White Lake,
Bladen County, NC

Lake Monitoring Results 2021

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LIMNOSCIENCES

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Introduction

White Lake is a relatively small (1,067-acre), shallow, Carolina Bay Lake located in the Coastal Plain of North Carolina. It has long been a tourist icon due to the clarity of its water and its five-mile shoreline is almost completely developed, with both residential and commercial areas. A search of digital records indicates long-standing concerns about boating activity stirring up algae and vegetation associated with the lake bottom; as this material washes ashore and decomposes it becomes unsightly and smelly. An additional, and related concern has been low lake levels, particularly during drought periods. The mean depth of the lake as determined by Frey (1949) is 1.9 meters (6.2 feet), so low lake levels can result in noticeably lower water depths.

Since the summer of 2013 there have been concerns about the green appearance of the water, and in 2017 a filamentous cyanobacterial bloom developed and persisted over the winter into the spring of 2018, with high levels of both nitrogen and phosphorus, and a substantial increase in pH. The Town of White Lake received permission to apply a low-dose alum treatment to strip phosphorus and algae from the water column in early May 2018. While the treatment reduced phosphorus and eliminated the filamentous cyanobacteria, those benefits were overshadowed by a fish kill associated with the period in which the pH levels were above 9.

Groundwater studies in 2018-2019 found no evidence of deep aquifer contributions to White Lake, and no evidence that nearby blueberry farms are affecting groundwater flows to the lake. Groundwater contributions to the lake vary with water table levels but are low (ranging from near zero to 6% of lake volume; Shank and Zamora 2019), particularly by comparison with the volume of water contributed by rainfall (for example, a one-inch rainfall on the 1,067-acre lake surface contributes roughly 29 million gallons of water to the lake).

An assessment of nutrient sources conducted in 2019-2020 indicated that rainfall on the lake surface is the largest external source of nitrogen to White Lake, while stormwater runoff from impervious surfaces and yards, and nutrient-enriched groundwater seepage into the lake occur at the same times as large rainfall events. Large flocks of roosting seagulls (5,000-7,000 birds) are found at the lake during winter months, but their contributions to the nutrient pool are likely minor. Assessment of sediment phosphorus levels from core samples taken in muddy areas found the highest concentrations in the first few centimeters of sediment; internal loading of phosphorus can occur when these sediments are resuspended due to wind and wave action and boating activity, and during algae blooms, when pH levels are high.

This report summarizes 2021 monitoring data for water quality (including nutrients), algae, aquatic vegetation, lake levels, and rainfall. Also included is monitoring data from 2017 (NC DEQ), and 2018-2020 (LIMNOSCIENCES) for comparison, and a discussion and synthesis of important trends gleaned from monitoring studies in recent years.

Sampling Schedules

Monthly sampling was conducted from January-December at three established monitoring stations (Fig. 1), except for November, when field measurements only were collected at three nearshore locations due to windy conditions. Grab samples for nutrients and chlorophyll a generally 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).

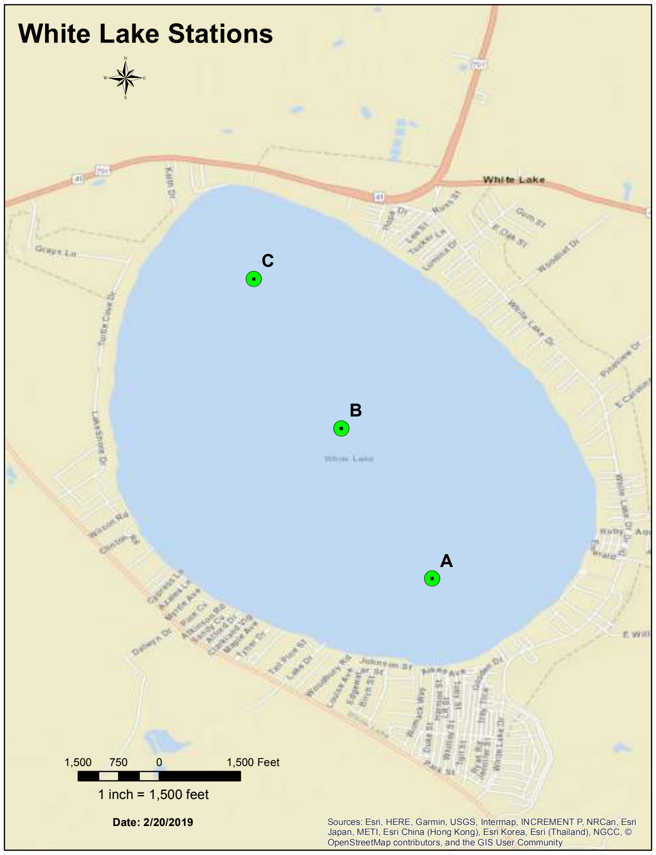


Figure 1. Monitoring stations for White Lake, which correspond to NC DEQ stations (CPF155C, CPF155B, and CPF155A).

A whole-lake aquatic vegetation survey was conducted on October 25, 2021, utilizing a protocol developed by North Carolina State University. At each sample point (Fig. 2) a 2-sided rake was thrown twice, and vegetation presence and abundance were recorded. Species abundance was ranked on a scale of 1–4 (1=trace, 2=sparse, 3=moderate, 4=dense). In addition to the point-intercept rake samples, each of the two survey boats were equipped with a high-definition sonar unit that can record plant percent biovolume (plant height) in the water column as well as overall water depth along the surveyed track.

Figure 2. Pre-determined sample points (a total of 202) for aquatic vegetation annual survey in October.

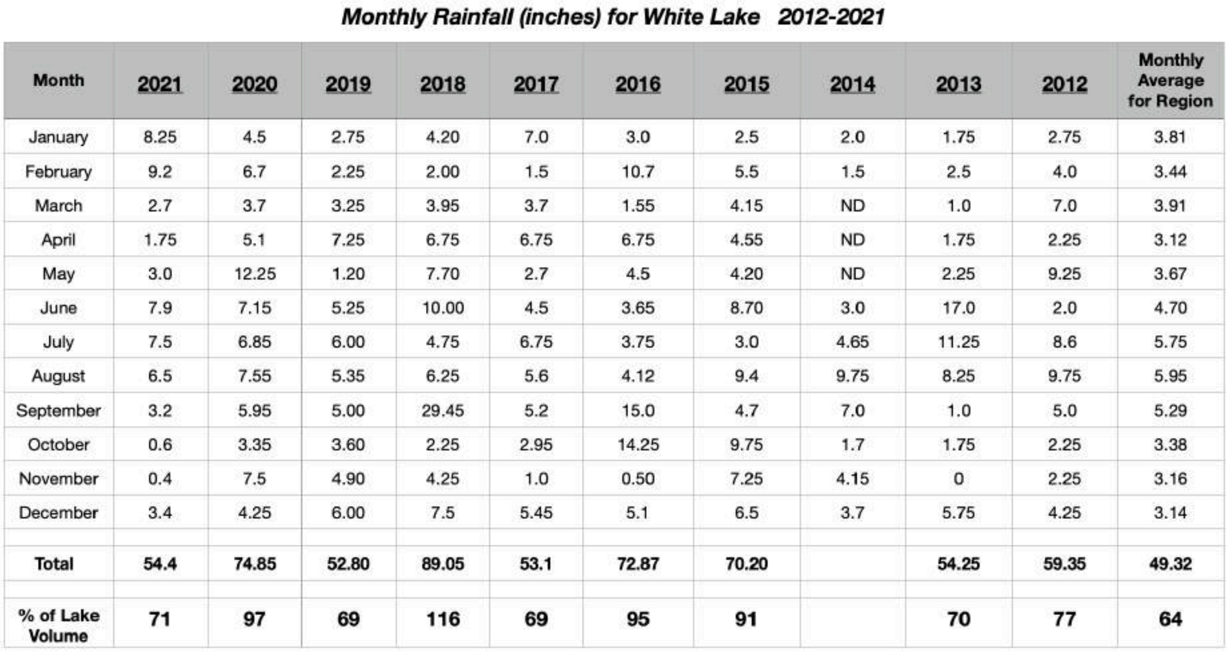
Results

Rainfall in 2021 totaled 54.4 inches, with the highest monthly amount (9.2 inches) measured in February, with two rain events that month exceeding three inches; the highest lake levels were observed in February. Rainfall in October and November was very low (a total of one inch for the two months) and the lowest lake levels were found in November. The lake level at the end of 2021 was nine inches lower than at the start of the year, and 16.8 inches below the highest level for the year (Table 1).

Rainfall nutrient sampling was done a single time in 2021 (and six times in 2020), during a 0.75-inch rainfall event; total phosphorus was below detection level, and total nitrogen was equal to the lowest value found in 2020 sampling. Both phosphorus and nitrogen varied considerably among sampling dates in 2020, with the highest values for both nutrients found in a 3.3-inch rainfall event in late May (Table 2).

Rainfall nitrogen (wet deposition of both nitrate and ammonium) is monitored at a nearby National Atmospheric Deposition Program station (NTN NC 35, at Clinton, NC). Mean annual ammonium deposition levels for all the program stations are mapped by the U.S. EPA Clean Air Status and Trends Network; for 2020, the Clinton, NC, monitoring station (7.5 kg/ha) had the highest value among the national locations, while the mean at Raleigh, at 5.1 kg/ha, was also high. (Fig. 3). Long-term monitoring at the Clinton station has shown a strong increase in ammonium deposition in recent years, indicating that ammonia emissions have increased. The reaction between ammonia (a strong base) and water in the atmosphere forms ammonium, which reduces hydrogen ion concentrations (and increases pH).

Table 1. Monthly rainfall at White Lake over the period 2012-2021, the long-term monthly average rainfall at Elizabethtown, and lake level elevation (NAVD 88 datum) ranges for 2019-2021.



Monthly Rainfall (inches) for White Lake 2012-2021

Month	2021	2020	2019	2018	2017	2016	2015	2014	2013	2012	Monthly Average for Region
January	8.25	4.5	2.75	4.20	7.0	3.0	2.5	2.0	1.75	2.75	3.81
February	9.2	6.7	2.25	2.00	1.5	10.7	5.5	1.5	2.5	4.0	3.44
March	2.7	3.7	3.25	3.95	3.7	1.55	4.15	ND	1.0	7.0	3.91
April	1.75	5.1	7.25	6.75	6.75	6.75	4.55	ND	1.75	2.25	3.12
May	3.0	12.25	1.20	7.70	2.7	4.5	4.20	ND	2.25	9.25	3.67
June	7.9	7.15	5.25	10.00	4.5	3.65	8.70	3.0	17.0	2.0	4.70
July	7.5	6.85	6.00	4.75	6.75	3.75	3.0	4.65	11.25	8.6	5.75
August	6.5	7.55	5.35	6.25	5.6	4.12	9.4	9.75	8.25	9.75	5.95
September	3.2	5.95	5.00	29.45	5.2	15.0	4.7	7.0	1.0	5.0	5.29
October	0.6	3.35	3.60	2.25	2.95	14.25	9.75	1.7	1.75	2.25	3.38
November	0.4	7.5	4.90	4.25	1.0	0.50	7.25	4.15	0	2.25	3.16
December	3.4	4.25	6.00	7.5	5.45	5.1	6.5	3.7	5.75	4.25	3.14
Total	**54.4**	**74.85**	**52.80**	**89.05**	**53.1**	**72.87**	**70.20**		**54.25**	**59.35**	**49.32**
% of Lake Volume	**71**	**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

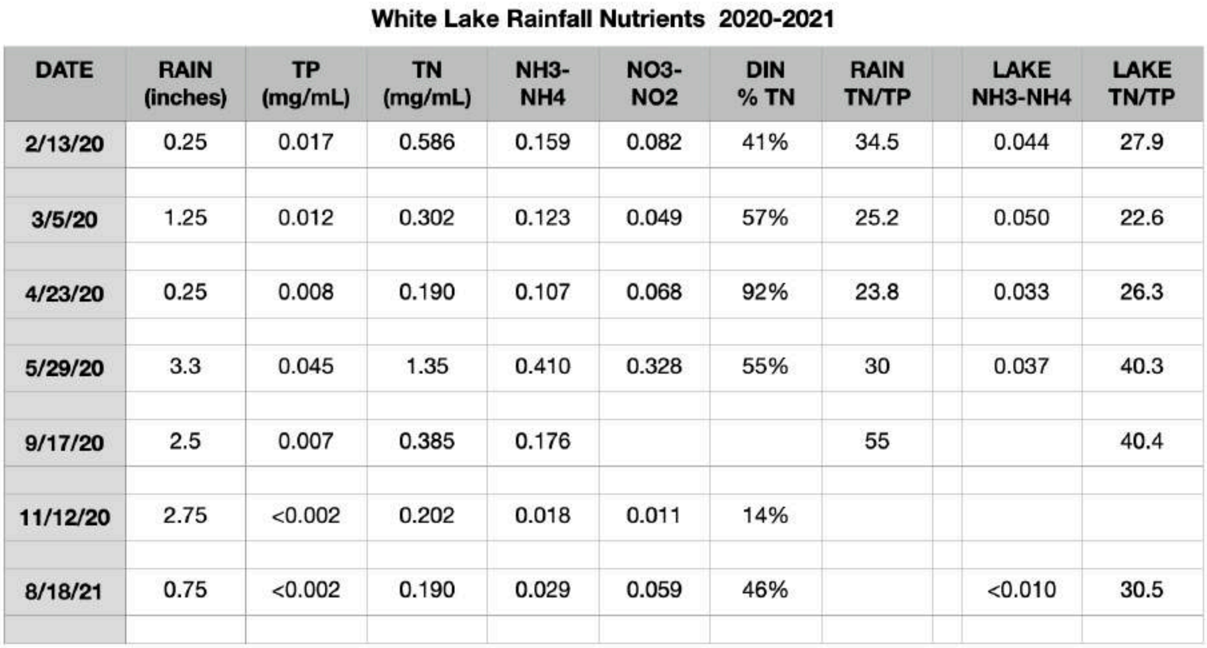
White Lake: Annual Lake Elevations, High and Low

2019 High (January 25): 64.6 Ft	**2019 Low** (July 9): 63.5 Ft
2020 High (June 16): 65.2 Ft	**2020 Low** (January 1): 64.3 Ft
2021 High (February 19): 65.3 Ft	**2021 Low** (November 29): 63.9 Ft

2019 Lake Level Variation (High to Low): 12.7 Inches
2020 Lake Level Variation (High to Low): 10.3 Inches
2021 Lake Level Variation (High to Low): 16.8 Inches

Variation (Highest-Lowest) Over the Three-Year Period 2019-2021: 21.1 Inches

Table 2. White Lake 2020-2021 rainfall sampling, with rainfall event amounts in inches and nutrient concentrations (Total Phosphorus [TP], Total Nitrogen [TN], NH_3 – NH_4, NO_3 - NO_2) in mg/L. Dissolved Inorganic Nitrogen (DIN) equals NH_3 – NH_4 + NO_3 - NO_2 .



White Lake Rainfall Nutrients 2020-2021

DATE	RAIN (inches)	TP (mg/mL)	TN (mg/mL)	NH3-NH4	NO3-NO2	DIN % TN	RAIN TN/TP	LAKE NH3-NH4	LAKE TN/TP
2/13/20	0.25	0.017	0.586	0.159	0.082	41%	34.5	0.044	27.9
3/5/20	1.25	0.012	0.302	0.123	0.049	57%	25.2	0.050	22.6
4/23/20	0.25	0.008	0.190	0.107	0.068	92%	23.8	0.033	26.3
5/29/20	3.3	0.045	1.35	0.410	0.328	55%	30	0.037	40.3
9/17/20	2.5	0.007	0.385	0.176			55		40.4
11/12/20	2.75	<0.002	0.202	0.018	0.011	14%			
8/18/21	0.75	<0.002	0.190	0.029	0.059	46%		<0.010	30.5

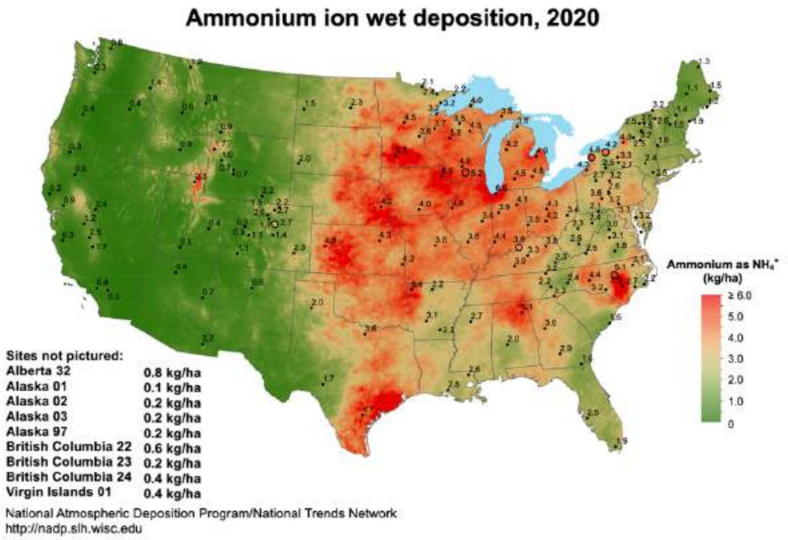


Figure 3. Mean annual wet deposition of ammonium, in kg/ha, in 2020. The mean at the Clinton, NC, monitoring station, 7.5 kg/ha, was the highest among the national monitoring locations, while the mean at Raleigh, at 5.1 kg/ha, was also high. U.S. EPA Clean Air Status and Trends Network: https://www.epa.gov/castnet (Accessed 1/4/22).

Rainfall pH is another parameter that is monitored at the National Atmospheric Deposition Program stations. Annual means for rainfall pH at the Clinton station (NTN NC 35) are now near 6 standard units (Fig. 4), whereas they were once in the 4.5 to 5 range, due to acid rain-producing emissions of sulfur dioxides and nitrous oxides (which have declined dramatically).

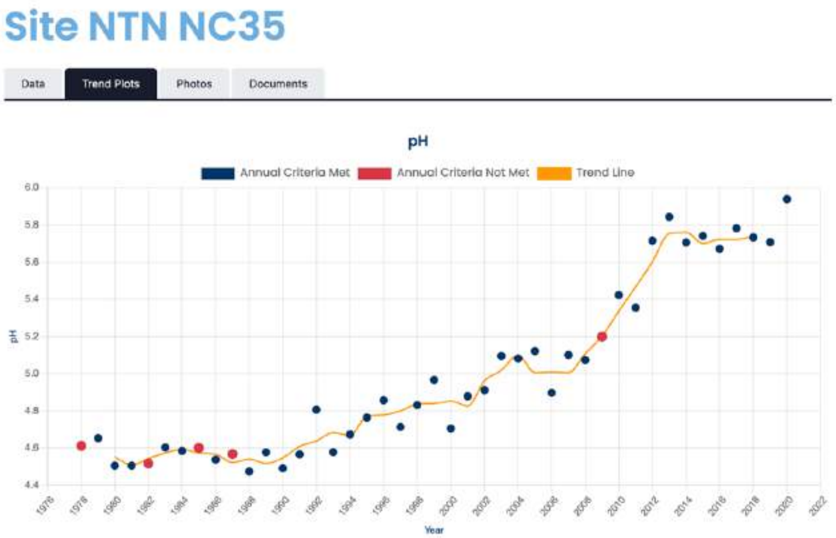


Figure 4. Mean annual rainfall pH (standard units) at Clinton, NC, from 1978-2020, National Atmospheric Deposition Program: https://nadp.slh.wisc.edu/ (accessed 1/4/2022. Data from 2021 not yet available).

White Lake pH Trends

White Lake pH levels have increased 2+ units in the past 20 years; the lowest pH levels are now around 6.5 standard units. Levels above 8 have been measured during algal/cyanobacterial blooms (fall of 2017, early May 2018, April 2021), as the alkalinity (buffering capacity) of the lake is very low (ranging from 4.0-4.6 mg $CaCO_3$/L on February 25, 2020). The red arrows in Figure 5 show the morning pH (8.5) and afternoon pH (9) on April 27, 2021, during a desmid bloom; this bloom had abated by May 20, and pH levels had dropped back to 6.5 (Fig. 5 and Table 3).

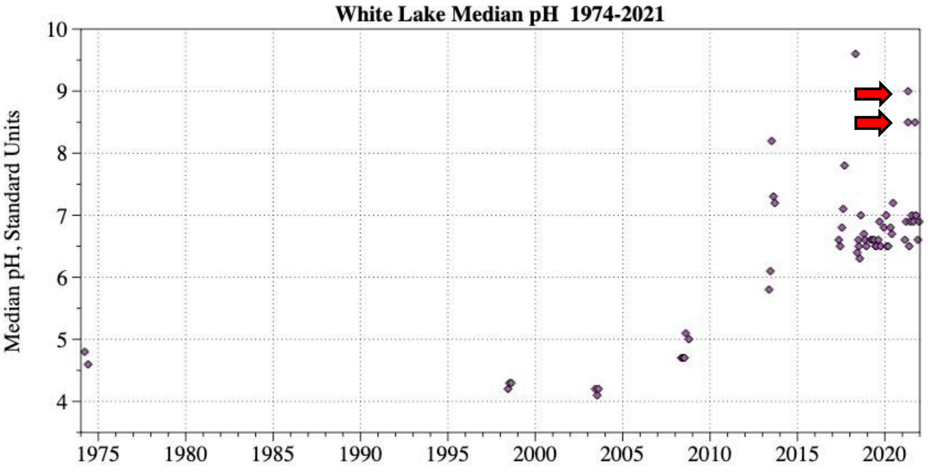


Figure 5. White Lake median pH (standard units) from 1974 (Weiss and Kuenzler 1976), 1998-2017 (NC DEQ data), 2018-2021 (LIMNOSCIENCES data). The red arrows show the morning and afternoon pH values during an algae bloom.

Groundwater Flow Rates from Springs

Seepage meters were constructed, based on the design in Lee (1977), allowing for the direct measurement of springs flow rates. The simple devices seal off a 3-square foot area of lake bottom, and a bag is attached to a valve to capture water flow for a timed period.

The first sampling was done in July 2018, with divers placing a seepage meter in a 30' diameter spring (#1); the flow rate was measured at 0.26 gallons/hr. (1 liter/hr.), and the seepage meter was removed after the measurement was made. Rainfall was above average in the early summer 2018, with June rain totaling 10 inches, but no lake level measurements were available.

On September 15, 2021, divers installed a seepage meter in a 15-foot diameter spring (#2); the flow rate was 0.63 gallons/hr. (2.4 liters/hr.), or an estimated 35 gallons/hr. total flow for the 15-ft. spring. Several other springs were tested, and no flow was detected. September rainfall was 3.2 inches, and lake level was 64.35 feet NAVD 88.

A second sampling trip was done October 8, 2021; there was no measurable flow from meter #2, while a newly installed meter in the 30'spring sampled in 2018 (#1) had a flow rate of 0.079 gallons/hr. (0.3 liters/hr.). October rainfall was 0.7 inches, with a lake level of 64.1 feet NAVD 88. This was over a foot below the lake level high found in February. Normal lake level variation ranges from 12 to 18 inches over an annual cycle.

Lake Nutrients

There was generally little variability in Total Phosphorus monthly means in 2021, with a notable exception being April, when a desmid bloom was peaking. Total P values ranged from 0.037 to 0.040 mg/L (mean 0.039, Table 3); this month also had the highest Soluble Reactive P (SRP) levels, ranging 0.002 [at both northern lake depths] to 0.026 [at the mid-lake 2.0 m depth] (mean 0.011, Table 3).

Another notable situation occurred during September sampling, when a brown trail (due to a wave-board boat churning up bottom sediments) was seen at the mid-lake station location (Fig.

6). A grab sample taken in this plume at 0.5 m had a TP level of 0.054 mg/L (compared to 0.025-0.026 mg P/L at the other stations). Total Nitrogen was also higher at 1.01 mg/L (compared to 0.696-0.899 mg N/L at the other stations).

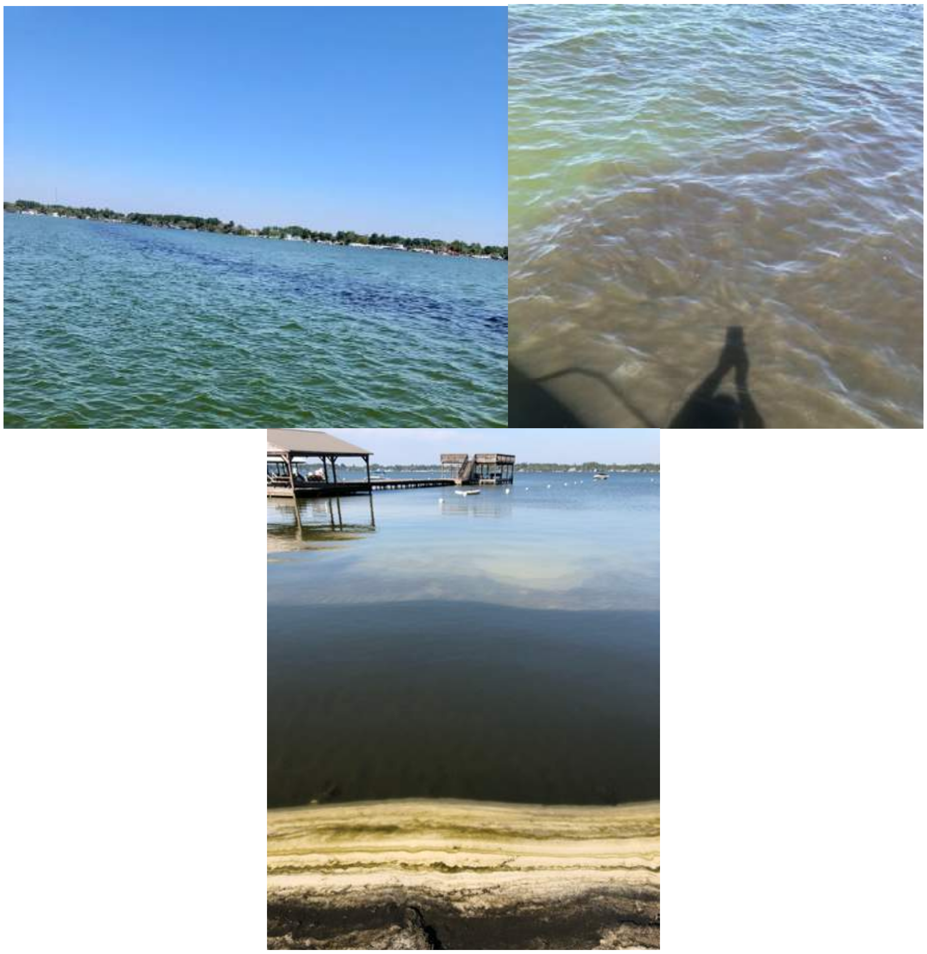
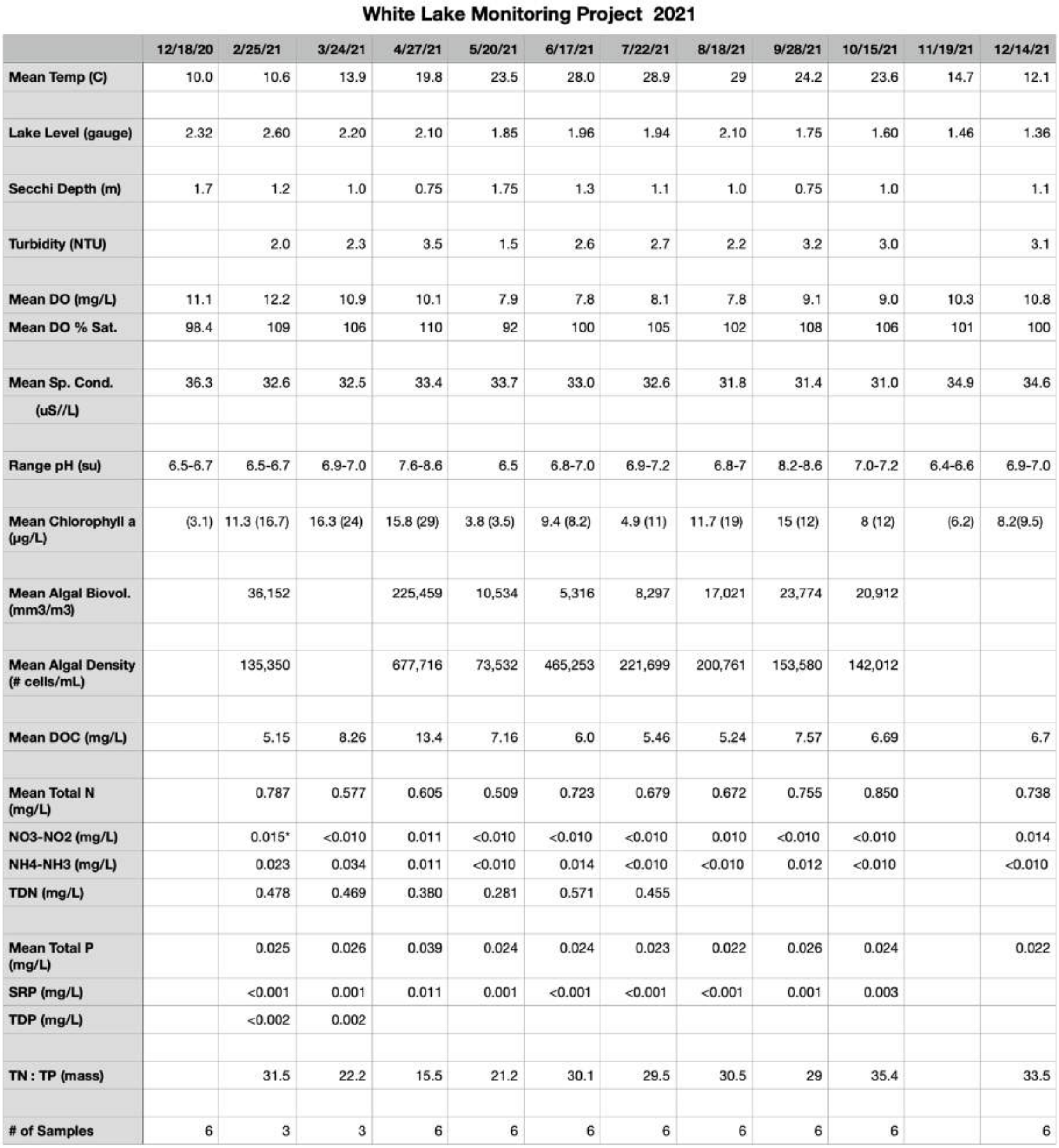


Figure 6. Top photos: the sediment plume, with a grab sample taken at sampling station WL-B1 (0.5 m depth); bottom photo: view of western lakeshore in early afternoon, showing a zone of sediments along the water's edge. Photos taken on September 28, 2021. The lake level was 64.4 feet NAVD 88.

Monthly mean Total Nitrogen levels varied by 40% over the course of 2021, with the highest levels found in February (0.787 mg/L) and October (0.850 mg/L) (Table 3). The highest Dissolved Inorganic Nitrogen (DIN) means were found in February and March (0.038 and 0.034 mg N/L respectively). DIN levels were below detection in May, July, and October; ammonium levels were generally higher than nitrate-nitrite (Table 3). By comparison, 2020 monthly mean DIN levels were highest in February through May (0.057, 0.063, 0.045, and 0.048 mg N/L respectively; Appendix 1) and were below detection in July.

Dissolved Organic Carbon (DOC) monthly means ranged from 5.15 mg/L in February to 13.4 mg/L in April 2021(Table 3). In 2020, DOC monthly means ranged from 5.04 to 6.20 mg C/L, the 2019 range was 4.66 to 7.53, and the 2018 range was 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 1).

Table 3. Means for physical and chemical parameters for White Lake, January-December 2021. Samples were generally collected at two depths (0.5 and 2.0 m) at each of three stations (equivalent to the monitoring stations used by NC DEQ). Chlorophyll *a* was measured by the analytical laboratory and in the field with a Turner hand-held fluorometer (field measurements are indicated in parenthesis). An asterisk indicates that one measurement in February 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 2021

	12/18/20	2/25/21	3/24/21	4/27/21	5/20/21	6/17/21	7/22/21	8/18/21	9/28/21	10/15/21	11/19/21	12/14/21
Mean Temp (C)	10.0	10.6	13.9	19.8	23.5	28.0	28.9	29	24.2	23.6	14.7	12.1
Lake Level (gauge)	2.32	2.60	2.20	2.10	1.85	1.96	1.94	2.10	1.75	1.60	1.46	1.36
Secchi Depth (m)	1.7	1.2	1.0	0.75	1.75	1.3	1.1	1.0	0.75	1.0		1.1
Turbidity (NTU)		2.0	2.3	3.5	1.5	2.6	2.7	2.2	3.2	3.0		3.1
Mean DO (mg/L)	11.1	12.2	10.9	10.1	7.9	7.8	8.1	7.8	9.1	9.0	10.3	10.8
Mean DO % Sat.	98.4	109	106	110	92	100	105	102	108	106	101	100
Mean Sp. Cond. (uS//L)	36.3	32.6	32.5	33.4	33.7	33.0	32.6	31.8	31.4	31.0	34.9	34.6
Range pH (su)	6.5-6.7	6.5-6.7	6.9-7.0	7.6-8.6	6.5	6.8-7.0	6.9-7.2	6.8-7	8.2-8.6	7.0-7.2	6.4-6.6	6.9-7.0
Mean Chlorophyll a (µg/L)	(3.1)	11.3 (16.7)	16.3 (24)	15.8 (29)	3.8 (3.5)	9.4 (8.2)	4.9 (11)	11.7 (19)	15 (12)	8 (12)	(6.2)	8.2(9.5)
Mean Algal Biovol. (mm3/m3)		36,152		225,459	10,534	5,316	8,297	17,021	23,774	20,912		
Mean Algal Density (# cells/mL)		135,350		677,716	73,532	465,253	221,699	200,761	153,580	142,012		
Mean DOC (mg/L)		5.15	8.26	13.4	7.16	6.0	5.46	5.24	7.57	6.69		6.7
Mean Total N (mg/L)		0.787	0.577	0.605	0.509	0.723	0.679	0.672	0.755	0.850		0.738
NO3-NO2 (mg/L)		0.015*	<0.010	0.011	<0.010	<0.010	<0.010	0.010	<0.010	<0.010		0.014
NH4-NH3 (mg/L)		0.023	0.034	0.011	<0.010	0.014	<0.010	<0.010	0.012	<0.010		<0.010
TDN (mg/L)		0.478	0.469	0.380	0.281	0.571	0.455					
Mean Total P (mg/L)		0.025	0.026	0.039	0.024	0.024	0.023	0.022	0.026	0.024		0.022
SRP (mg/L)		<0.001	0.001	0.011	0.001	<0.001	<0.001	<0.001	0.001	0.003		
TDP (mg/L)		<0.002	0.002									
TN : TP (mass)		31.5	22.2	15.5	21.2	30.1	29.5	30.5	29	35.4		33.5
# of Samples	6	3	3	6	6	6	6	6	6	6		6

Lake Nutrient Ratios

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]). Present day ratios were more variable in 2021 compared with 2020, ranging from 15.5 in April to 35.4 in October (Table 3).

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). Mass ratios of DIN:TP in 1974 were 4 and 2.9 (Weiss and Kuenzler 1976), while ratios in February-April 2020 were 2.4, 3 and 2.1 (and the February-April rainfall mean ratio was 15.4.) In 2021, mass ratios of DIN:TP were 1.5 in February, 1.3 in March, and 0.6 in April. White Lake DIN levels were below testing detection limits in three of the ten sample periods in 2021, indicating that phytoplankton productivity was controlled by nitrogen limitation. 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.

Water Clarity Trends

Water clarity measured as Secchi depth ranged from 0.75 meters to 1.75 meters, with the highest clarity in 2021 in May (Fig. 7, which reports data in feet, and Table 3).

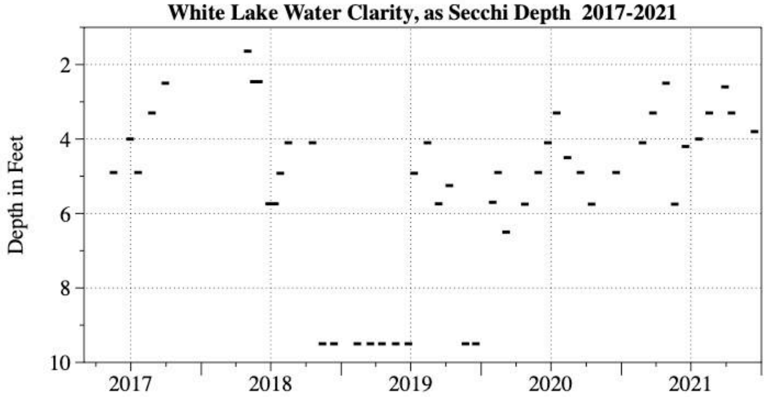
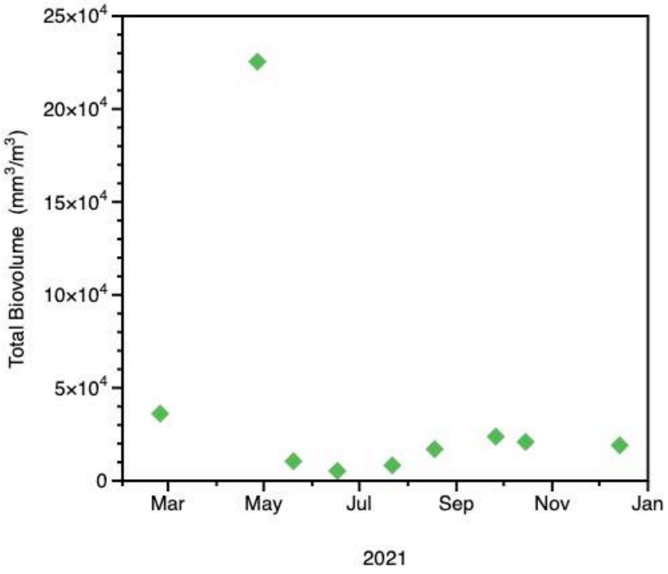


Figure 7. White Lake monthly mean Secchi depths in feet, from 2017 (NC DEQ data) and 2018-2021 (LIMNOSCIENCES data).

Turbidity levels were highest in April (monthly mean 3.5 NTU) and September-December (3.2-3.1 NTU) (Table 3).

White Lake Phytoplankton: Biovolumes

Chlorophyll *a* means in March and April did not reflect the magnitude of the algae bloom although the taxon-specific biovolume calculations did (Table 3), with the laboratory chlorophyll results being particularly low by comparison with values from a handheld fluorometer (which are indicated in parenthesis in Table 3). Total phytoplankton biovolume as calculated directly from algal analysis by Spirogyra Diversified Environmental Sciences was quite high in April, with the desmid *Cosmarium tinctum* constituting the majority of biovolume in the winter/spring bloom (Fig. 8).



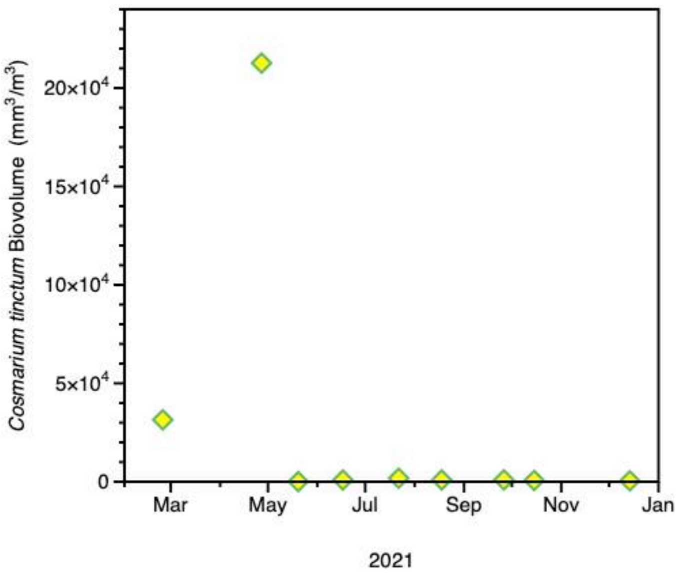


Figure 8. Top graph: White Lake mean Total Phytoplankton biovolume (mm^3/m^3) in 2021. A grab sample was collected at 0.5 m at each of the three stations on each date, and phytoplankton were identified, enumerated, and measured for biovolume calculations. Bottom graph: mean *Cosmarium tinctum* biovolume (mm^3/m^3); this desmid constituted 94% of total biovolume in the April bloom.

The filamentous desmid *Gonatozygon brebissoni* was a dominant constituent of biovolume in the fall/early winter of 2021 (September 40%, October 52%, December 51%; Fig. 9). This desmid species had also been dominant in June and July 2017, prior to the filamentous cyanobacteria *Planktolyngbya limnetica* establishing dominance in August and September (NC DEQ 2017).

Appendix 2 includes phytoplankton biovolume plots for 2018 and 2020, as well as 2021 (data from 2019 was not plotted as phytoplankton analysis was done for 4 months, rather than 8). A comparison of the relative magnitude of the cyanobacterial bloom in early May 2018, prior to the alum treatment, to the magnitude of the desmid bloom on April 27, 2021: May 2 mean total biovolume = 151,563 mm^3/m^3, and April 2021 mean total biovolume = 225,459 mm^3/m^3 , nearly 50% higher than 2018 biovolume (Appendix 2).

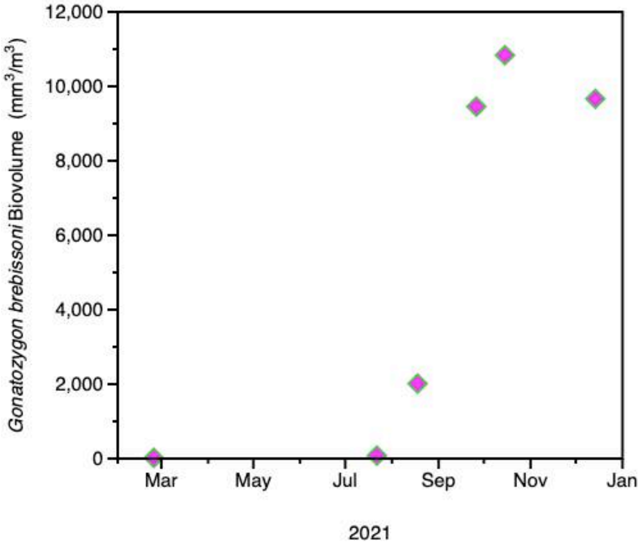


Figure 9. White Lake mean *Gonatozygon brebissoni* biovolume (mm^3/m^3) in 2021 (note the difference in scale of the y-axis by comparison with the previous two graphs). This filamentous desmid constituted 40% of total biovolume in September, 52% of biovolume in October, and 51% in December.

In 2021, Total Cyanobacteria ranged from near zero (in April) to 17% (in August) of total biovolume. *Aphanizomenon* sp. was the dominant cyanobacterial taxon with respect to biovolume with the highest mean values found in August (2,790 mm^3/m^3 [16% of total biovolume]), September (2,166 mm^3/m^3 [9%]), and October (1,822 mm^3/m^3 [9%]).

In 2020, cyanobacterial biovolumes ranged from near zero to a high of 5% in October. 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 1). By July 2018, cyanobacteria biovolume was less than 1% of total biovolume, and it remained low for the rest of the year.

White Lake Phytoplankton: Densities

Monthly mean Total Phytoplankton Densities (based on cell counts, or the number of cells/mL) showed the same peak in April 2021 (677,716 cells/mL, Fig. 10) as with biovolume. By comparison, the highest monthly mean phytoplankton cell density in 2020 was found in August (460,836 cells/mL, with the multi-celled filamentous cyanobacterium Planktolyngbya limnetica comprising 93% of total cell density) (Appendix 1 and 2). Prior to the alum treatment in May 2018, the phytoplankton cell density was dominated by *P. limnetica;* the graphs in Appendix 2 show the relative sizes of the 2018 and 2021 blooms.

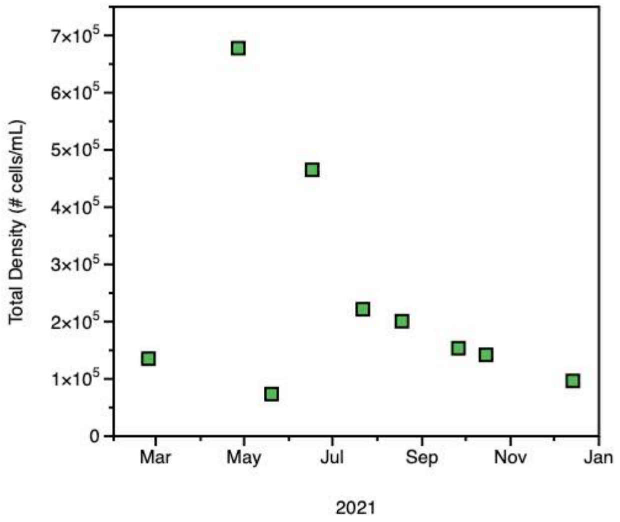


Figure 10. White Lake mean Total Phytoplankton densities (# cells/mL) in 2021.

In 2020, monthly mean phytoplankton densities were highest from June through September (Appendix 2), with the highest mean density found in August (468,836 cells/mL).

Monthly mean densities of the dominant species in the 2021 bloom (at 61% of total cell density), *Cosmarium tinctum*, declined dramatically the following month (181 cells/mL in May), comprising 1% or less of total phytoplankton density for the remainder of the year (Fig. 11).

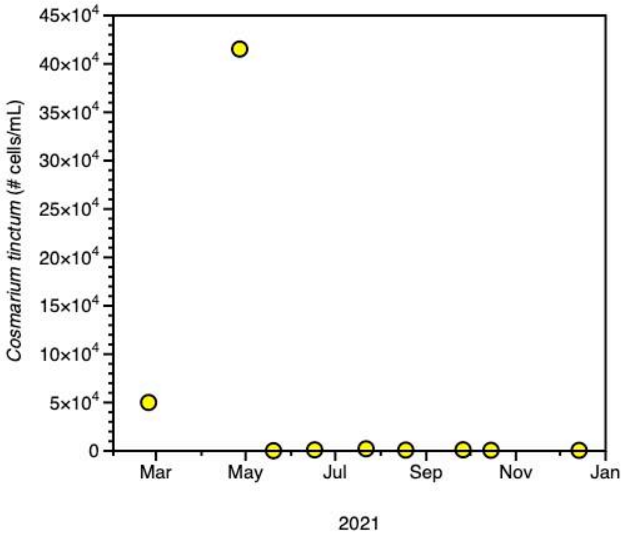


Figure 11. White Lake mean *Cosmarium tinctum* densities (# cells/mL) in 2021.

Cyanobacteria Densities

Cyanobacteria dominated phytoplankton densities from May onwards, ranging from 73 to 96% of total phytoplankton mean density. The highest monthly mean cyanobacteria densities were found in April (233,817 mm^3/m^3; Fig. 12), with *Aphanocapsa* spp. the dominant cyanobacterial taxa (154,758 mm^3/m^3, which was 23% of total phytoplankton density), June (447,872 mm^3/m^3; Fig 12), with *Planktolyngbya limnetica* the dominant taxa (89% of total phytoplankton density), and July (205,035 mm3/m3; Fig. 12), with *P. limnetica* (32% of total phytoplankton density) and *Aphanocapsa* sp. (37% of total phytoplankton density as the dominant taxa.

Monthly mean densities of a second *Planktolyngbya* species, *Planktolyngbya crassa*, ranged from less than 1% to 12% of total phytoplankton density, with the highest monthly means found in September and October (Fig. 12).

Monthly mean densities of *Aphanizomenon* sp. were highest in August (25,676 cells/mL), September (19,627 cells//mL), and October (16,770 cells/mL). It was not found in December samples.

Picoplankton-sized cyanobacteria such as *Synechococcus* sp. are often important in oligotrophic waters and occasionally in more productive systems, and some species are "superior competitors for phosphorus" (Wehr and Sheath 2003). This taxon has been present in every month of sampling over the past four years (Appendix 3), and at times it is the dominant taxon with respect to density (Table 4).

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 *Dolichospermum* sp. (formerly *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 during the sampling period (NC DEQ unpublished data).

Planktolyngbya limnetica was the dominant species in the cyanobacterial bloom of 2017-2018 (NC DEQ 2017, LIMNOSCIENCES 2018). Prior to the alum treatment in May 2018, the phytoplankton cell density was dominated by *P. limnetica;* the graphs in Appendix 2 show the relative size of the 2018 bloom compared to the 2021 desmid bloom. A total of 17 cyanobacterial taxa were found prior to the start of the alum treatment (sampling on May 2, 2018). By comparison, 19 cyanobacterial taxa were found in 2021 (Appendix 3).

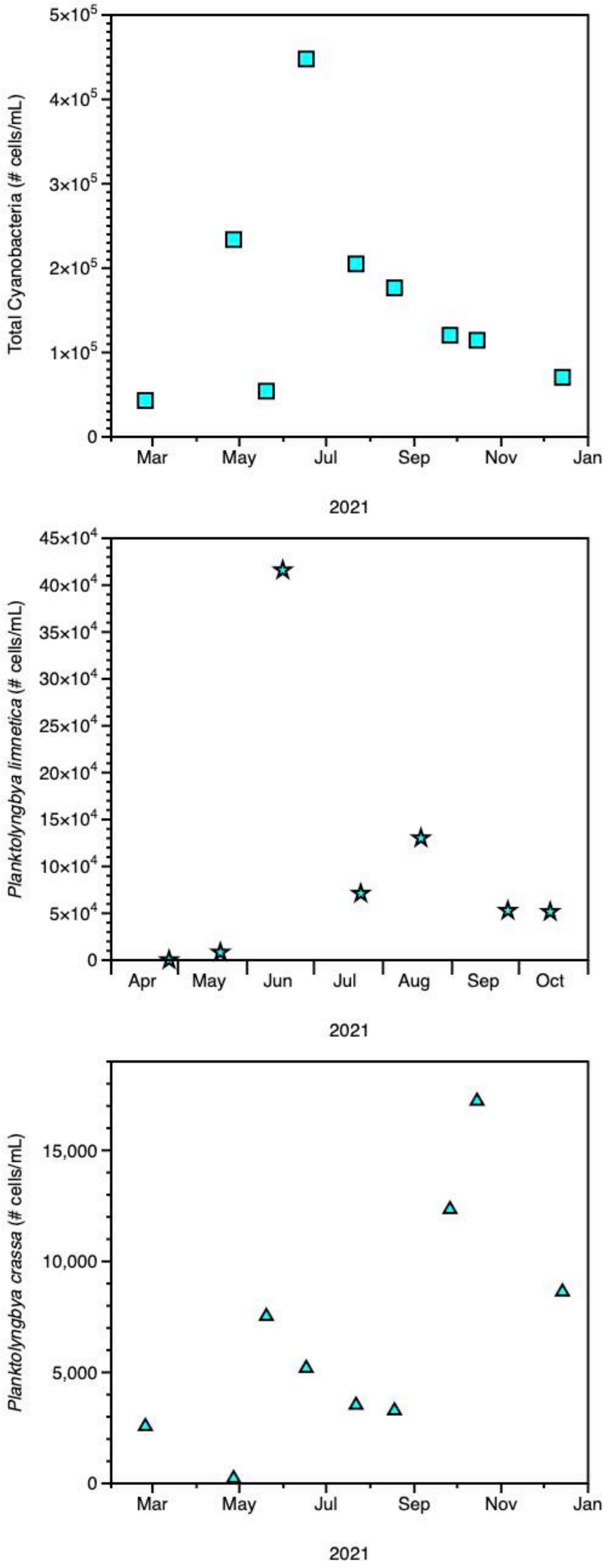
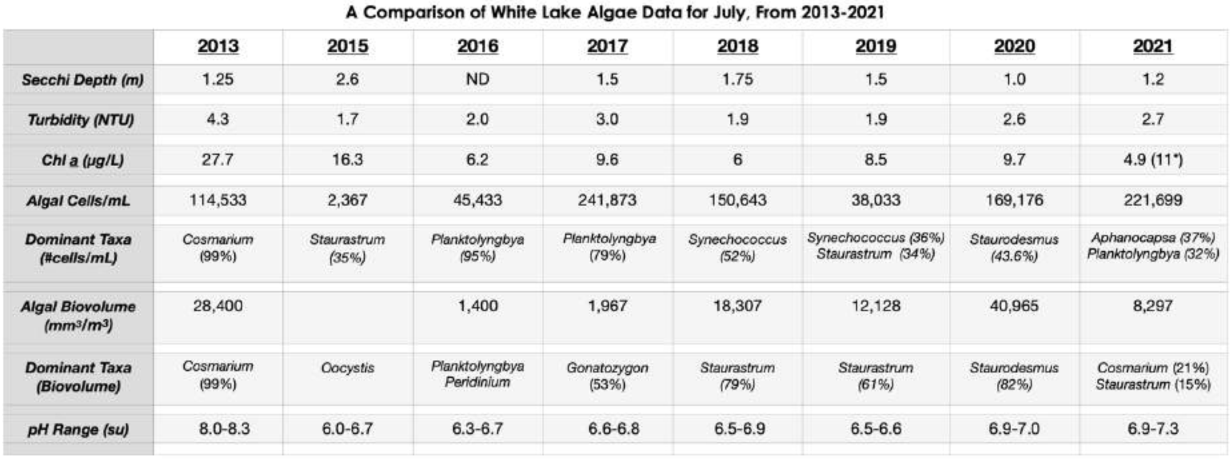


Figure 12. White Lake mean Total Cyanobacteria (top graph), mean *Planktolyngbya limnetica* (middle graph), and *Planktolyngbya crassa* (bottom graph) densities, all in # cells/mL. Note differences in scale of the y-axis in each graph.

The first documented phytoplankton bloom in White Lake occurred in July 2013, after extreme precipitation events in June of that year (Table 4). That bloom was dominated by a unicellular desmid, *Cosmarium* sp. (NC DEQ unpublished data). This was also the first time that pH levels were at or above 8 standard units. High photosynthetic activity during blooms can result in a 2-unit or more increase in pH because of the low alkalinity (3-4.6 mg $CaCO_3$/L; Weiss and Kuenzler 1976, and this report) of the lake water.

Table 4. White Lake July comparison data, with 2013-2017 collected and analyzed by NC DEQ (data reported in NC DEQ 2017). Data from 2018-2021 was collected and analyzed by LIMNOSCIENCES and Spirogyra Diversified Environmental Services. ND = no data. Differences in methodologies between the two data sets include the way cell densities and biovolumes were determined, with algae data from 2018 onwards including all taxa found in samples, including picoplankton (such as *Synechococcus* sp.).



A Comparison of White Lake Algae Data for July, From 2013-2021

	2013	2015	2016	2017	2018	2019	2020	2021
Secchi Depth (m)	1.25	2.6	ND	1.5	1.75	1.5	1.0	1.2
Turbidity (NTU)	4.3	1.7	2.0	3.0	1.9	1.9	2.6	2.7
Chl a (µg/L)	27.7	16.3	6.2	9.6	6	8.5	9.7	4.9 (11*)
Algal Cells/mL	114,533	2,367	45,433	241,873	150,643	38,033	169,176	221,699
Dominant Taxa (#cells/mL)	*Cosmarium* (99%)	*Staurastrum* (35%)	*Planktolyngbya* (95%)	*Planktolyngbya* (79%)	*Synechococcus* (52%)	*Synechococcus* (36%) *Staurastrum* (34%)	*Staurodesmus* (43.6%)	*Aphanocapsa* (37%) *Planktolyngbya* (32%)
Algal Biovolume (mm^3/m^3)	28,400		1,400	1,967	18,307	12,128	40,965	8,297
Dominant Taxa (Biovolume)	*Cosmarium* (99%)	*Oocystis*	*Planktolyngbya* *Peridinium*	*Gonatozygon* (53%)	*Staurastrum* (79%)	*Staurastrum* (61%)	*Staurodesmus* (82%)	*Cosmarium* (21%) *Staurastrum* (15%)
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	6.9-7.3

White Lake is unusual in having a phytoplankton community that is generally dominated in summer months by desmids; *Cosmarium*, *Gonatozygon*, *Staurodesmus*, and *Staurastrum* are desmid taxa with one or more species found abundantly in the summer (Table 4), and sometimes in winter months as well. The number of species found in some taxa has increased recently (for example, 3 different species of *Staurastrum* were found in February 2020, and 6 different species were found in February 2021).

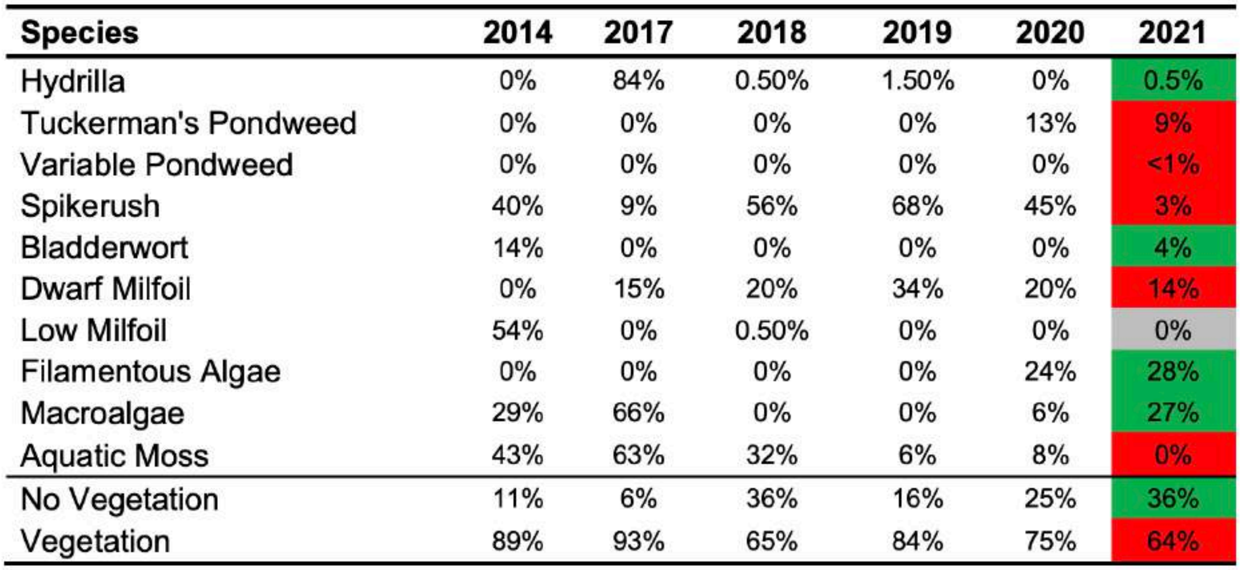
Green algae (Chlorophyta) have been very abundant at times, such as *Oocystis* sp. in July 2015 (Table 4), the very small unicellular form *Nannochloris* sp. in February 2020 (LIMNOSCIENCES 2021), and *Elakatothrix viridis* in December 2021. While the number of cells/mL can be very high, their relatively small size means that they generally do not dominate phytoplankton biovolume.

The golden algal (Chrysophyta) taxon *Dinobryon* has been a dominant component of biovolume (it is a relatively large colonial form) of White Lake phytoplankton at times, and more species were found in 2021 (4 species) compared to previous years (one or two species found).

Aquatic Vegetation

The 2021 White Lake vegetation survey conducted by NCSU Extension personnel found a decrease in the percentage occurrence of aquatic vegetation/filamentous algae compared to 2020, with 64% of the sample sites having aquatic vegetation (Table 5). The lake elevation at the time of the 2021 survey was 64.1 feet above sea level (NAVD 88), and the Secchi depth was 1.0 m. Lake elevation at the time of the 2020 survey was 64.55 feet (due to high rainfall that year) and Secchi depth was 1.0 m, while the lake level was much lower at the time of the 2019 survey (63.68 feet) and the Secchi depth was 1.6 m. The 2018 survey was conducted about five weeks after Hurricane Florence, and floodwaters had subsided quickly; the Secchi depth was 1.25 m. In September 2017, White Lake Secchi depths were less than 1 m due to the cyanobacterial bloom (NC DEQ 2018).

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 2021 NCSU White Lake Aquatic Vegetation Survey Report). Green indicates an increase from the previous year, and red indicates a decrease.



Species	2014	2017	2018	2019	2020	2021
Hydrilla	0%	84%	0.50%	1.50%	0%	0.5%
Tuckerman's Pondweed	0%	0%	0%	0%	13%	9%
Variable Pondweed	0%	0%	0%	0%	0%	<1%
Spikerush	40%	9%	56%	68%	45%	3%
Bladderwort	14%	0%	0%	0%	0%	4%
Dwarf Milfoil	0%	15%	20%	34%	20%	14%
Low Milfoil	54%	0%	0.50%	0%	0%	0%
Filamentous Algae	0%	0%	0%	0%	24%	28%
Macroalgae	29%	66%	0%	0%	6%	27%
Aquatic Moss	43%	63%	32%	6%	8%	0%
No Vegetation	11%	6%	36%	16%	25%	36%
Vegetation	89%	93%	65%	84%	75%	64%

Many of the sample points on the western side of the lake had two or more kinds of vegetation found (Fig. 13). A single occurrence of the invasive weed hydrilla was found in the same general areas where it was found in 2018 and 2019 (Fig. 14).

Spikerush has been recorded from the lake as far back as vegetation sampling has been conducted, and it is often seen floating on the lake surface in the summer. Aquatic moss and filamentous algae have also been very abundant at times (e.g., Tebo 1961). Concerns about boating activity stirring up bottom-dwelling filamentous algae mats (which then collect along the shoreline, decompose and smell) go back at least as far as 1950. It should be noted that filamentous algae (*Mougiotia* sp.) mats were abundant in shallow areas in late 2018 and persisted until the middle of 2019 (Fig. 15).

While the presence of different kinds of vegetation can vary from year to year, there can also be variability over the course of the summer season. Mid-year monitoring events were conducted in June and August of 2020 for hydrilla detection, with results indicating a trend of more vegetation present in early summer, particularly for spikerush and macroalgae *Chara/Nitella* (both have been found in the lake and are very similar in appearance) (Figure 16; NCSU 2020).

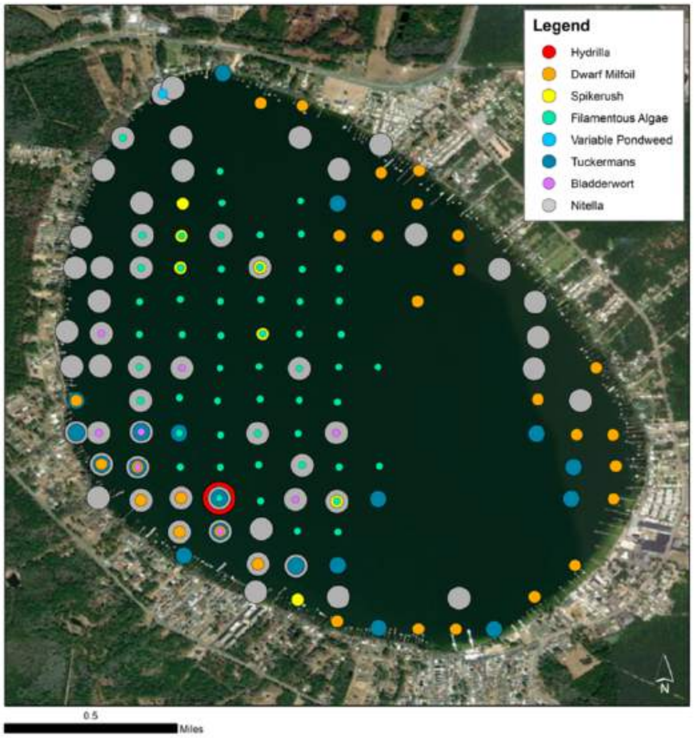


Figure 13. Sample locations where aquatic vegetation/algae was found in 2021 (NCSU 2021).

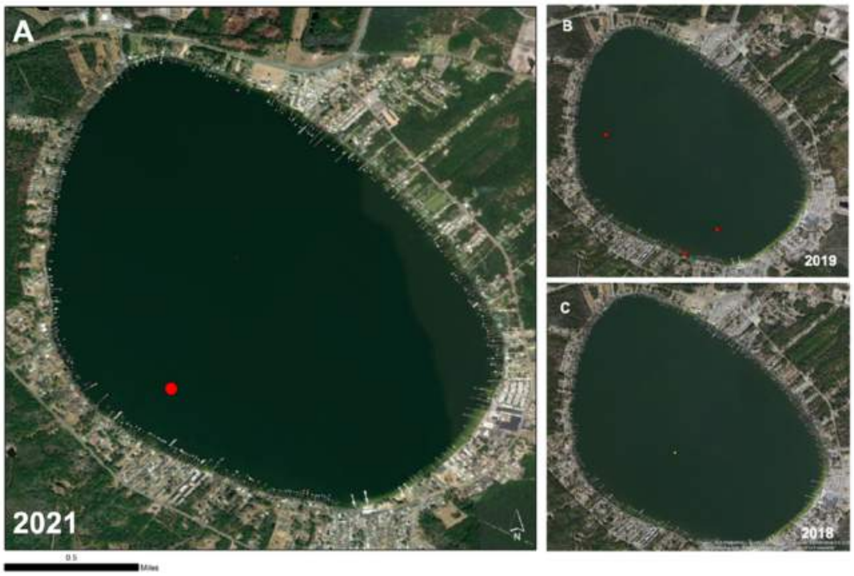


Figure 14. Locations where the aquatic weed *Hydrilla verticillata* was found, A) in 2021; B) in 2019; and C) in 2018 (NCSU 2021).

Figure 14. Mats of filamentous green algae (*Mougiotia* sp.) found in the shallows along the western side of White Lake in July 2019.

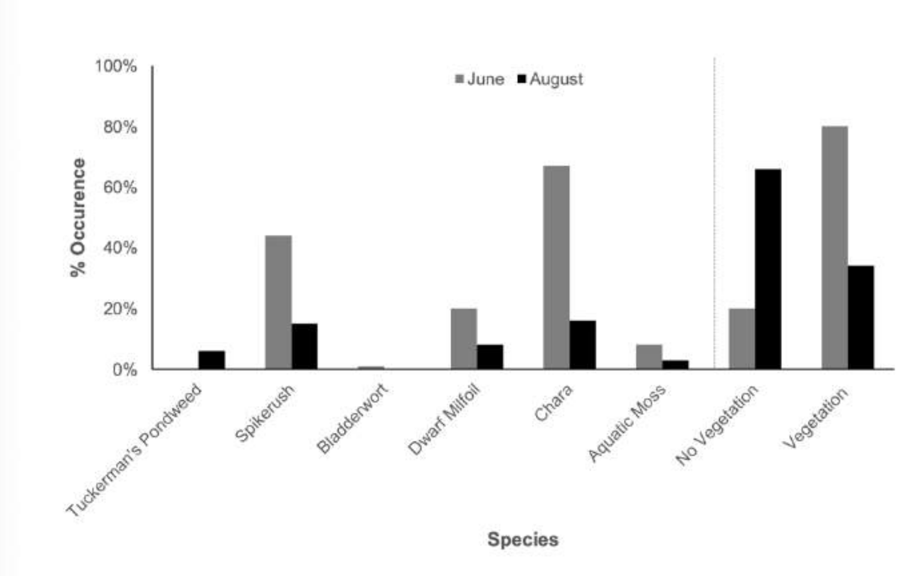


Figure 16. White Lake % occurrence of submerged aquatic vegetation in June and August 2020 (NCSU 2020).

Tuckerman's pondweed (*Potamogeton confervoides*, also known as algal pondweed) was first found in White Lake in 2020, and it was the only species that was classified as "dense" in the 2021 survey (Fig. 17).

Plant biovolume was estimated by using BioSonics equipment and software. The map generated (Fig. 18)) shows that submerged aquatic vegetation biovolume was relatively low (mean biovolume from stations with vegetation was 9.8%) with plant heights less than 12 inches, with few observations of emergent vegetation (NCSU 2021).

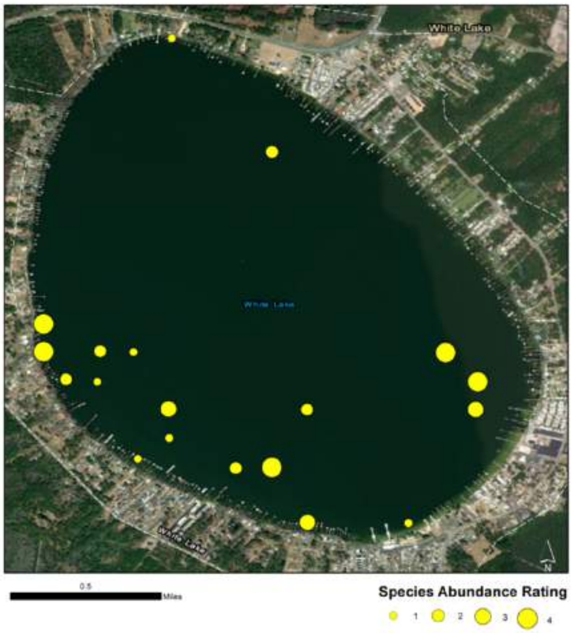


Figure 17. Relative abundance of Tuckerman's pondweed (*Potamogeton confervoides*) in White Lake in October 2021 (NCSU 2021).

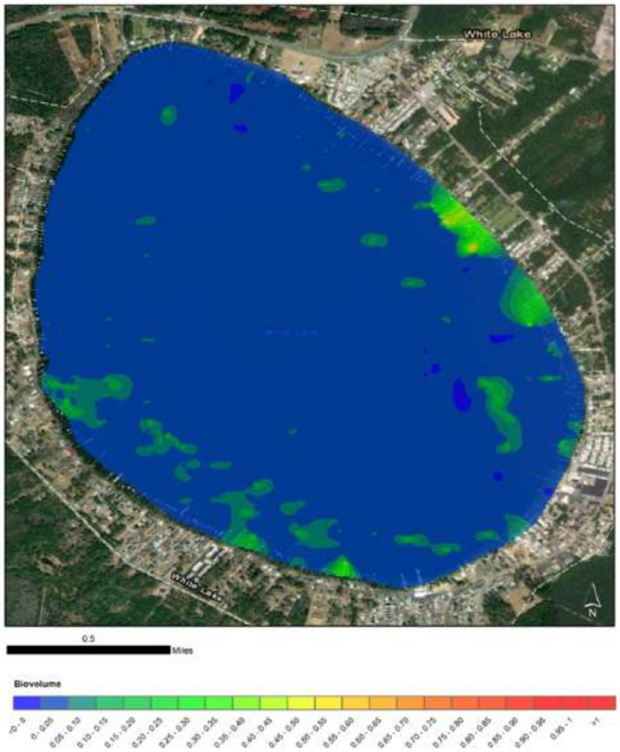


Figure 18. White Lake submerged aquatic vegetation biovolume in October 2021 (NCSU 2021).

Summary

1. The 2021 total annual rainfall was equivalent to the long-term average for the region, but it was much above average in February and much below average in late fall. The range in lake levels (high to low) was greater than in the previous two years, but still in line with historical ranges.

2. Measurements of groundwater flow using seepage meters placed in the springs found variable but low flow rates.

3. Rainfall, particularly big rain events, can provide a significant source of bioavailable nitrogen to the lake.

4. Low ratios of DIN:TP indicate that White Lake remains a nitrogen-limited system, even though present-day total nitrogen levels are higher than they were in the past.

5. Phytoplankton blooms are associated with high rainfall periods when bioavailable nitrogen (DIN) levels in the lake are higher. For 2020 and 2021, this has been in late winter-early spring.

6. The April 2021 desmid bloom caused a spike in pH levels, with high Dissolved Organic Carbon (DOC) levels, and high Total Phosphorus (TP) levels. These high values dropped in May, when the bloom had dissipated, and water clarity improved dramatically. Bioavailable nitrogen (DIN) levels were below detection levels in May, indicating that the bloom decline was associated with the decline in DIN (and DIN:TP was below 1).

7. White Lake's phytoplankton community is quite dynamic, although there are several general trends: small forms tend to respond quickly to increases in DIN; a variety of desmids tend to dominate in the summer; diversity is increasing; and filamentous cyanobacteria have been minor constituents of the phytoplankton community since the 2018 alum treatment. The first two of these have been long-standing trends, while the latter two suggest that a diverse phytoplankton community includes a variety of taxa that have a competitive advantage compared to filamentous cyanobacteria. However, the filamentous cyanobacteria *Aphanizomenon* sp. had a greater (but relatively brief) presence (biovolume) in 2021 compared to 2020.

8. White Lake's phytoplankton community is unique (even by comparison with the other Bay lakes), and this is another aspect of what makes the lake a special place. Lake monitoring, in winter as well as summer months should continue over the long term so that protection and management actions are based on sound science.

9. The presence and relative abundance of native aquatic vegetation varies from year to year, and in 2021, benthic filamentous algae and macroalgae (*Chara* and *Nitella*) were the most widely distributed, with two-thirds of the lake bottom containing vegetation.

10. 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 recent intensive surveys have detected it rarely or not at all. 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.

11. The Boating-Clarity Connection: The association between increased boating activity (particularly weekend and holiday) and reductions in water clarity in this very shallow lake have long been recognized, as evidenced by numerous letters, memos, reports, and newspaper articles produced since 1950; this relationship has also been noted in other shallow lakes (e.g, Beachler and Hill 2001, Hoverson and McGinley 2007). Recent studies on boat types and operations indicate that lake depths of 10 feet or greater are needed to prevent sediment resuspension caused by propeller turbulence (Keller 2017, Fay et al. 2022, Marr et al. 2022). Maximum depths in White Lake are in the 8.5-to-9.5-foot range, depending on lake level (when the sediment plume was sampled in late September 2021, the lake level was 64.4 feet above sea level NAVD 88, so the boat that produced the plume would have been operating in depths of 9 feet or less).

12. The Boating-Nutrient Connection: muddy sediments, which comprise about half of the lake bottom area in White Lake, are a storehouse for phosphorus (Lauritsen et al. 2019), so it is no surprise that sediment plumes generated from wave board boats have high phosphorus levels; resuspension of nutrients by boats has been noted by other lake researchers as well (e.g., Keller 2017).

13. About half of While Lake's shoreline is hardened with seawalls. These areas can be collection zones for sediments and vegetation that has been stirred up by boating activity, keeping the material in the lake rather than washing ashore, where it can be raked up and removed. In addition, the seawalls deflect wave energy back to the lake, lengthening the period of disturbance, which helps to keep material suspended in the water.

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.

Appreciation is also due to NC State Parks personnel for field assistance, NC Division of Water Resources for data sharing and *Hydrilla* monitoring, NC State University's Aquatic Weed staff for their detailed reports on aquatic vegetation, Dr. Linda Ehrlich with Spirogyra Diversified Environmental Sciences for her deep dive into algal taxonomy and biovolume determinations, Steve Bunn, Bill Stafford and the White Lake Rescue Dive Team for seepage meter/springs sampling, QA Officer Shannon Brattebo with Tetra Tech, and Dr. Damien Gadomski with IEH Analytical Laboratories.

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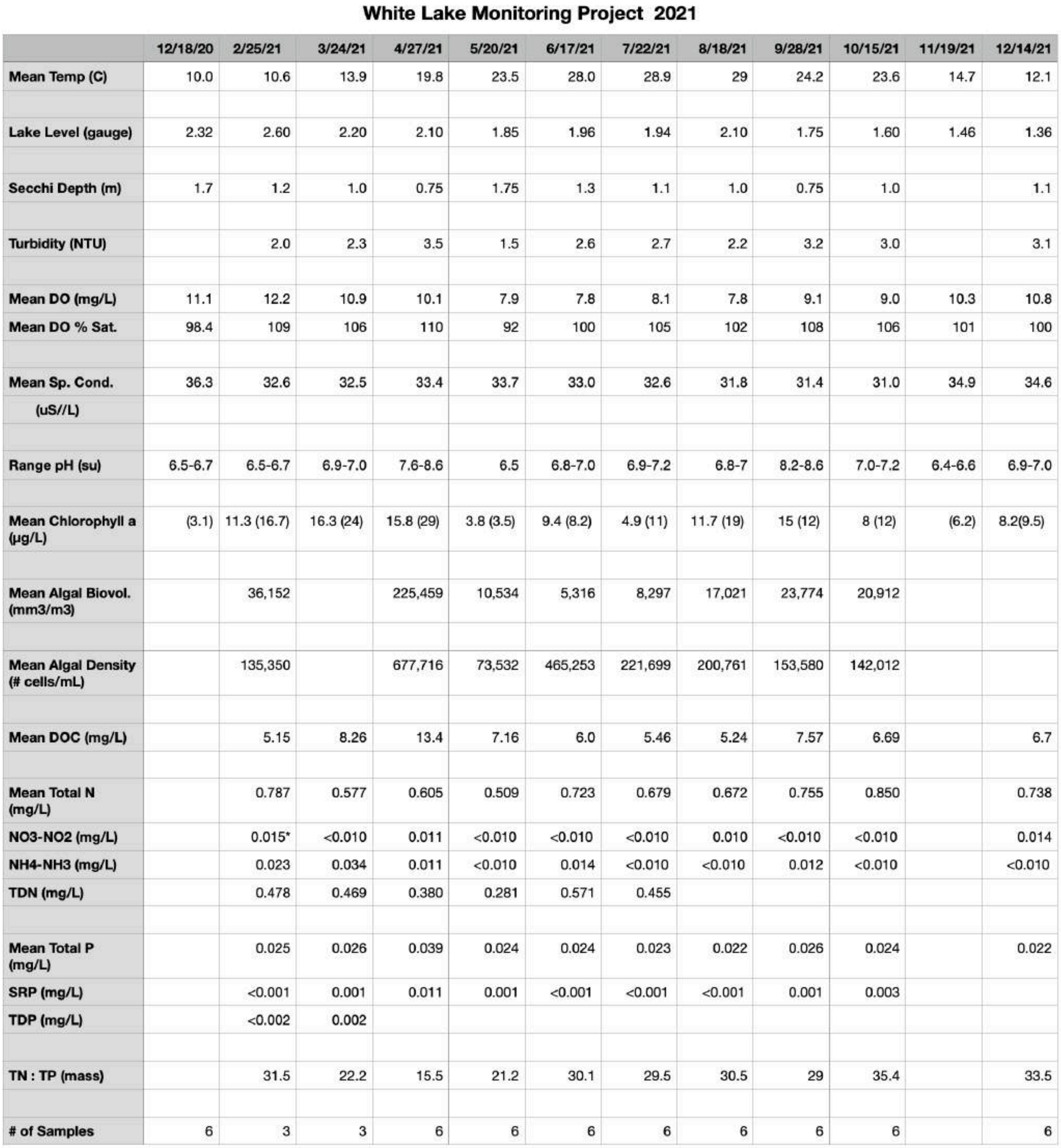
Appendix 1. White Lake Monitoring Data. Data is reported as monthly means for all parameters except pH, in which ranges are given. For 2021 (and December 2020) a Turner handheld fluorometer was used for field measurements of chlorophyll *a*, with mean data in parenthesis. Also in 2021: the asterisk at NO_3 - NO_2 data from February 25, excludes an outlier (lab results included one very high value from Station B-1 (0.124 mg/L), whereas the values from the other stations were 0.015 and 0.013 mg/L.; and due to windy conditions, November 2021 sampling was limited to 3 points around the lakeshore.



White Lake Monitoring Project 2021

	12/18/20	2/25/21	3/24/21	4/27/21	5/20/21	6/17/21	7/22/21	8/18/21	9/28/21	10/15/21	11/19/21	12/14/21
Mean Temp (C)	10.0	10.6	13.9	19.8	23.5	28.0	28.9	29	24.2	23.6	14.7	12.1
Lake Level (gauge)	2.32	2.60	2.20	2.10	1.85	1.96	1.94	2.10	1.75	1.60	1.46	1.36
Secchi Depth (m)	1.7	1.2	1.0	0.75	1.75	1.3	1.1	1.0	0.75	1.0		1.1
Turbidity (NTU)		2.0	2.3	3.5	1.5	2.6	2.7	2.2	3.2	3.0		3.1
Mean DO (mg/L)	11.1	12.2	10.9	10.1	7.9	7.8	8.1	7.8	9.1	9.0	10.3	10.8
Mean DO % Sat.	98.4	109	106	110	92	100	105	102	108	106	101	100
Mean Sp. Cond. (uS//L)	36.3	32.6	32.5	33.4	33.7	33.0	32.6	31.8	31.4	31.0	34.9	34.6
Range pH (su)	6.5-6.7	6.5-6.7	6.9-7.0	7.6-8.6	6.5	6.8-7.0	6.9-7.2	6.8-7	8.2-8.6	7.0-7.2	6.4-6.6	6.9-7.0
Mean Chlorophyll a (µg/L)	(3.1)	11.3 (16.7)	16.3 (24)	15.8 (29)	3.8 (3.5)	9.4 (8.2)	4.9 (11)	11.7 (19)	15 (12)	8 (12)	(6.2)	8.2(9.5)
Mean Algal Biovol. (mm3/m3)		36,152		225,459	10,534	5,316	8,297	17,021	23,774	20,912		
Mean Algal Density (# cells/mL)		135,350		677,716	73,532	465,253	221,699	200,761	153,580	142,012		
Mean DOC (mg/L)		5.15	8.26	13.4	7.16	6.0	5.46	5.24	7.57	6.69		6.7
Mean Total N (mg/L)		0.787	0.577	0.605	0.509	0.723	0.679	0.672	0.755	0.850		0.738
NO3-NO2 (mg/L)		0.015*	<0.010	0.011	<0.010	<0.010	<0.010	0.010	<0.010	<0.010		0.014
NH4-NH3 (mg/L)		0.023	0.034	0.011	<0.010	0.014	<0.010	<0.010	0.012	<0.010		<0.010
TDN (mg/L)		0.478	0.469	0.380	0.281	0.571	0.455					
Mean Total P (mg/L)		0.025	0.026	0.039	0.024	0.024	0.023	0.022	0.026	0.024		0.022
SRP (mg/L)		<0.001	0.001	0.011	0.001	<0.001	<0.001	<0.001	0.001	0.003		
TDP (mg/L)		<0.002	0.002									
TN : TP (mass)		31.5	22.2	15.5	21.2	30.1	29.5	30.5	29	35.4		33.5
# of Samples	6	3	3	6	6	6	6	6	6	6		6

Appendix 1 (continued).

White Lake Monitoring Project 2020

	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
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
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
Secchi Depth (m)	2.0	1.75	1.5	1.75	1.75	1.5	1.25	1.0	1.3	1.5	1.75	1.7
Turbidity (NTU)	0.93	2.35	2.50	1.80	1.5	1.6	2.3	2.6	1.9	1.7	1.7	
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
Mean DO % Sat.	102.3	102.5	98.3	100	97	100	109	102	95	99	101	98.4
Mean Sp. Cond.	33	33.8	32.5	32.2	33.3	32.5	32.7	38.8	39.0	39.9	39.5	36.3
(uS//L)												
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
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)
Mean Total Biovol. (mm3/m3)			12,644		4,177	10,997	23,360	40,965	10,236	11,155	4,442	
Mean Algal Density (# cells/mL)			93,508		44,927	25,395	273,399	140,965	460,836	196,622	85,373	
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	
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	
NO3-NO2 (mg/L)	0.017	<0.010	0.013	0.013	0.012	0.011	0.013	<0.010	<0.010		0.010	
NH4-NH3 (mg/L)			0.044	0.050	0.033	0.037	0.006	<0.010	0.010			
TDN (mg/L)											0.347	
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	
SRP (mg/L)	0.001	0.002	0.001	<0.001	0.001	0.002	<0.001	0.002	0.001		0.001	
TDP (mg/L)												
TN : TP (mass)	34.2	36.6	27.9	22.6	26.3	40.3	30.3	26.7	36.9	40.4	26	
# of Samples	6/3	6/3	6	6	6	6	6	6	6	3	6	6

Appendix 1 (continued).

A note on Secchi depths: as the lake depths vary over time, when the Secchi depth rests on the lake bottom and is still visible, this is recorded on the table below as a yes.

White Lake Monitoring Project 2019

	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 Total Biovol. (mm3/m3)					12,128					
Mean Algal Density (# cells/mL)		17,164	15,665		38,001		65,604			
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
TN : TP (mass)		17.9	23.6	34.4	41.1	20.3	32.7	26.7	31.3	32.1
# of Samples	3	6	6	6	6	6	6	6	6	6

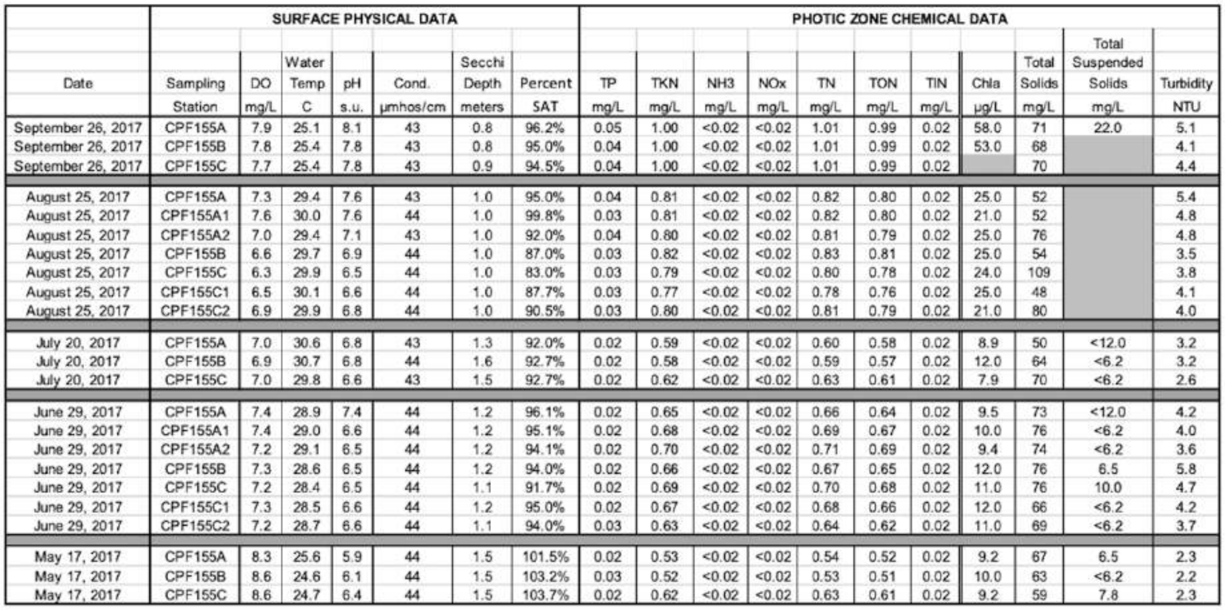
Appendix 1 (continued).

White Lake Monitoring Data—May 2, 2018 (pre-alum treatment)

pH range = 9.12-9.62
Mean Secchi Depth = 0.5 m
Total P = 0.09 mg/L (DEQ data from same day, mean 0.06 mg/L)
Soluble P = 0.05 mg/L (DEQ does not measure Sol. P or SRP)
Mean TKN = 1.2 mg/L
DIN below detection limits
Mean chlorophyll a = 52 µg/L
Mean Total Biovolume = 151,563 mm^3/m^3 (95% cyanobacteria)
Mean # cells/mL = 12,617,892

White Lake Monitoring Data—DEQ 2017

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

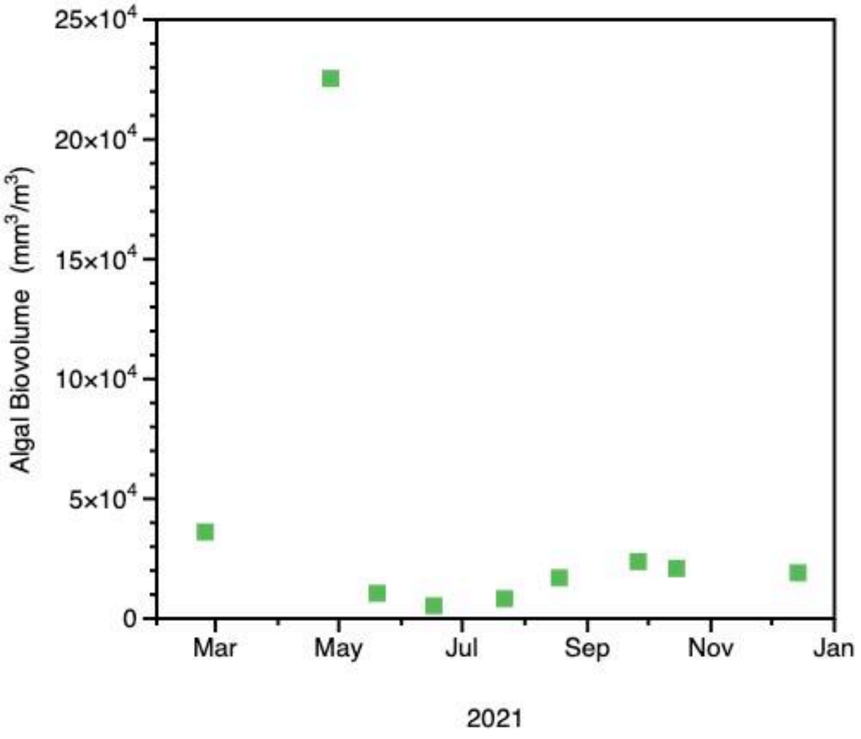


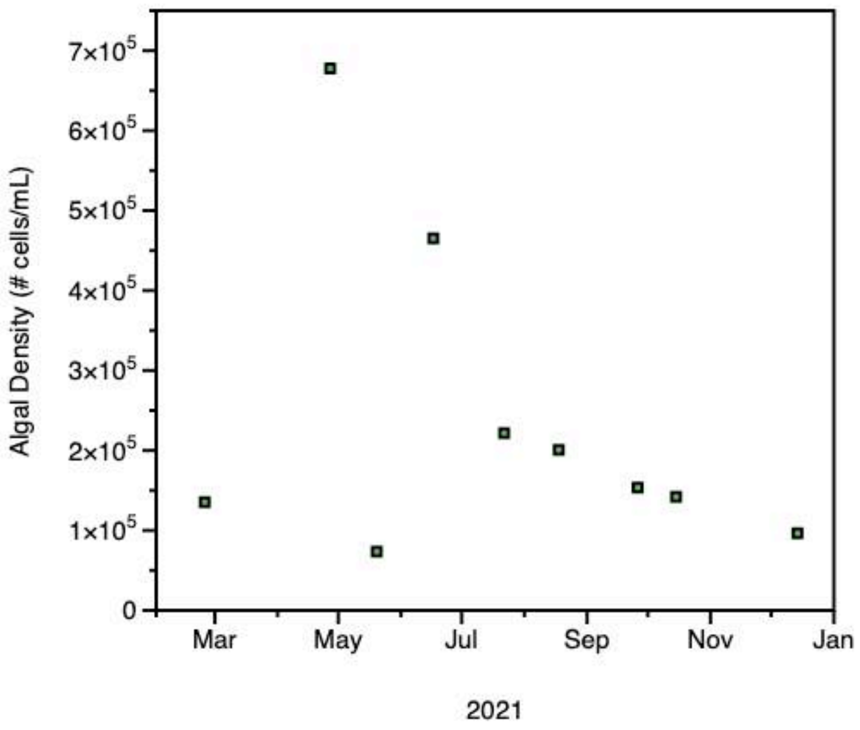
	SURFACE PHYSICAL DATA							PHOTIC ZONE CHEMICAL DATA										
Date	Sampling Station	DO mg/L	Water Temp C	pH s.u.	Cond. µmhos/cm	Secchi Depth meters	Percent SAT	TP mg/L	TKN mg/L	NH3 mg/L	NOx mg/L	TN mg/L	TON mg/L	TIN mg/L	Chla µg/L	Total Solids mg/L	Total Suspended Solids mg/L	Turbidity NTU
September 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).

Appendix 2. White Lake phytoplankton Biovolumes and Cell Densities, 2018 and 2020-2021.

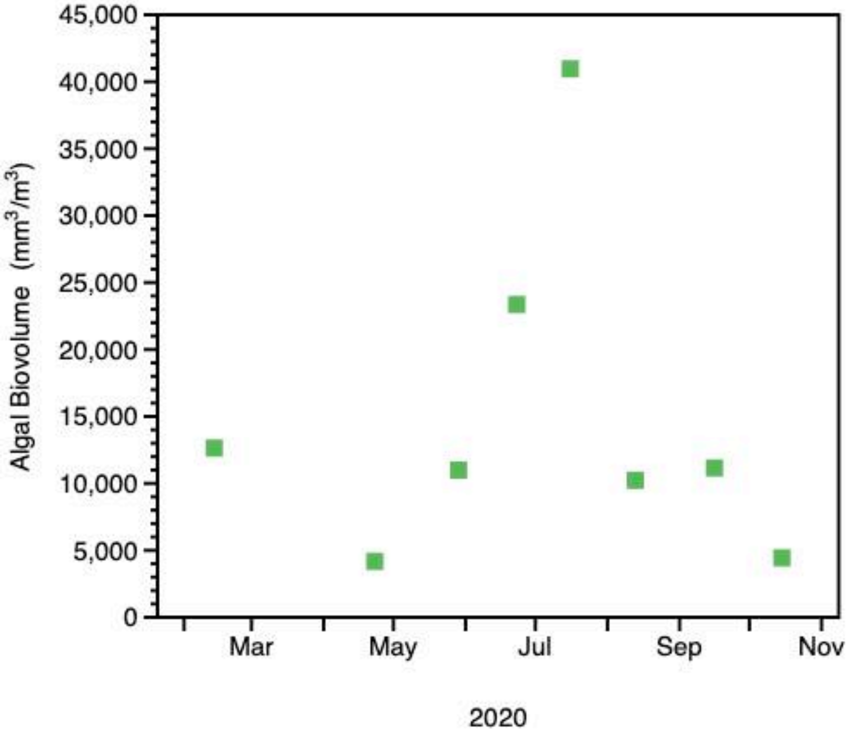
White Lake Phytoplankton Biovolumes and Densities--2021

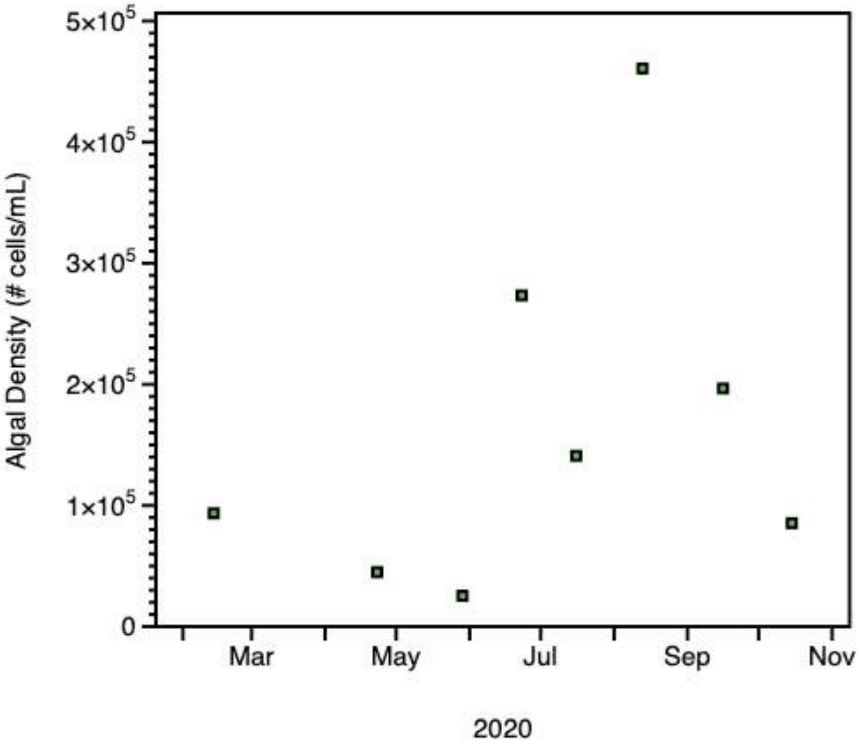




Appendix 2 (continued).

White Lake Phytoplankton Biovolumes and Densities—2020

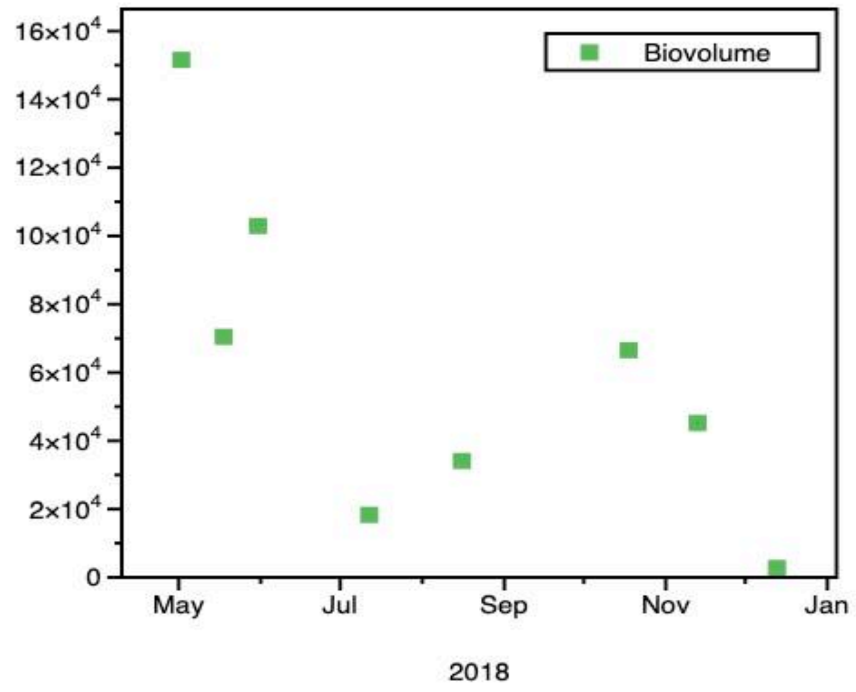


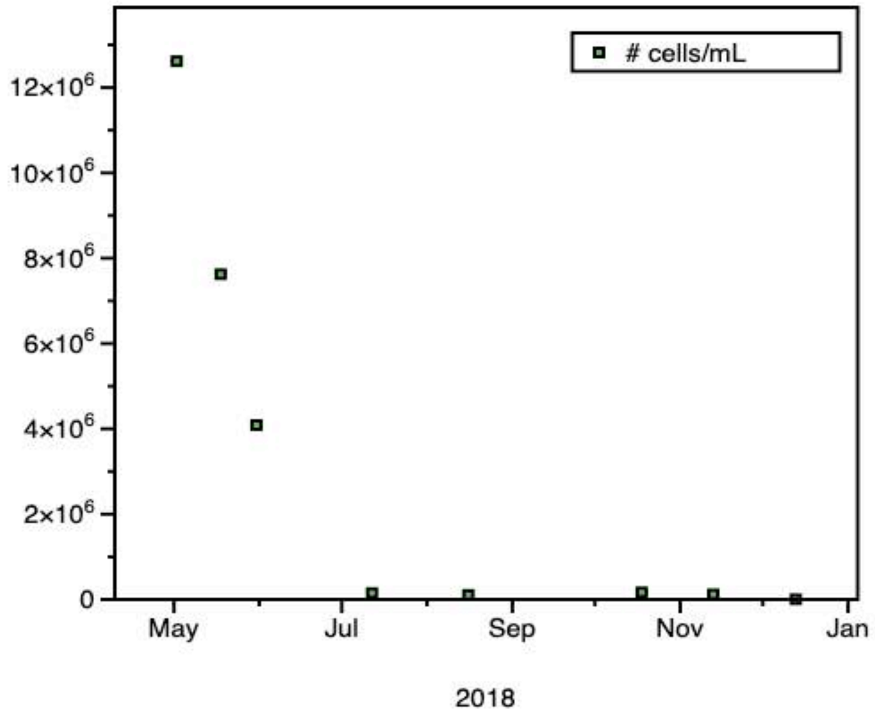


Appendix 2 (continued).

White Lake Phytoplankton Biovolumes and Densities—2018

Pre-treatment sampling May 2; alum treatment May 3-16
Hurricane Florence in September





Appendix 3. White Lake cyanobacterial taxa lists for 2018-2021.

White Lake Cyanobacteria Taxa 2021

	2/25/21	**4/27/21**	**5/20/21**	**6/17/21**	**7/22/21**	**8/18/21**	**9/26/21**	**10/15/21**	**12/14/21**
Synechococcus	x	x	x	x	x	x	x	x	x
Aphanocapsa delicatissima	x	x	x	x	x	x	x	x	x
Aphanocapsa incerta				x	x	x			x
Aphanocapsa sp.	x	x	x	x	x	x	x	x	x
Borzia sp.	x	x	x	x	x	x	x	x	x
Chroococcus aphanocapsoides	x	x	x	x	x	x	x	x	x
Aphanothece sp.	x	x	x	x	x	x	x	x	x
Planktolyngbya crassa	x	x	x	x	x	x	x	x	x
Planktolyngbya limnetica		x	x	x	x	x	x	x	x
Planktothrix isothrix							x		
Limnococcus sp.		x							
Cyanoganis ferriginea	x	x		x	x	x	x	x	x
Pseudanabaena limnetica		x	x	x			x	x	x
Jaaginema sp.	x	x	x	x	x	x			
Planktothrix sp.									
Aphanizomenon sp.	x	x	x	x	x	x	x	x	x
Cylindrospermopsis phillipinensis		x							
Cylindrospermopsis raciborskii					x	x	x	x	x
Komvophoron sp.						x	x	x	x
Sphaerospermopsis aphanocapsoides			x		x				
Total Cyanos = 19									

Appendix 3 (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 = 18								

Appendix 3 (continued).

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			
Dolichospermum sp.				x
Total # Taxa	**7**	**4**	**4**	**10**
Total Cyanos = 12				

Appendix 3 (continued).

White Lake Cyanobacteria Taxa 2018

	5/2/18	5/18/18	5/31/18	7/12/18	8/16/18	10/17/18	11/13/18	12/13/18
Synechococcus	x	x	x	x	x	x	x	x
Aphanocapsa delicatissima		x						
Aphanocapsa sp.						x	x	
Aphanothece sp.								x
Chroococcus aphanocapsoides	x		x	x				
Raphidiopsis curvata	x			x	x	x		
Limnococcus sp.	x							
Planktolyngbya sp.	x	x	x	x	x	x		x
Romeria chlorina	x							
Trichodesmium lacustre	x			x				
Cuspidothrix sp.	x							
Geitlerinema sp.	x	x						
Pseudanabaena limnetica			x	x	x			
Jaaginema sp.		x	x	x	x			
Merismopedia tenuissima					x			
Aphanizomenon sp.	x	x						
Cylindrospermopsis phillipinensis	x			x	x		x	
Limnolyngbya circumcreta				x	x			
Total Cyanos = 17								