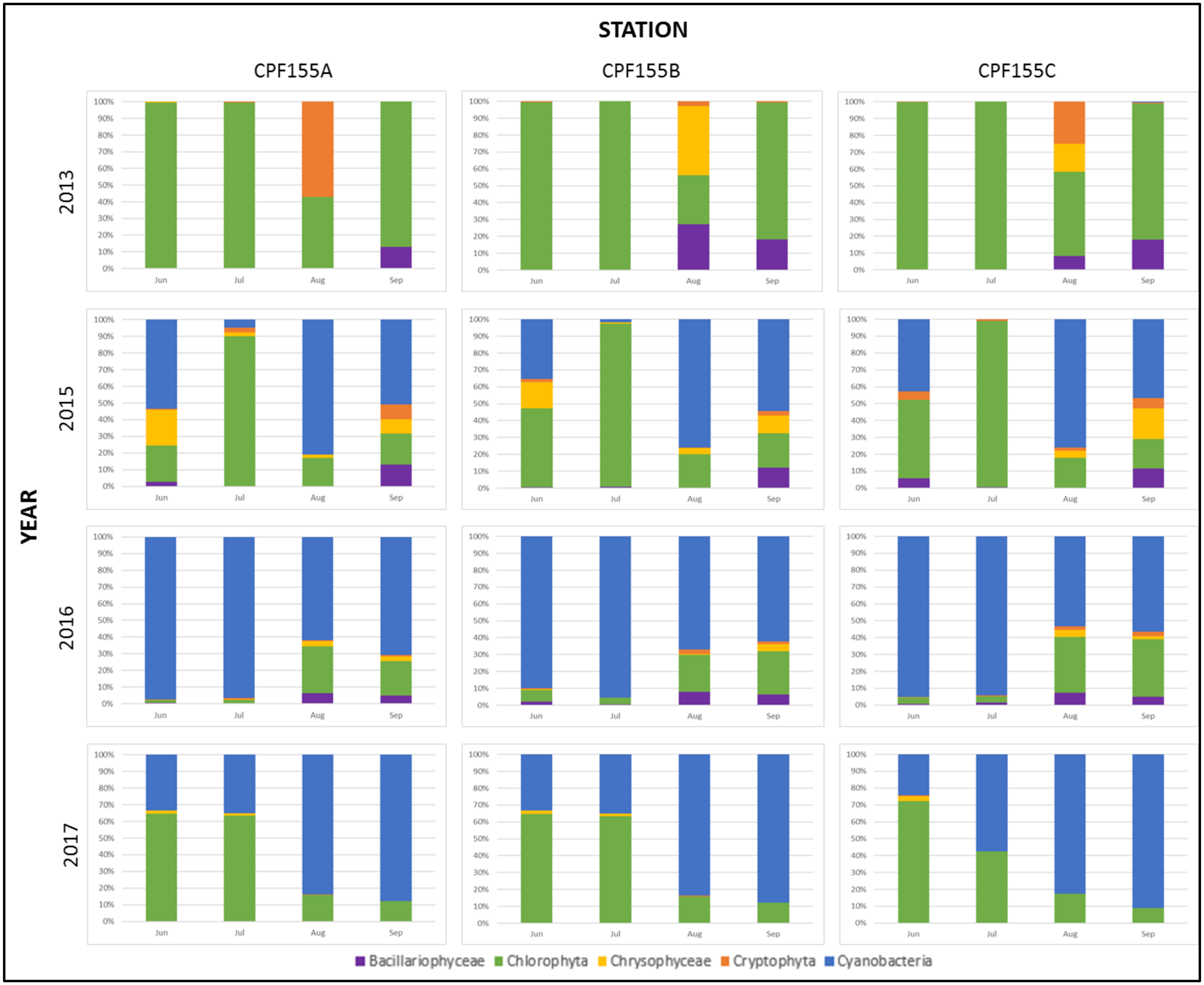


Figure 7. Algal community composition at ambient stations in White Lake from 2013 to 2017.

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in White Lake, Bladen County, 2015. February 2016.

Appendix C

White Lake Study Data

White Lake 2017 Physical and Chemical Data

	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

White Lake Spring Water Data

Location	Date	Water Temperature °C	Dissolved Oxygen mg/L	Conductivity µmhos/cm	pH s.u.	Total Phosphorus mg/L	Total Kjeldahl N mg/L	Ammonia NH_3 mg/L	Nitrite + Nitrate mg/L	Total N mg/L	Total Organic N mg/L	Total Inorganic N mg/L
PS-A	July 1, 2017	27.9	5.4	42	6.0	<0.02	0.42	<0.02	<0.02	0.43	0.41	0.02
PS-B	July 1, 2017	27.2	2.0	42	5.8	0.03	0.51	0.22	<0.02	0.52	0.29	0.23

White Lake Near-shore Groundwater Well Data

Date m/d/yr	Sampling Station	Water Temperature °C	Dissolved Oxygen mg/L	pH s.u.	Conductivity umhos/cm	Total Phosphorus mg/L	Total Kjeldahl N mg/L	Ammonia NH3 mg/L	Nitrite + Nitrate mg/L	Total N mg/L	Total Organic N mg/L	Total Inorganic N mg/L
June 30, 2017	MW-1S	27.0	3.0	4.8	242	0.30	4.90	2.90	<0.02	4.91	2.00	2.91
June 30, 2017	MW-1D	19.6	0.8	4.4	56	0.17	1.00	0.30	<0.02	1.01	0.70	0.31
June 30, 2017	Guyton Dock *	31.5	7.4	7.3	44	0.02	0.75	<0.02	<0.02	0.76	0.74	0.02
June 30, 2017	MW-2S	25.9	0.8	5.6	129	0.50	3.40	2.60	<0.02	3.41	0.80	2.61
June 30, 2017	MW-2D	20.9	0.7	5.9	102	0.09	0.59	0.41	<0.02	0.60	0.18	0.42
July 20, 2017	MW-1S					0.61	5.30	3.00	<0.02	5.31	2.30	3.01
July 20, 2017	MW-1D					0.13	0.88	0.35	<0.02	0.89	0.53	0.36
July 20, 2017	Guyton Dock *					<0.02	0.52	<0.02	<0.02	0.53	0.51	0.02
July 20, 2017	MW-2S					0.59	2.60	1.20	0.10	2.70	1.40	1.30
July 20, 2017	MW-2D					0.09	0.58	0.40	<0.02	0.59	0.18	0.41
July 20, 2017	NCPR Dock *					<0.02	0.56	<0.02	<0.02	0.57	0.55	0.02
August 28, 2017	MW-1S					0.52	5.50	3.10	<0.02	5.51	2.40	3.11
August 28, 2017	MW-1D					0.16	0.86	0.33	<0.02	0.87	0.53	0.34
August 28, 2017	Guyton Dock *					<0.02	0.46	<0.02	<0.02	0.47	0.45	0.02
August 28, 2017	MW-2S					0.53	2.80	1.50	<0.02	2.81	1.30	1.51
August 28, 2017	MW-2D					0.10	0.58	0.39			0.19	
August 28, 2017	NCPR Dock *					0.03	0.75	<0.02	<0.02	0.76	0.74	0.02

* In-lake comparison data

Stormwater Drainage Ditch Nutrient Data

Date m/d/yr	Sampling Station	Total Phosphorus mg/L	Total Kjeldahl N mg/L	Ammonia NH3 mg/L	Nitrite + Nitrate mg/L	Total N mg/L	Total Organic N mg/L	Total Inorganic N mg/L
4/3/2017	INF-1	0.12	1.2	0.03	0.07	1.27	1.17	0.10
4/6/2017		0.04	1.3	0.02	<0.02	1.31	1.28	0.03
4/6/2017	INF-2	0.04	3.4	0.03	0.02	3.42	3.37	0.05

INF-1 Located at 408 White Lake Dr.

INF-2 Located at 580 White Lake Dr.

Inputs only flowed when rain events exceeded 1.25 inches of rain.