White Lake, Bladen County, NC

Lake Monitoring Results 2023



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Introduction

White Lake is a unique and valuable resource that has undergone changes due to human activities. There are, however, several fundamental attributes of White Lake that have not changed over time:

- It is a small and very shallow Bay lake (a lake type described in Frey 1949). The maximum depth is less than 3 meters, with a mean depth of less than 2 meters.
- It is well-mixed, and water temperatures can change quickly. The growing season extends through most of the year.
- Roughly half of the lake bottom is muddy sediments (Frey 1949), with sandy sediments found in the shallow perimeter of the lake.
- It is a rain basin, or seepage lake, as there is no natural surface water inlet to the lake. Rainfall on the lake surface is the primary source of water with groundwater being a secondary source.
- The clarity of the lake water is due to the minimal influence of wetlands (whereas the other Bay Lakes are wetlands-influenced, blackwater systems) and to the natural water flow patterns east to west.

Understanding what has changed (and why) has been a focus of recent study of White Lake. Lake chemistry (pH in particular) and productivity have changed since 2008, with phytoplankton blooms (2013 and 2017-18) and the presence of the invasive aquatic weed hydrilla in most of the lake (in 2017). Special projects that have been conducted in recent years include:

- May 2018 Alum Treatment: The treatment was done to mitigate the 2017-2018 filamentous cyanobacterial bloom, which had caused pH levels to spike rapidly (to 9+, which denotes impaired waters) by the time the treatment was initiated; the extreme conditions resulted in a fish kill, which subsided as the treatment lowered pH to pre-bloom levels.
- o NCSU 2019-2020: Propagation of a rare aquatic plant found in the lake, and an assessment of herbicide effects on it, in the event that herbicide treatment of hydrilla would be needed.
- <u>Lauritsen et al. 2019</u>: Sediment phosphorus analysis, and comparisons with Lake Waccamaw. Aluminum-bound phosphorus is the dominant fraction with iron-bound phosphorus secondary in the muddy sediments of both lakes.
- Shank and Zamora 2019: Development of a groundwater model, delineation of the groundwatershed, confirmation that rainfall on the lake surface is the primary source water for the lake, and confirmation that the surficial aquifer is the source of the springs.
- o Consolvo 2022: A geohydrological assessment of groundwater flow in the area, and confirmation that the semi-confined surficial aquifer is the source of the springs.
- o <u>Lumber River Council of Governments 205(j) Grant 2018-2020:</u> Assessment of stormwater outfalls to the lake, rainfall nutrient monitoring, and winter waterfowl counts.
- <u>Lumber River Council of Governments 2022:</u> Lake Management Strategic Plan, Town of White Lake. Included land use strategies and a draft stormwater ordinance to facilitate lake stewardship.

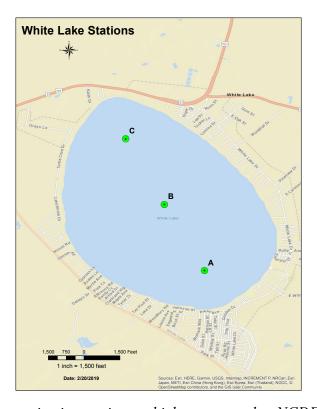
The Town of White Lake has also invested \$5 million in its wastewater collection system since 2019.

White Lake water quality monitoring has been conducted for the past six consecutive years (2018-2023). The 2021 White Lake Monitoring report (LIMNOSCIENCES 2022, available at www.whitelakewatch.com, along with a quality assurance QAPP document and other annual reports) was developed as a comprehensive review document which includes data from most of the special projects as well as monitoring data from previous years and a literature review.

This 2023 monitoring report focuses primarily on the data collected for the year, including:

- Lake levels, rainfall, and physical-chemical parameters
- White Lake's nutrient levels, including comparisons with nearby Singletary Lake
- The productivity of the lake and its variability over time

The Town of White Lake has provided financial support for special studies and lake monitoring work, while personnel from the Singletary Lake office of NC State Parks have provided logistical assistance. Dr. Linda Ehrlich, with Spirogyra Diversified Environmental Services, has provided detailed taxonomic work on phytoplankton abundance and biovolumes (which was completed in July 2024, so this latest version of the report now includes that data). No aquatic vegetation sampling was conducted in 2023.

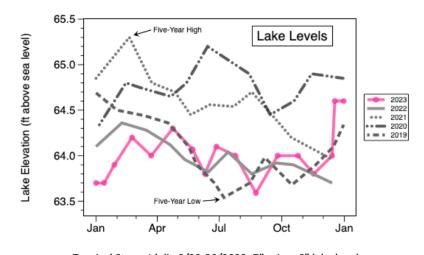


White Lake monitoring stations, which correspond to NCDEQ stations

Results

1. Lake Levels Highest in December, Two Large Rain Events in 2023

Lake elevations hovered around 64 feet (NAVD 88 datum) for much of the year, with a total variation low to high of 12 inches (Fig. 1). The five-year (2019-2023) mean high-water level is 64.8 feet NAVD 88. Total annual rainfall was 10% above the long-term average for the region in 2023, with large rain events occurring in August (Tropical Storm Idalia) and December (Winter Storm Finn)(Table 1).



Tropical Storm Idalia 8/29-30/2023, 7'' rain, +6'' lake level Nor'easter storm 12/17/2023, 7'' rain, +7.2'' lake level

Figure 1. A comparison of Lake Levels in White Lake for 2019-2023. The 2023 high was measured on December 18, while the low, 63.6 ft, was seen on August 28 (elevation reported in feet above sea level, NAVD 88 datum).

Table 1. White Lake monthly rainfall, in inches, measured at the Town WWTP (the long-term monthly averages were determined for Elizabethtown).

Monthly Rainfall (inches) for White Lake 2012-2023												
Month	2023	2022	2021	2020	2019	2018	2017	2016	2015	2013	2012	Monthly Average for Region
January	4.3	5.75	8.25	4.5	2.75	4.20	7.0	3.0	2.5	1.75	2.75	3.81
February	3.6	1.0	9.2	6.7	2.25	2.00	1.5	10.7	5.5	2.5	4.0	3.44
March	2.5	2.45	2.7	3.7	3.25	3.95	3.7	1.55	4.15	1.0	7.0	3.91
April	8.5	3.75	1.75	5.1	7.25	6.75	6.75	6.75	4.55	1.75	2.25	3.12
May	1.5	2.2	3.0	12.25	1.20	7.70	2.7	4.5	4.20	2.25	9.25	3.67
June	6.3	6.2	7.9	7.15	5.25	10.00	4.5	3.65	8.70	17.0	2.0	4.70
July	3.8	10.5	7.5	6.85	6.00	4.75	6.75	3.75	3.0	11.25	8.6	5.75
August	7.5	5.5	6.5	7.55	5.35	6.25	5.6	4.12	9.4	8.25	9.75	5.95
September	3.05	6.5	3.2	5.95	5.00	29.45	5.2	15.0	4.7	1.0	5.0	5.29
October	1.75	0.6	0.6	3.35	3.60	2.25	2.95	14.25	9.75	1.75	2.25	3.38
November	3.25	1.55	0.4	7.5	4.90	4.25	1.0	0.50	7.25	0	2.25	3.16
December	8.5	1.2	3.4	4.25	6.00	7.5	5.45	5.1	6.5	5.75	4.25	3.14
Total	54.55	47.2	54.4	74.85	52.80	89.05	53.1	72.87	70.20	54.25	59.35	49.32
% of Lake Volume	71.4	61.8	71	97	69	116	69	95	91	70	77	64

The total variation in lake levels over the five-year period was 21 inches (Fig. 2), which is equivalent to what has been measured historically (e.g., Fig. 3).

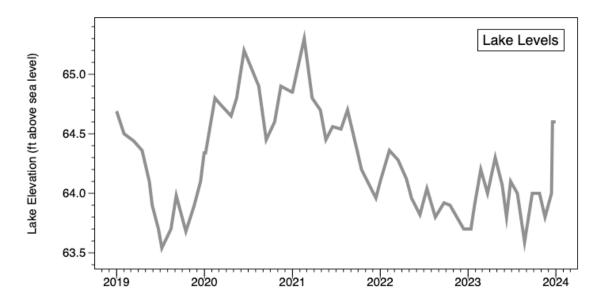


Figure 2. White Lake elevations for the period 2019-2023 (elevation reported in feet above sea level, NAVD 88 datum).

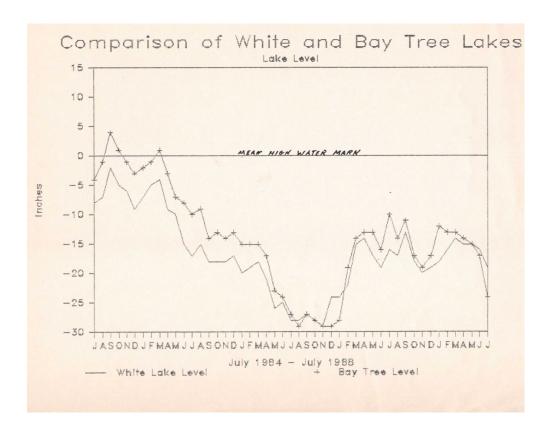


Figure 3. White Lake and Bay Tree lake levels measured by NC State Parks personnel 1984-1988.

2. Rainfall pH Continues to Increase

Improvements in air quality that have reduced acidic SO_x and NO_x emissions have eliminated acid rain across the continent in recent years, including at White Lake, so that the baseline pH of the rainfall and lake water has increased 1.5 units (Fig. 4 and 5). Human activity such as intensive confined agriculture can create nitrogen emissions which also affect the pH of the rain (ammonia is a strong base) as well as providing bioavailable nitrogen which can stimulate phytoplankton growth. The median annual pH level at a nearby National Atmospheric Deposition Program monitoring station was above 6 for the first time in 2022, (the most recent year that data is available; Fig. 5).

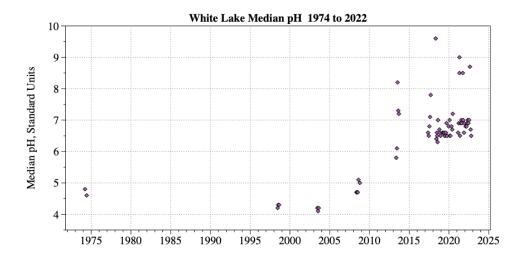


Figure 4. White Lake median pH (SU) levels from 1974 (data from Weiss and Kuenzler 1976) to 2022 (1998-2017 data from NCDEQ, 2018-2022 data from LIMNOSCIENCES).

Site NTN NC35



Figure 5. Median annual pH (SU) at the Clinton Crops Research Station in Sampson County (NC35). NADP web site, https://nadp.slh.wisc.edu/sites/ntn-NC35/ accessed 1/14/24.

3. Lake Clarity Lowest in July

Lake clarity, as measured by Secchi depth, was greater than 1.5 meters in early summer and in fall-early winter, with the lowest measurement (1.0 m) found in July (Fig. 6). Turbidity was slightly higher in July (2.7 NTU) as well (Fig. 7).

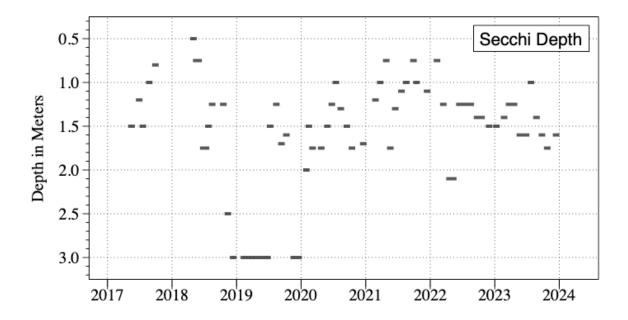


Figure 6. White Lake water clarity (in feet), as measured with a Secchi disk, from 2017 (NC DEQ data) through 2022 (LIMNOSCIENCES data for 2018-present).

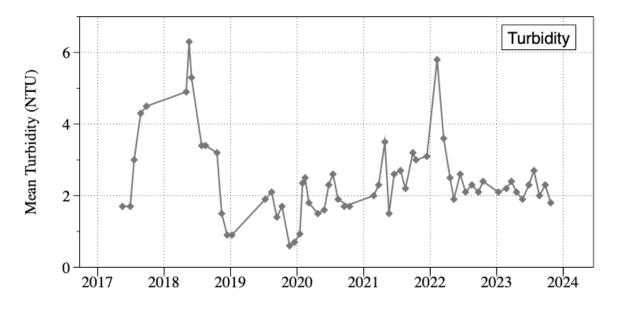


Figure 7. White Lake turbidity (in NTU), from 2017 (NC DEQ data) through 2022 (LIMNOSCIENCES data for 2018-present).

Nearshore clarity was also lower in summer in the areas where sediments and organic material stirred up from the bottom washes ashore (Fig. 8).





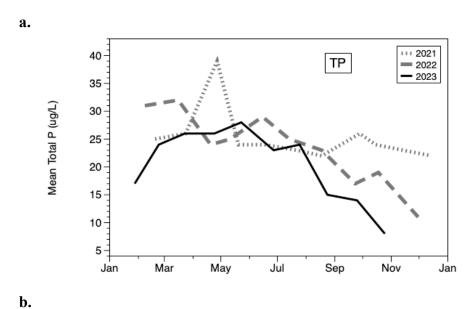
Figure 8. White Lake southwestern shoreline at Lake Place condos (top photo) and at Nathan's Cove, where a barrier was installed (bottom photo), August 24, 2023. The barrier was dislodged by the storm at the end of August.

4. White Lake Nutrient Levels Show Seasonal Variability

Of the 10 months in which nutrient sampling was conducted in 2023, Total Phosphorus (TP) levels were below 20 μ g/L in four of them (also, winter and fall months had lower TP levels compared to the previous two years), with the highest monthly mean found in May (28 μ g/L) and the lowest in October (8 μ g/L) (Fig. 9a, Appendix 1). Soluble reactive phosphorus (SRP) levels were at or below detection limits (1 μ g/L) for 8 months with the highest mean found in June (3 μ g/L; Appendix 1).

Total Nitrogen (TN) levels in 2023 showed a similar general trend as in 2022, with the lowest levels found from September onward (Fig. 9b). Dissolved inorganic nitrogen (DIN) was the highest in May (36 μ g/l, comprising 6% of Total Dissolved N (Appendix 1.)

Ratios of TN/TP (mass) varied from 21.3 in March to >50 in January, August, and October (Appendix 1).



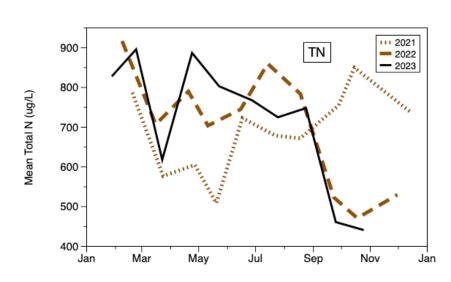


Figure 9. White Lake monthly means for a) Total Phosphorus (TP); and b) Total Nitrogen (TN) for the three-year period 2021-2023. All parameters reported as μ g/L.

Dissolved Organic Carbon (DOC) levels can vary considerably from month to month in White Lake, and in 2023, the highest levels were measured in March, September, and October (Fig. 10, Appendix 1.) Note that the graphs for TN and TP show units as $\mu g/L$, while the graph for DOC shows units as mg/L.

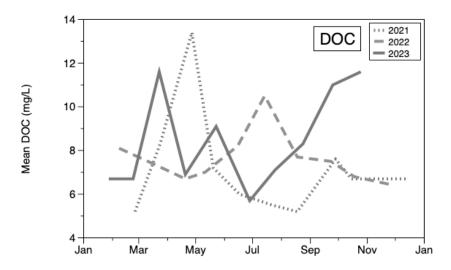


Figure 10. White Lake monthly means for Dissolved Organic Carbon (DOC) for the three-year period 2021-2023, reported as mg/L.



Eastern shoreline of White Lake, February 23, 2023

5. Phytoplankton and pH

In White Lake, the trends in phytoplankton biomass (as measured by chlorophyll *a* levels) have been similar since the 2017-2018 cyanobacterial bloom, with late winter-early spring peaks in some years (e.g., 2021) and mid-late summer peaks commonly (Fig. 11a) A comparison of chlorophyll *a* data using two methods, 1) laboratory analysis of samples, and 2) field measurements with a handheld Turner fluorometer, found generally good agreement between the two, and in December only field data was collected (Fig. 11a). The pH levels mirror chlorophyll levels, with both higher in the summer months (June-August) in 2023 (Fig. 11a, b).

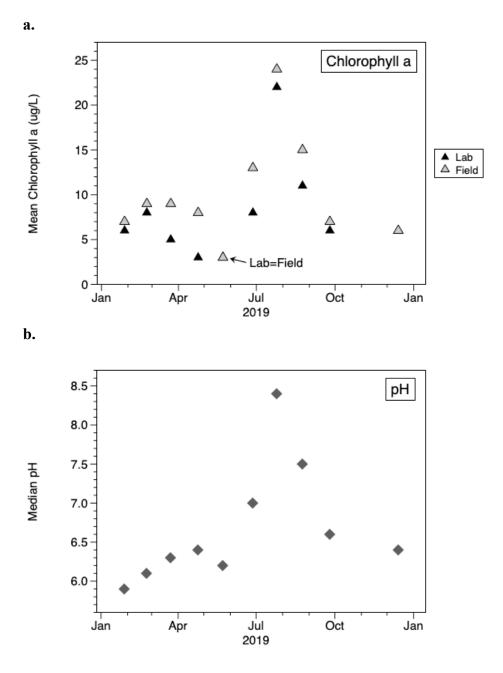


Figure 11. White Lake 2023 data for a) mean chlorophyll a ($\mu g/L$)(field measurements were taken with a handheld fluorometer); and b) median pH (SU). January-March pH was measured by the analytical lab due to servicing of the YSI Pro DSS field meter.

Biovolume measurements are more accurate assessments of phytoplankton community dynamics in White Lake, and they do not always match the chlorophyll *a* trends, as was seen again in 2023. The highest biovolumes were seen in February and April, consisting primarily of the desmid *Cosmarium tinctum*, while a smaller biovolume peak was seen in July-August, consisting primarily of the desmid *Staurodesmus dejectus v. apiculatum* (Fig. 12).

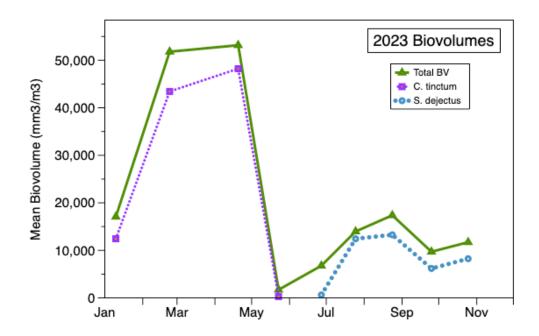


Figure 12. White Lake 2023 mean total phytoplankton biovolume (BV as mm³/m³) in green, with mean biovolume of the desmids *Cosmarium tinctum* (purple) and *Staurodesmus dejectus v. apiculatum* (blue).

Total cyanobacterial biovolume was below 1% of total biovolume in eight of the nine months sampled; in September mean total cyanobacterial volume was 185 mm³/m³, which was 1.8% of total biovolume (9,710 mm³/m³ [Appendix 1]).



The Lilly III at White Lake, circa 1970s

Comparisons of the White Lake phytoplankton community in the month of July provide a snapshot of summer conditions over time; the data show that desmids (Charophyta) have dominated the biovolume since 2017 (Table 2). The first documented phytoplankton bloom in White Lake occurred in July 2013, after a large amount of rain in June-July (Table 1); this was the first time that pH levels above 8 were seen, but the elevated levels did not persist once the bloom (dominated by an "unidentified green alga") dissipated (Fig. 4, NCDEQ 2014). In July 2023, the pH levels were above 8, but dropped below 7 by September (Fig. 11b).

Table 2. White Lake phytoplankton data comparisons for the month of July, from 2013 to 2023 (2013-2017 data from NC DEQ; 2018 to 2023 data from LIMNOSCIENCES, with algal identifications by Dr. Linda Ehrlich, with Spirogyra Diversified Environmental Services).

A Comparison of White Lake Algae Data for July, From 2013-2023											
	2013	2016	2017	2018	2019	2020	2021	2022	2023		
Secchi Depth (m)	1.25	ND	1.5	1.75	1.5	1.0	1.2	1.25	1.0		
Turbidity (NTU)	4.3	2.0	3.0	1.9	1.9	2.6	2.7	2.1	2.7		
Chl a (µg/L)	27.7	6.2	9.6	6	8.5	9.7	4.9 (11)	6.5 (9.8)	22 (24)		
Algal Cells/mL	114,533	45,433	241,873	150,643	38,033	169,176	221,699	34,488	105,308		
Dominant Taxa (#cells/mL)	Unidentified green (99%)	Planktolyngbya (95%)	Planktolyngbya (79%)	Synechococcus (52%)	Synechococcus (36%) Staurastrum (34%)	Staurodesmus (43.6%)	Aphanocapsa (37%) Planktolyngbya (32%)	Synechococcus (42%) Planktolyngbya (13%)	Planktolyngbya (71% Staurodesmus (21%		
Algal Biovolume (mm³/m³)	28,400	1,400	1,967	18,307	12,128	40,965	8,297	1,011	13,974		
Dominant Taxa (Biovolume)	Unidentified green (99%)	Planktolyngbya Peridinium	Gonatozygon (53%)	Staurastrum (79%)	Staurastrum (61%)	Staurodesmus (82%)	Cosmarium (21%) Staurastrum (15%)	Cosmarium (23%)	Staurodesmus (89%		
pH Range (su)	8.0-8.3	6.3-6.7	6.6-6.8	6.5-6.9	6.5-6.6	6.9-7.0	6.9-7.3	6.9-7.0	8.3-8.5		

NCDEQ reported turbidity as µmhos/cm and LIMNOSCIECES reported turbidity as NTU

6. Nutrient and Phytoplankton Comparisons Between White Lake and Singletary Lake

The earliest nutrient data for the Bay Lakes was collected in 1974-1975, as part of a statewide survey of lakes and reservoirs (Weiss and Kuenzler 1976). Samples were collected in February and June in each year for most of the lakes, although White Lake was sampled only in 1974. Comparison tables with June data for both White Lake and Singletary Lake show the same trend of increased TN compared with 1974 data, resulting in higher TN:TP mass ratios in recent years. Total Phosphorus (TP) levels have not changed substantially in either lake over time; TP levels are generally higher in Singletary Lake compared to White Lake. In June 2023, Soluble Reactive Phosphorus (SRP) constituted 47% of TP in Singletary Lake, and 13% in White Lake (Table 3 and 4).

Table 3. White Lake monitoring data comparisons for the month of June, from 1974 (Weiss and Kuenzler 1976), to 2023 (2003-2017 data from NC DEQ; 2018 to 2023 data from LIMNOSCIENCES). The 2017-2018 filamentous cyanobacterial bloom is denoted by the green line on the data table; June 2018 sampling took place 6 weeks after a water column P-stripping alum treatment was completed.

White Lake Monitoring Data Collected in June, From 1974 to 2023

	<u>1974</u>	2003	<u>2013</u>	<u>2017</u>	<u>2018</u>	<u>2019</u>	<u>2020</u>	<u>2021</u>	2022	2023
Mean Temperature (°C)	26.1	27.6	27.5	28.6	30.2	29.0	27.5	28	29.6	28.3
Mean Secchi Depth (m)	>3.0	2.6	2.8	1.2	1.75	>3.0	1.25	1.25	1.25	1.6
Turbidity (NTU)	3**			4.3			2.3	2.6	2.6	2.3
Mean Chlorophyll a (μg/L)	13 [*]	5	2.5	10.7	8	5.5	6.4	9.4 (7.5)	3.4 (6.2)	8.3(13)
Mean Biovolume (mm₃/m₃)	156				18,318	12,128	23,360	5,316	657	6,769
pH Range (std. units)	4.6	4.2	6.0-6.8	6.5-7.4	6.6-7.3	6.2-6.7	7.1-7.3	6.8-7.0	6.7-6.9	6.7-7.2
Mean Dissolved Oxygen (mg/L)	8.6	8.0	7.0	7.3	7.6	7.9	8.6	7.8	8.1	8.8
Mean Total Nitrogen (mg/L)	0.211	0.11	0.39	0.68	0.50	0.481	0.757	0.870	0.745	0.768
Mean NO₃-NO₂ (mg/L)	0.011			<0.02	<0.02	<0.010	0.013	<0.010	<0.010	<0.010
Mean NH3-NH4 (mg/L)	0.038			<0.02			0.006	0.014	0.010	<0.010
Mean Total Phosphorus (mg/L)	0.017	<0.02	<0.02	0.02	0.02	0.014	0.025	0.031	0.029	0.023
Mean SRP (mg/L)	0.016					<0.001	<0.001	<0.001	<0.001	0.003
TN/TP (mass)	12.4			34	25	34.4	30.3	28.1	26.0	33.4
# of Samples		3	3	7	7	6	6	6	6	6

NCDEQ reported conductivity as µmhos/cm and LIMNOSCIECES reported conductivity as y as NTU Weiss and Kuenzler (1976) reported chlorophyll a as Turner units (denoted with an asterisk) and turbidity as JTU

Dissolved Organic Carbon (DOC) levels are generally higher in blackwater systems such as Singletary Lake compared to clearwater systems such as White Lake, but at times, DOC levels can be higher in White Lake than in Singletary. February 2023 DOC levels were 11.7 mg/L in Singletary, June DOC was 12.3 mg/L, and September DOC was 10.6 mg/L, while in White Lake, February levels averaged 6.67 mg/L, June was 5.72 mg/L and September DOC was 11.0 mg/L (Appendix 1 and 2).

Table 4. Singletary Lake monitoring data comparisons for the month of June, from 1974 (Weiss and Kuenzler 1976), to 2023 (2013 and 2018 data from NC DEQ; 2021 to 2023 data from LIMNOSCIENCES).

	1974	2013	2018	2021	2022	2023
Temp (oC)	25.6	27.9	30.4	29.1	29.2	31.4
Secchi Depth (m)	0.9	0.70	0.4	0.25	0.5	0.6
Turbidity (NTU)	8 (JTU)	9.1	8.6	2.6	3.9	4.4
DO (mg/L)	8.5	8.7	7.7	7.3	6.36	8.19
DO % saturation		111	102	95	83	11
Conductivity (µS/L)	58*	72*	54*			52.
Sp. Cond. (µS/L)				34.5	26	
pH (su)	4.2	5.6	4.2	4.3	4.3	4.2
Chlorophyll a (µg/L)	34**	10	12	11 (14)	11(10)	12(11
hytoplankton Biovolume (mm3/m3)	908			4,127	2,448	27,00
Phytoplankton Density (# cells/mL)	430			17,156	14,140	30,13
DOC (mg/L)				19.6	15.2	12.
Total N (mg/L)	0.306	0.43	0.76	0.881	0.625	0.64
NO3-NO2 (mg/L)	0.031	<0.02	0.12	0.101	<0.010	0.01
NH4-NH3 (mg/L)	0.020	0.02	<0.02	0.036	0.059	<0.01
TDN (mg/L)				0.623	0.624	0.45
Total P (mg/L)	0.022	0.03	0.04	0.038	0.030	0.03
SRP (mg/L)	0.008			0.030	0.022	0.01
TN : TP (mass)	13.9	14.3	18.3	23.2	20.8	17.

NCDEQ reports turbidity as µmhos/cm and LIMNOSCIECES reports conductivity as µS/L Weiss and Kuenzler (1976) reported chlorophyll a as Turner units and turbidity as JTU

Despite the lower water clarity and pH, phytoplankton biomass (as measured both by chlorophyll *a* levels and algal biovolume calculations) can be higher in Singletary Lake than in White Lake (Fig. 13), although diversity is much lower in Singletary (e.g., LIMNOSCIENCES 2023). In June 2023, the desmid *Closterium gracile* (55%) and cryptomonads (28%) dominated Singletary biovolume, while in White Lake, the desmid *Staurodesmus dejectus v. apiculatum* comprised 30% of biovolume.

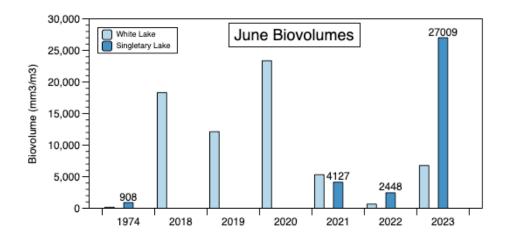


Figure 13. Phytoplankton biovolume (mm³/m³) comparisons between White Lake and Singletary Lake in the month of June, 1974-2023 (data from Table 3 and Table 4).



Singletary Lake is an acidic blackwater lake with an undeveloped shoreline which is sampled as a reference lake.

7. Benthic/Floating Algal Flocs Found Again in 2023

The individual cells of the cyanobacterial taxon *Aphanothece* contain polyphosphate granules, which are distinctive phosphorus storage particles (e.g., Sanz-Luque et al. 2020). Polyphosphate accumulating organisms, or PAOs, can thus be important in phosphorus removal in aquatic ecosystems or wastewater systems (where they are introduced), as they can accumulate large amounts of intracellular polyphosphate (Chen et al. 2020, referenced in Trebuch et al. 2023). The relative abundance of this cyanobacteria in White Lake (since 2022 and in decades past; Fig. 14) is another example of the fierce competition for nutrients by primary producers.

It is likely that these cyanobacteria colonies could limit submerged aquatic vegetation growth at times when they form a dense floc in the deeper benthic zone of White Lake.



Individual colonies of Aphanothece stagnalis are large enough to distinguish with the naked eye



Figure 14. Colonial cyanobacteria identified as *Aphanothece stagnina*. Small cells are embedded in a mucilaginous matrix, which allows them to float to the surface and clump together. Flocs generally appear more frequently around the marina boat landing on the northern shore of the lake and along the western shore.

8. Bass Fishing Tournaments

A weekly bass fishing tournament was organized in April 2023, and continued until mid-September (it is one of several that utilize the lake). Results were posted on a Facebook group page and have been summarized from that source (Table 5). Many weeks the biggest fish (BF) was over 5 pounds. Schools of small forage fish and a variety of sizes of largemouth bass can be observed in shallow areas of the lake.

Table 5. White Lake Thursday Bass Tournament participation and results from 2023.

White Lake 2023 Thursday Night Bass Tournaments

			•	
Date	# Boats	# People	BF (lbs)	Comments
April 13	13	23	4.83	
April 20	19	36	5.45	2 fish > 5
April 27	22	41	4.85	
May 4	20	35	4.95	
May 11	26	46	5.65	5 fish >5
May 18	33	62	5.85	2 fish >5
May 25	31	59	5.2	
June 1	38	72	5.5	28 fish in weigh in; "a lot of new people"
June 8	47	89	5.55	
June 15	46	86	5.25	23 fish in weigh in
June 22	36	64	5.4	25 fish in weigh in
June 29	50	90	6.35	17 fish in weigh in
July 6	46	84	5.45	
July 13	36	66	4.95	
July 20	26	53	5.85	
July 27	31	55	4.60	
August 3	37	59	4.60	
August 10	18	30	4.30	
August 17	24	39	5.15	
August 24	21	34	3.30	
August 31	Cancelled			Hurricane/Tropical Storm Idalia, 7" rain
September 7	12	20	5.25	
September 14	21	37	4.50	



Summary

- 1. While total annual rainfall was only slightly above normal, there were several months with little rain and two very large rainfall events in 2023. As a result, the total annual variation (low to high) in lake level was very similar to what has been seen historically.
- 2. Flushing of the lake does not occur in the same way that it does in drainage lakes with significant surface inflow and outflow. Water loss is a result of evaporation and groundwater seepage (Shank and Zamora 2019) as groundwater flows through the lake (which can influence nitrogen dynamics, e.g., Stoliker et al. 2016). The small outlet at Turtle Cove should be maintained as a flood control device (which is why and how it was designed), as it does not serve to either regulate lake levels or facilitate flushing of the lake.
- 3. Natural processes can help regulate nutrient levels. Incorporation of nutrients into the aquatic food web—microscopic to macroscopic life—and chemical transformations such as denitrification (e.g., Qin et al. 2020) influence the availability of water column nutrients.
- 4. White Lake has always been a relatively productive lake, with most of the productivity associated with the lake bottom, as the sediments are a source of nutrients. Variability in the relative abundance of bottom algae/cyanobacteria and/or aquatic vegetation both seasonally and annually has been substantial both historically and recently. In 2022 and 2023, benthic/pelagic cyanobacterial flocs were abundant in the summer and fall, and this material may serve as a rich food supply for invertebrates such as grass shrimp, and fish.
- 5. White Lake nitrogen levels are substantially higher than historical levels (the same is true in Singletary Lake), and levels can vary considerably from month to month, with the lowest levels generally found in October. Rainfall is a significant source of both organic and inorganic nitrogen to the lake. Inorganic nitrogen fluxes to the biosphere from agricultural activities have increased five-fold in the past sixty years (Battye et al. 2017). The increase has been even more dramatic in the region around White Lake (as measured at the Clinton NADP monitoring station [NC35]). Using 2022 NADP data as an example, the annual deposition of DIN (NH_x and NO_x) in 2022 totaled 9.257 kg/ha (a map of ammonium wet deposition for 2022 is included in the appendix). So, for White Lake, at an area of 836.485 ha, this loading is equivalent to 7,743.3 kg of DIN to the lake from rainfall in 2022. Dry deposition of N can also be high in this region (e.g., Wiegand et al. 2022).
- 6. Water column phosphorus levels in White Lake are equivalent to historical levels, except during phytoplankton blooms (e.g., the 2017-2018 cyanobacteria bloom and the desmid bloom in Feb.-April 2021).
- 7. As a result of atmospheric nitrogen deposition, the N:P ratios in White Lake have changed substantially (this has been seen in many lakes around the world [e.g., Bergström and Jansson 2006, Li et al. 2016]) with P now the primary growth-limiting nutrient.
- 8. There are several natural means for sequestering P in White Lake: the P-binding capacity of aluminum found in the muddy sediments, and primary producers such as cyanobacteria, which have strategies for excess, or luxury P storage (e.g., Xiao et al. 2022). Very small cyanobacteria (picoplankton) are often numerically dominant in White Lake, and Canadian

- researchers have found that picocyanobacteria abundance is much higher in oligotrophic to mesotrophic lakes with lower total phosphorus levels (Lavallée and Pick 2002).
- 9. Other life forms in White Lake that are adapted to low-nutrient conditions include the carnivorous bladderwort *Utricularia purpurea* (which utilizes the nutrients in its prey) as well as the colonial cyanobacteria *Aphanothece stagnalis*.
- 10. White Lake's phytoplankton community continues to be healthy and quite dynamic, with general trends including the dominance of desmids (different desmid taxa may dominate at different times), slight increases in phytoplankton diversity, and low filamentous cyanobacterial biovolume since the 2018 alum treatment.
- 11. Singletary Lake has higher levels of bioavailable phosphorus and nitrogen, and at times has more phytoplankton biovolume than does White Lake. It is a much less diverse system, however.
- 12. Lake clarity can at times be very good, although there are also times when the lake appears to be cloudy or green. Boating activity which stirs up the muddy sediments can influence the appearance of the water, and churned up vegetative matter and sediments can cause degraded conditions in places along the lake shore, particularly where there are seawalls. This has been a long-standing issue.
- 13. Stewardship actions which can improve nearshore conditions include removal of seawalls and first and foremost, responsible boating practices which can reduce the amount of material stirred up from the lake bottom.
- 14. Bass fishing tournaments attract many fishers, and boat/trailer inspections would help to ensure that invasive weeds such as hydrilla are not re-introduced into the lake. While no aquatic vegetation survey was conducted in 2023, the southern naiad was identified in the lake for the first time, generating concerns about accidental introductions.



Seeing is believing? A brown plume from churned up sediments near the boat landing, April 2023.

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Appendix 1. White Lake Monitoring Data 2023. Data is reported as monthly means for all parameters except pH, in which ranges are given. Temperature, dissolved oxygen, conductivity, and pH were measured with a YSI Pro DSS sonde at 0.5 and 2.5 m depths (except in January-March when pH and conductivity analysis were done in the lab, as the sonde had been sent in for servicing), and field measurements of chlorophyll *a* were made with a Turner handheld fluorometer with mean data in parenthesis. IEH Analytical Laboratories was used for analysis of nutrients, turbidity, and chlorophyll *a*.

White Lake Monitoring Project 2023

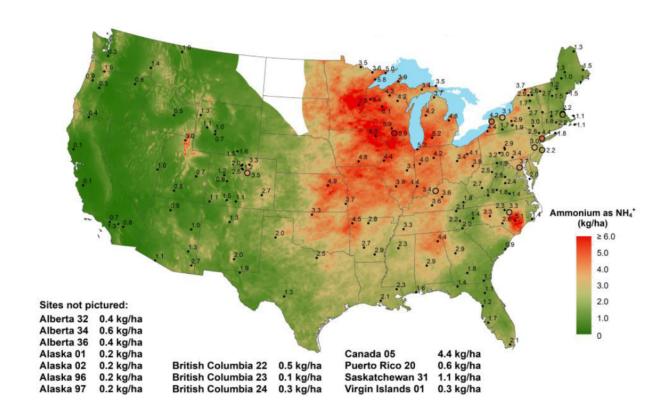
						-					
	1/28/23	2/23/232	3/23/23	4/20/23	5/23/23	6/27/23	7/25/23	8/24/23	9/25/23	10/25/23	12/14/23
Mean Temp (C)	11.1	16.9	14.8	21.8	23.0	28.2	30.8	29.7	23.0	18.1	10.8
Lake Level (gauge)	1.20	1.60	1.42	1.50	1.52	1.55	1.50	0.99	1.50	1.50	1.50
Secchi Depth (m)	1.5	1.4	1.25	1.25	1.6	1.6	1.0	1.4	1.6	1.75	1.6
Turbidity (NTU)	2.1	2.2	2.4	2.1	1.9	2.3	2.7	2.0	2.3	1.8	
Mean DO (mg/L)	11.3	9.5		9.3	8.4	8.8	9.0	8.81	9.25	18.1	11.9
Mean DO % Sat.	103			105	98	112	120	115	107	110	107
Mean Cond. (uS/L)		45.7(L)	47(L)	44.1	44.4	48.2	53.0	55.9	45.8	41.7	34.7
Range pH (su)	5.9 (L)	6.0-6.1(L)	6.2-6.3(L)	6.2-6.7	6.1-6.2	6.7-7.2	8.3-8.5	7.1-7.7	6.5-6.6	6.6-7.0	6.4-6.5
Mean Chlorophyll a (μg/L)	6(7)	8(9)	5(9)	3(8)	3(3)	8(13)	22(24)	11(15)	6(7)	13(5)	(6)
Mean Algal Biovol. (mm3/m3)	17,070	51,796		53,165	1,708	6,769	13,974	17,377	9,710	11,712	
Mean Algal Density (# cells/mL)	50,880	91,515		105,209	56,650	52,524	105,308	147,267	143,816	114,414	
Mean DOC (mg/L)	6.69	6.67	11.6	6.94	9.13	5.72	7.14	8.29	11.0	11.6	
Mean Total N (mg/L)	0.828	0.896	0.618	0.887	0.803	0.768	0.725	0.748	0.461	0.441	
NO3-NO2 (mg/L)	0.018	<0.010	<0.010	0.028	0.026	<0.010	0.028	<0.010	<0.010	0.024	
NH4-NH3 (mg/L)	0.010	<0.010	0.010	<0.010	0.010	<0.010	<0.010	<0.010	<0.010	<0.010	
TDN (mg/L)	0.646	0.588	0.449	0.616	0.600	0.571	0.567	0.585	0.265	0.329	
Mean Total P (mg/L)	0.017	0.024	0.026	0.026	0.028	0.023	0.024	0.015	0.014	0.008	
SRP (mg/L)	0.001	0.001	<0.001	<0.001	<0.001	0.003	0.002	0.001	<0.001	<0.001	
Mean TN : TP (mass)	50.5	35.6	21.3	34.9	29.1	34.6	30.4	50.6	32.9	56.4	

Appendix 2. Singletary Lake Monitoring Data for June 2021-2023. Temperature, dissolved oxygen, conductivity, and pH were measured with a YSI Pro DSS sonde at 0.5 and 2.5 m depths, and field measurements of chlorophyll *a* were made with a Turner handheld fluorometer with mean data in parenthesis. IEH Analytical Laboratories was used for analysis of nutrients, turbidity, and chlorophyll *a*.

Singletary Lake Monitoring June 2021-2023

	6/17/21	6/15/22	6/27/23
Temp (oC) at 0.5m	29.1	29.2	31.4
Secchi Depth (m)	0.25	0.5	0.6
Turbidity (NTU)	2.6	3.9	4.4
DO (mg/L)	7.3	6.36	8.19
DO % saturation	95	83	111
Conductivity (uS/L)			52.5
Sp. Cond. (uS/L)	34.5	26	
pH (su)	4.3	4.26	4.20
Chlorophyll a (µg/L)	11 (14)	11(10)	12(11)
ALGAL BIOVOLUME (mm3/m3)	4,127	2,448	27,009
Gonyostomum semen % T. BV	12.7%	21%	
Carteria sp. % T. BV	48.4%		
Pleodorina california % T. BV		29%	
Komma caudata % T. BV			14.9%
Closterium gracile % T. BV			55.5%
Cryptomonas sp. % T. BV	11.1%		11%
Chlorophyta % T. BV	60.8%	40.7%	0.8%
Cryptophyta % T. BV	20.8%	17.8%	27.7%
Charophyta % T. BV	1.2%	12%	56.3%
ALGAL DENSITY (# cells/mL)	17,156	14,140	30,134
Synechococcus % T. Density	69.5%	32%	38.8%
Cyanoganis ferriginea %T. Density		45%	
Closterium gracile % T. Density			22.8%
Chlorophyta % T. Density	27.4%	15%	
DOC (mg/L)	19.6	15.2	12.3
Total N (mg/L)	0.881	0.625	0.641
NO3-NO2 (mg/L)	0.101	<0.010	0.015
NH4-NH3 (mg/L)	0.036	0.059	<0.010
TDN (mg/L)	0.623	0.624	0.453
Total P (mg/L)	0.038	0.030	0.036
SRP (mg/L)	0.030	0.022	0.017
TDP (mg/L)			
TN : TP (mass)	23.2	20.8	17.8
# of Samples	1	1	1

Appendix 3. Wet deposition of ammonium in 2022. The total at the Clinton Crops Research Station in Sampson County (NC35) was 5.1 kg/ha, among the highest in the nation. National Atmospheric Deposition Program 2022 Annual Summary https://nadp.slh.wisc.edu/wp-content/uploads/2023/10/2022as2.pdfweb accessed 1/23/24.



Ammonium ion concentration (top) and wet deposition (bottom), 2022.