2018 White Lake Monitoring Report

White Lake, Bladen County, NC

September 2019

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Background

White Lake is a shallow, 1,068-acre Carolina Bay lake located near Elizabethtown, NC in the Cape Fear River basin (Figure 1). The maximum depth of this lake is approximately nine feet and estimated residence time is 292 days. Except for a small, 0.12-mile long strip of land along the northern shoreline, the entire 4.8-mile shoreline is developed for residential and some commercial uses. Approximately two-thirds of the lake shoreline is bulk-headed with the remaining one-third of the lake shoreline being gently sloped. As part of the NC State Parks Singletary Lake complex, White Lake provides recreational opportunities such as swimming, fishing and boating.

White Lake is an unusual Carolina Bay lake in that the water of this lake has historically been clear rather than colored by tannins (i.e., tea colored). The clarity has been attributed to the numerous springs at the bottom of the lake which dominate water inputs as opposed to shallow (near surface and organic) groundwater inflow typically observed in other Carolina Bay lakes. The water level of White Lake is determined by the regional water table and, in drought years, will drop in response to the decrease in rainfall and groundwater (springs) input. The outlet channel is in the northwestern section of the lake as opposed to the southeastern section as in other bay lakes (Frey, D.G., June 1949; Wells, B.W. et al., 1953).

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

In 2014 at the request of the Town of White Lake, NC Division of Parks and Recreation (DPR) and the NC Division of Water Resources (DWR) reviewed historical ambient lake data from 1981 to 2015 (White Lake Water Quality Trends and Analysis, December 2015). Ambient monitoring efforts, which began in 1981, consisted of lake water sampling during the summer months to evaluate water quality conditions in respect to lake use. Based on evaluation of this historic data, the 2013 trophic state of the lake had shifted from oligotrophic (low productivity) to mesotrophic (moderate productivity). Short periods of eutrophic conditions (high productivity) have also been observed. The most dramatic water quality change has been the lake's pH. The acidic nature of White Lake (~4.5 historic average) has risen to a more neutral average pH value of 6.9 over the last 10 years.

In 2015, DWR began a special study to determine if these changes were a trend or an ephemeral response to unusual weather conditions. The special study also assessed phytoplankton, the algae that grows in the water column and a potential cause of water discoloration, as well as the color of the water. The 2015 study identified an increasing pH trend exhibiting signs of eutrophication. Evaluation of the phytoplankton and water color found the true color of the water to be clear with relatively low densities of phytoplankton in the water column. The apparent discoloration observed in the water column was hypothesized to be caused by light reflecting off the bright green submergent vegetation on the lake bed (DWR 2016). The changes in pH and increasing nutrients began affecting the lake biota where oligotrophic and low pH tolerant genera began to be replaced by meso and eutrophic circumneutral genera.

Special studies, including the phytoplankton assessments, continued throughout the following years. From 2015 to 2017, a study was conducted to determine potential sources of nutrient loading to White

Lake that may be contributing to the increased productivity observed in the lake (2017 White Lake Water Quality Investigation, December 2017). This study monitored surface waters as well as near shore groundwaters up and down gradient from the lake. The study showed increasing nutrient concentrations and a shift in dominant algal community from chlorophytes (green algae) to cyanobacteria (blue-green algae). The shallower groundwater wells monitored as part of the study showed elevated total Kjeldahl nitrogen (TKN) concentrations while deep groundwater wells had low nutrient concentrations. Surface water inputs from stormwater also exhibited elevated nutrient concentrations, but these inputs were limited to rainfall events equal to or greater than 1.25" (2017 White Lake Water Quality Investigation, December 2017).

Figure 1 – Map of White Lake.

Alum Application on White Lake

In early 2018, a Technical Advisory Committee (TAC) was established by DPR to develop strategies for the deteriorating water quality as well as noxious weed control (hydrilla) and consisted of multiple state agencies, municipal representatives, and concerned citizens. The TAC was established with the express purpose to develop strategies for the improvement of deteriorating water quality, specifically water clarity, as well as control of observed hydrilla, an aquatic noxious weed. After much deliberation, the TAC agreed that applying Aluminum sulfate (alum) was a possible short-term strategy for improving water quality in the lake. Alum had been used in other states to flocculate phosphorus and suspended material from the water column in an effort to reduce nutrients in the water column which could limit algal blooms. The Town of White Lake requested and was granted approval to apply alum to the lake under their existing NC DWR Pesticide General Permit No. NCG560043. A one-time alum treatment was authorized by DWR and DPR in April 2018. This authorization required monitoring of water quality before, during, and after the treatment application, with concurrent monitoring by DWR.

A cyanobacteria bloom persisted through late 2017 and into the spring of 2018. Pre-application monitoring on the morning of May 3, 2018 indicated that an intense algal bloom was occurring just prior to commencing the alum application. DWR observed pH levels across the lake ranging from 8.4-8.8 S.U. and dissolved oxygen (DO) percent saturation levels of 112.5-115.0%. Elevated pH and dissolved oxygen levels are most often attributed elevated photosynthetic activity from algal blooms outside of natural geomorphic circumstances. Following application, the Fayetteville Regional Office (FRO) began receiving reports of a fish kill at White Lake in the afternoon.

The FRO responded to the fish kill on May 4, 2018, and monitored the fish kill and water quality conditions through the weekend. DWR Water Sciences Section (WSS) staff monitored the lake on May 7th and 8th collecting water samples and dead/dying fish for necropsy analysis. On May 7th, DWR requested that the Town of White Lake cease alum application until the cause of the fish kill could be determined. Reports of fish actively dying continued through May 9, 2018. Based on the preliminary necropsy report and water quality data available at the time, DWR allowed the Town to recommence the alum treatment on May 10, 2018. The treatment continued through May 16, 2018, during which DWR monitored water quality at a near shore station. DWR continued monthly sampling associated with the Ambient Lakes Monitoring Program (ALMP) and stationed a monitoring platform at a center-lake station (Figure 2, CPF155B) in June to continuously monitor the lake for pH, DO, chlorophyll α, phycocyanin, and turbidity. The platform was removed September 11th prior to Hurricane Florence.

Water Quality Monitoring

Except for sampling conducted as part of the alum application and following fish kill response, all monitoring in 2018 was conducted at established lake monitoring stations. These stations are shown in Figure 2 and run north-south along the centerline of the lake. During the fish kill, some monitoring was conducted at a near shore station (also shown in Figure 2). All monitoring was conducted in accordance with the *Intensive Survey Branch Standard Operating Procedure Manual: Physical and Chemical Monitoring*, Version 2.1, December 2013 and the *Ambient Lakes Monitoring Program (ALMP) Quality Assurance Project Plan*, Version 2.0, March 2014.

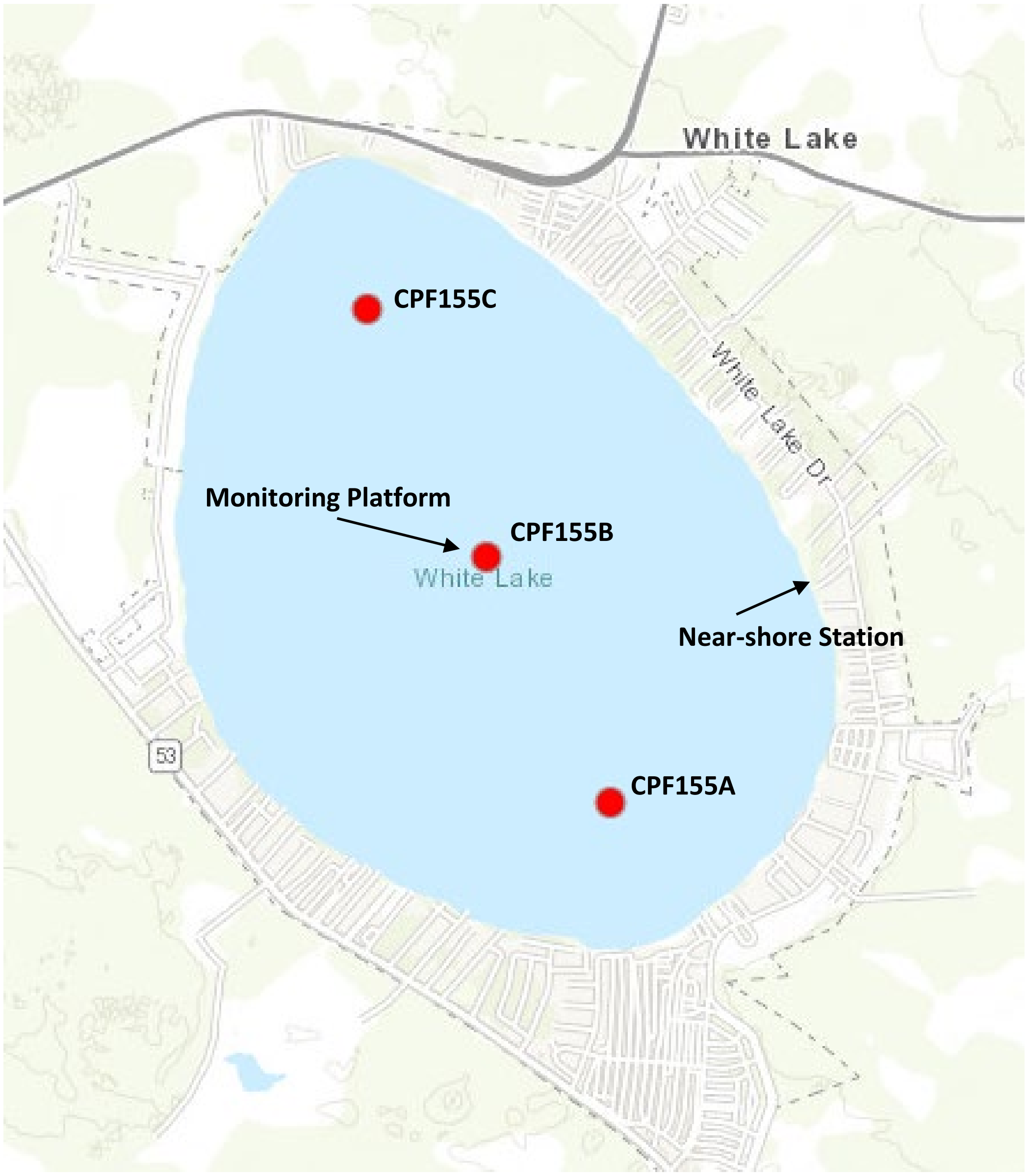

Figure 2 – White Lake monitoring station locations.

Alum Treatment and Fish Kill Response

The pre-treatment monitoring was conducted to get baseline data for a variety of parameters prior to the alum treatment. The parameters monitored prior to the treatment are listed in Table 1 below.

Table 1 – Pre-treatment monitoring parameters.

Parameter (Units)	Sample Type[1]
pH (S.U.)	Depth profile using a multiparameter probe
Dissolved oxygen (mg/L and % saturation)	Depth profile using a multiparameter probe
Specific conductance (µmhos/cm)	Depth profile using a multiparameter probe
Water temperature (°C)	Depth profile using a multiparameter probe
Secchi depth (m)	
Turbidity (NTU)	Composite within photic zone
Nutrients (mg/L) – Ammonia as N, Total Kjeldahl Nitrogen, Nitrate+Nitrite, Total Phosphorus	Composite within photic zone
Chlorophyll α (µg/L)	Composite within photic zone
Fecal coliform (CFU/100 mL)	Surface Grab
Hardness (mg/L)	Surface Grab
Dissolved Metals (µg/L unless otherwise noted) – Silver, Aluminum, Arsenic, Beryllium, Calcium[2] (mg/L), Cadmium, Chromium, Copper, Mercury[2], Potassium (mg/L), Magnesium[2] (mg/L), Manganese, Sodium (mg/L), Nickel, Lead, Selenium[2], Zinc	Surface grab

[1] – Photic zone is defined as two times the Secchi depth.

[2] – Reported as total metals concentration.

After the fish kill was reported on May 4th, the monitoring transitioned into an environmental emergency response. A water quality meter was set up at a near shore location to regularly monitor physical water quality parameters. Chemical parameters listed in Table 1 above were monitored as well as an expanded suite of parameters listed in Table 2.

Table 2 – Expanded monitoring parameters.

Dissolved Metals (µg/L) – Antimony, Barium, Cobalt, Iron, Lithium, Molybdenum, Strontium, Thallium, Titanium, Vanadium	Surface Grab
Bromide (mg/L)	Composite within photic zone
Chloride (mg/L)	Composite within photic zone
Fluoride (mg/L)	Composite within photic zone
Sulfate (mg/L)	Composite within photic zone
Microcystins (µg/L)	Composite within photic zone

Ambient Lakes Monitoring Program

The ALMP monitoring was conducted from May 2018 through September 2018 at three monitoring stations in the lake (See Figure 2). The water quality parameters monitored at White Lake are listed in Table 3 below.

Table 3 – Parameters monitored as part of the ALMP.

Parameter (Units)	Sample Type[1]
pH (S.U.)	Depth profile using a multiparameter probe
Dissolved oxygen (mg/L and % saturation)	Depth profile using a multiparameter probe
Specific conductance (µmhos/cm)	Depth profile using a multiparameter probe
Water temperature (°C)	Depth profile using a multiparameter probe
Secchi depth (m)	
Turbidity (NTU)	Composite within photic zone
Nutrients (mg/L) – Ammonia as N, Total Kjeldahl Nitrogen, Nitrate+Nitrite, Total Phosphorus	Composite within photic zone
Total and suspended solids	Composite within photic zone
Chlorophyll *α* (µg/L)	Composite within photic zone

[1] – Photic zone is defined as two times the Secchi depth.

Monitoring Platform

A multiparameter sonde with manual wiper was deployed suspended from a floating buoy anchored at CPF155B by WSS staff. The sonde measured physical parameters including DO, pH, temperature, specific conductance, chlorophyll *α* (chl *α*), and phycocyanin at a depth of approximately 1 m. Chlorophyll *α* and phycocyanin are measures of algal productivity with phycocyanin being specific to blue-green algae and were measured using in-situ fluorometric probes. Sondes were calibrated in lab according to the *Intensive Survey Branch Standard Operating Procedures Manual: Physical and Chemical Monitoring Version 2.1, December 2013,* and initially deployed on June 5th, 2018. Chlorophyll *α* sensors were calibrated according to manufacturer recommended methods for Rhodamine WT dye to calibrate the total algal sensors to a single standard. Sondes were replaced at 2 to 3-week intervals.

Data Corrections

Water quality instrumentation deployed for extended lengths of time often experience fouling and calibration drift inherent to environmental monitoring. The United States Geological Survey (USGS) has developed data correction methods documented in *USGS Guidelines and Standard Procedures for Continuous Water-Quality Monitors: Station Operation, Record Computation, and Data Reporting 2006*. As per this method, during routine servicing of the deployed sondes, a "dirty" and "clean" reading is collected from both the deployed sonde and from a clean, freshly calibrated field sonde. Dirty readings are collected before the deployed sonde is cleaned, while clean readings are collected after. These two readings are compared to the field sonde readings, which are collected at the same time. This field sonde is then returned to the lab and checked for post calibration drift in the same standards in which it was previously calibrated. Readings collected as part of this process are applied to the following formula:

$$C_f = E_f = (D_a - D_b) - (F_e - F_s)$$

where

C_f = fouling correction,

E_f = fouling error,

D_a = monitor reading after the sensor is cleaned,

D_b = monitor reading before the sensor is cleaned,

F_s = field meter reading at the start of servicing, and

F_e = field meter reading at the end of servicing.

Fouling correction (C_f) is applied linearly over the course of the deployment for the study period between service intervals. For chl *α* values, correction factors were not applied. A 92% correlation was calculated between lab results, collected as photic samples, an area defined as twice the Secchi depth, and the recorded meter values collected within the hour. However, due to issues of *in situ* fluorometry, data extrapolated with this method should be considered qualitative and not used for assessment purposes.

Fouling correction factors were applied to the data set when USGS guidance thresholds were exceeded (Table 4).

Table 4 - Fouling correction factor thresholds for physical parameters.

Physical Parameter Measured	**C_f Threshold**
Temperature (°C)	± 0.2°C
Specific conductance (µS/cm)	± 30 µS/cm
Dissolved oxygen (mg/L, % saturation)	± 0.3 mg/L, ± 10%
pH (S.U.)	± 0.2 S.U.

USGS Guidelines and Standard Procedures for Continuous Water-Quality Monitors: Station Operation, Record Computation, and Data Reporting 2006.

Physical parameters that exceed thresholds for correction were altered in the data set assuming that fouling resulted in linear degradation of the field measurement. Correction factors were applied based on this model with scalar increases during the deployment periods. Calibration drift was not significant during the deployment period.

Results

Alum Application, Near Shore Monitoring, and Fish Kill Investigation

The lake was experiencing hypereutrophic conditions along with an unusual spring algal bloom when the alum application began. The applicator, HAB Aquatic Solutions, proposed the process would take 10 days for a total of 200,000 gallons of alum to be applied (HAB 2018). The fish kill was first reported to DWR on May 3rd, the evening the alum application started, and continued to May 9th. The Wildlife Resources Commission estimated the mortality at 114,770 fish (yellow perch, lake chubsucker, largemouth bass, yellow bullhead, chain pickerel, and sunfish) for a total of 42,779 pounds of fish at a value of $634,132 (WRC 2018). The near shore monitoring during the fish kill showed the dissolved oxygen levels remained between 67% to 113% saturation (5.7 mg/L and 9.3 mg/L, respectively) and pH ranged between 8.3 S.U. and 7.0 S.U. (Figure 3) during the fish kill, both adequate to support aquatic life.

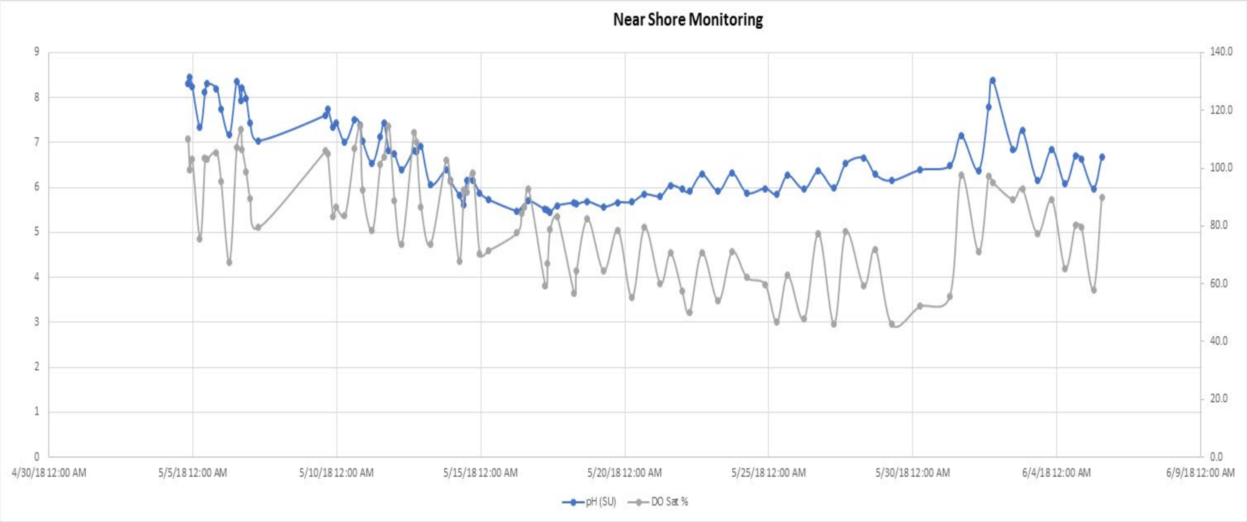

Figure 3 - Results of the near shore monitoring from May 4th to May 9th.

The results of the metals sampling on May 8th found the concentrations of two metals, copper and aluminum, at levels of concern. Copper levels were between 2.2 µg/L and 2.4 µg/L dissolved and 2.6 µg/L and 2.9 µg/L total (Table 5) which is above the calculated dissolved copper standard of 0.6 µg/L at a hardness of 7.7 mg/L. Pre-application metals monitoring results showed that dissolved copper was present at similar concentrations (2.1-2.3 µg/L). Total copper values from monitoring conducted in 1993 ranged from <2.0 to 5.5 µg/L).

Aluminum levels were between 1,600 µg/L to 1,700 µg/L dissolved, and 1,900 µg/L to 2,000 µg/L total. The EPA released their final criteria on aluminum for freshwater in December 2018. Aquatic life toxicity is dependent on pH, total hardness, and dissolved organic carbon (DOC) at the sampling location. DOC was not collected along with the metals; therefore, the EPA-recommended default value for the Middle Atlantic Coastal Plain Ecoregion of 2.2 mg/L DOC was used. The calculated acute criterion for aluminum using the default DOC value, an observed pH of 7.5 S.U., and an observed hardness of 7.7 mg/L was 1,100 µg/L total Al and the calculated chronic criterion was 610 µg/L total Al. Pre-application dissolved aluminum levels ranged from non-detect (PQL = 50 µg/L) to 50 µg/L. Total aluminum values from monitoring conducted in 1993 ranged from 160 to 280 µg/L. The levels of copper and aluminum in the lake during the fish kill exceeded criterion for aquatic life support.

Table 5. Results of the metals sampling conducted on May 8th in White Lake

Station	Cu* (µg/L)	As * (µg/L)	Mn* (µg/L)	Ca* (mg/L)	K* (mg/L)	Mg* (mg/L)	Na* (mg/L)	Fe* (µg/L)	Al * (µg/L)	Sr* (µg/L)	Chloride (mg/L)	Sulfate (mg/L)	Hardness (mg/L)
155A	**2.3/2.9**	3.4/3.6	10/26	1.8/1.9	1.3/1.4	0.67/0.72	8.6/8.8	160/270	**1700/1900**	10/10	7.5	8.8	**7.7**
155B	**2.4/2.6**	3.4/3.6	10/13	1.7/1.8	1.3/1.3	0.67/0.70	8.2/8.3	160/200	**1700/2000**	10/10	8	7.8	**7.4**
155C	**2.2/2.6**	3.2/3.8	10/12	1.8/1.9	1.3/1.3	0.66/0.68	8.2/8.3	130/180	**1600/1900**	10/10	8	8.1	**7.5**
PQL	2	2	10	0.1	0.1	0.1	0.1	50	50	10	1	2	1

*Shown as dissolved/total metal portions
Non-detect results below the laboratory practical quantitation limit (PQL) are shown at the PQL, e.g., Sr and dissolved Mn.

Ambient Lakes Monitoring Program

Water quality in White Lake has been monitored as part of an ongoing study for the past 4 years part of the ALMP since the 1980s. The data has shown changes in pH and increased eutrophication (nutrient enrichment) since 2013.

pH

One of the most important changes in the water chemistry of White Lake has been the increase in pH over time. Some forms of aquatic life thrive in low pH (≈3 S.U.) whereas others are adapted to a more circumneutral (≈7 S.U.) environment. The pH of White Lake has increased over the years from historical values of 3-5 S.U. to values of 6-8 S.U. in 2018, with some values even greater than 8.5 S.U. (Figure 4). This shift in pH could result in a shift in dominant taxa in the ecosystem over the long term.

While the cause of the pH shift cannot be acutely determined, possible sources include increased algal productivity which can cause changes in pH through photosynthesis and changes in the Lake's dominant source water (deep spring fed vs. shallow ground water). A more through discussion on the effects of these changes is discussed in the phytoplankton and continuous monitoring data sections below.

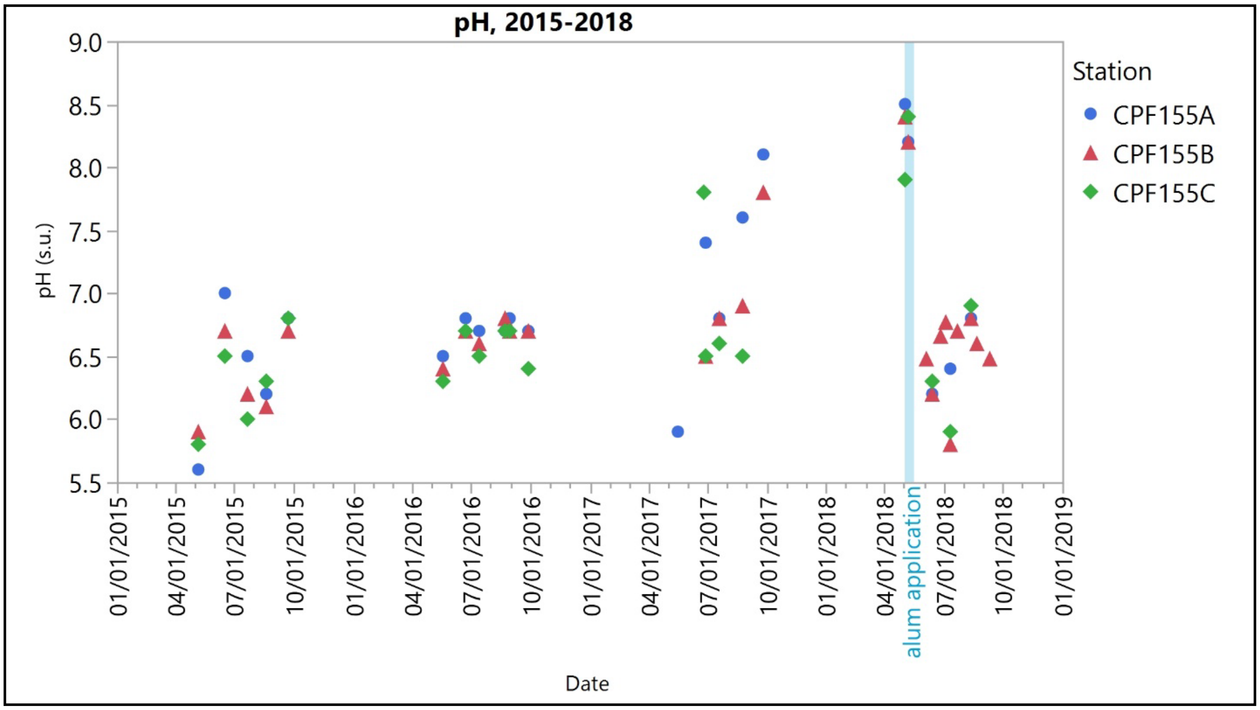

Figure 4 - pH measures in White Lake, 2015 - 2018.

North Carolina Trophic State Index (NCTSI)

The NCTSI rating for White Lake has historically been oligotrophic (2013 BAR DWR), which is defined as having low nutrient bioavailability. However, since May 2015, the rating has increased from oligotrophic to hypereutrophic (early May 2018), a shift indicating increase productivity in the lake. Following the alum treatment, NCTSI scores indicate a mesotrophic status similar to 2015 and 2016 levels (Figure 5), but it is unclear if this is a long-term shift, or the result of other environmental factors.

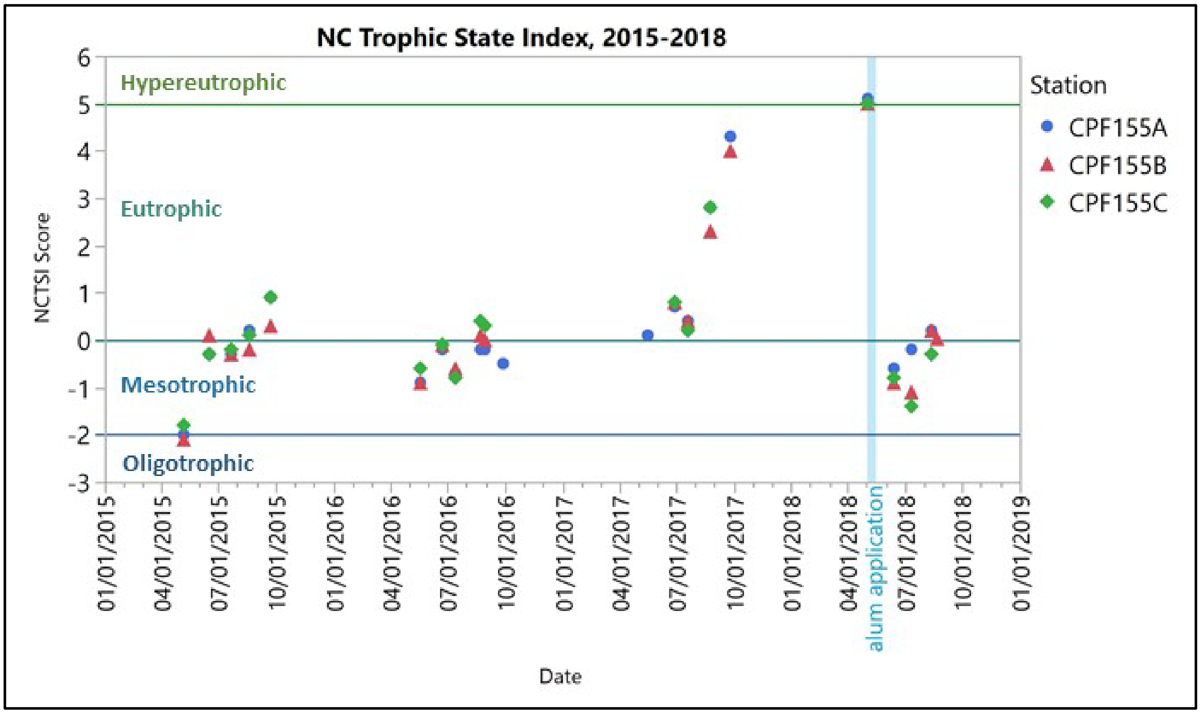

Figure 5 - NCTSI ratings for White Lake, 2015-2018.

The NCTSI rating is based on four parameters:

- Total Nitrogen
- Total Phosphorus
- Secchi Depth
- Chlorophyll *α*

Total Nitrogen (TN)

Total nitrogen is calculated by adding together Total Kjeldahl Nitrogen (TKN) and Nitrate+Nitrite (NO_3+NO_2) concentrations. Total Organic Nitrogen (TON) is calculated by subtracting Ammonia (NH_3) from TKN.

Both NH_3 and NO_3+NO_2 have consistently been below detection levels, with the exception of May 2018 (Table 6). Therefore, TON, is the most abundant form of nitrogen in White Lake and represents biological uptake during the growing season. TON has been increasing since 2017 with the highest concentration of TON calculated in early May 2018. Concentrations of TON decreased after the alum application (Figure 6). Note: TON includes nitrogen found in phytoplankton.

Table 6 - NH_3, NO_3+NO_2, and TKN concentrations at White Lake, 2015-2018.

Parameter	2015	2016	2017	2018
Ammonia*‡ (mg/L)	12 non-detects <0.02; 3 results = 0.02	All 18 non-detects <0.02	All 13 non-detects <0.02	All 17 non-detects <0.02
Nitrate+Nitrite†‡ (mg/L)	All 15 non-detects <0.02	All 18 non-detects <0.02	All 13 non-detects <0.02	11 non-detects <0.02; 6 results, range: 0.02-0.03
TKN (mg/L)†*	15 results, range: 0.42-0.61	18 results, range: 0.43-0.60	13 results, range: 0.53-1.0	17 results, range: 0.56-1.4
Non-detects are results that are less than the laboratory's practical quantitation limit (PQL).				
†Total N = TKN + NO_3+NO_2. Since most NO_3+NO_2 results were non-detect, and TKN magnitude was much greater than NO_3+NO_2, calculated TN concentrations closely reflected measured TKN concentrations.				
*Total Organic N = TKN - NH_3. Since most NH_3 results were non-detect, and TKN magnitude was much greater than NH_3, calculated TON concentrations closely reflected measured TKN concentrations.				
‡Total Inorganic N = NO_3+NO_2 + NH_3. Since most NO_3+NO_2 and NH_3 results were non-detect, calculated TIN concentrations were estimated as close to the PQL for these parameters.				

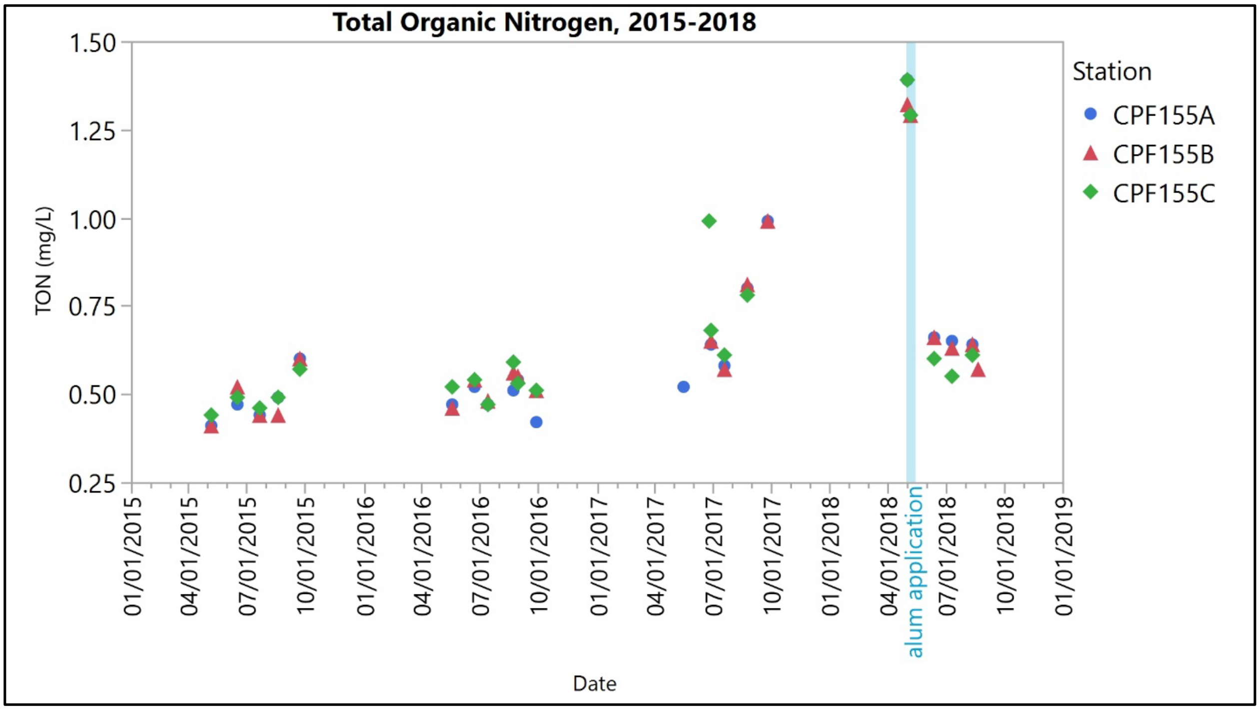

Figure 6 - TON concentrations at White Lake, 2015-2018.

Total Phosphorous (TP)

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

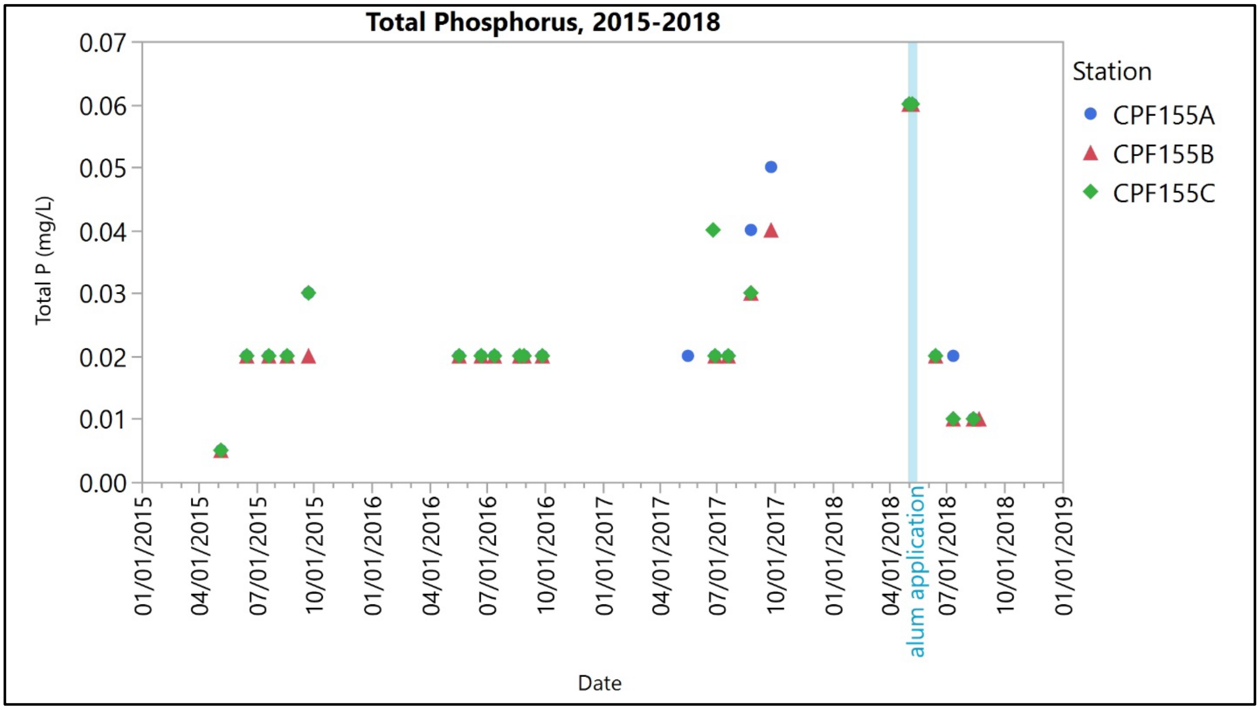

Figure 7 - TP concentrations at White Lake, 2015-2018.

Secchi Depth

Secchi depth is a measure of the distance that light that can penetrate the water column and is used to quantify water clarity. Secchi depth has been decreasing since 2013 (DWR 2017). Secchi depth increased temporarily after the alum treatment to depths seen in 2016 (>1.5 m). However, by early September 2018 Secchi depths had returned to less than a meter.

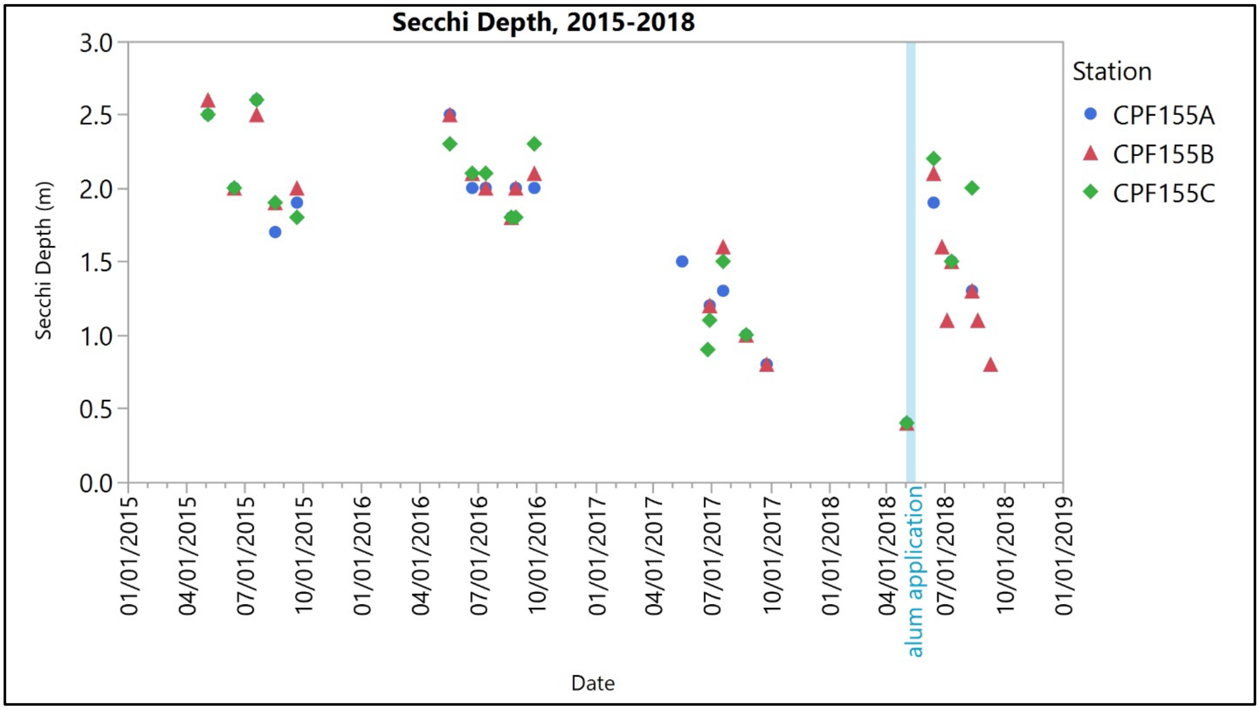

Figure 8 - Secchi depth at White Lake, 2015-2018.

The Secchi depth, and therefore water clarity, is affected by total suspended residue (i.e. solids) (TSS) which is also related to turbidity. Historically, suspended solids concentrations in the water column have been below detection levels. TSS began increasing in 2017 with the highest concentration, 29 mg/L, measured in early May 2018. TSS declined below detection levels after the alum treatment (Figure 9).

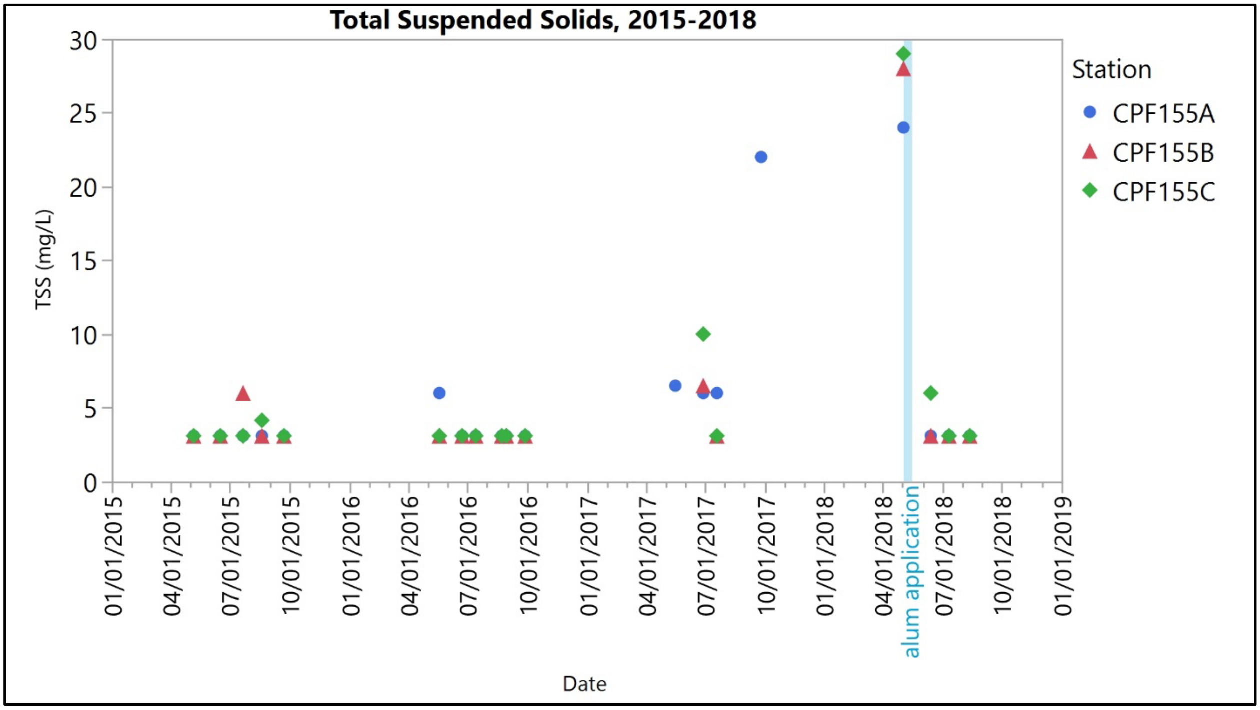

Figure 9 - TSS concentrations at White Lake, 2015-2018.

Turbidity has been increasing since 2013 (DWR 2017). Unlike TSS, turbidity initially decreased after the alum treatment but increased to the highest observed levels post alum treatment on August 13, 2018, then returned to approximately 2017 levels as of August 24, 2018 (Figure 10).

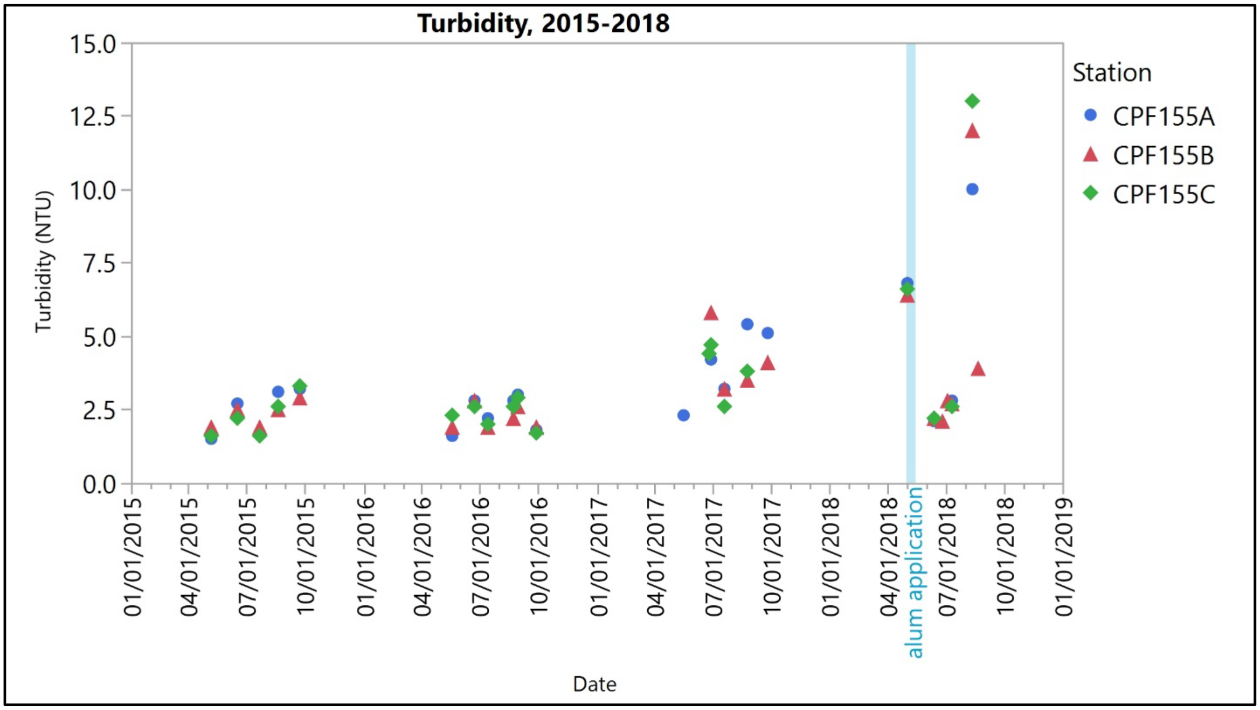

Figure 10 – Turbidity concentrations at White Lake, 2015-2018.

Chlorophyll α

Chlorophyll α, a photosynthetic pigment in phytoplankton, is a common measure of algal abundance and algal productivity. Chlorophyll α exhibited historically lower levels prior to 2013. However, starting in May 2015, chl α concentrations began increasing and continued throughout the summer similar to other lakes in the piedmont and coastal plain with higher trophic states (Figure 11). Chlorophyll α continued its upward trend in late 2017, and blooms were reported to continue through the winter with the highest recorded chl α values observed in September 2017 (58 µg/L) which exceeded state standard of 40 µg/L. Although levels decreased somewhat by May 2018, chl α concentrations were still considerably higher than previously recorded levels from similar seasonal time periods. Following the alum treatment, chl α levels decreased to the nominal levels of 2015 – 2016, but then, increased over the following months and into late summer. More information on chl α can be found in the continuous monitoring section.

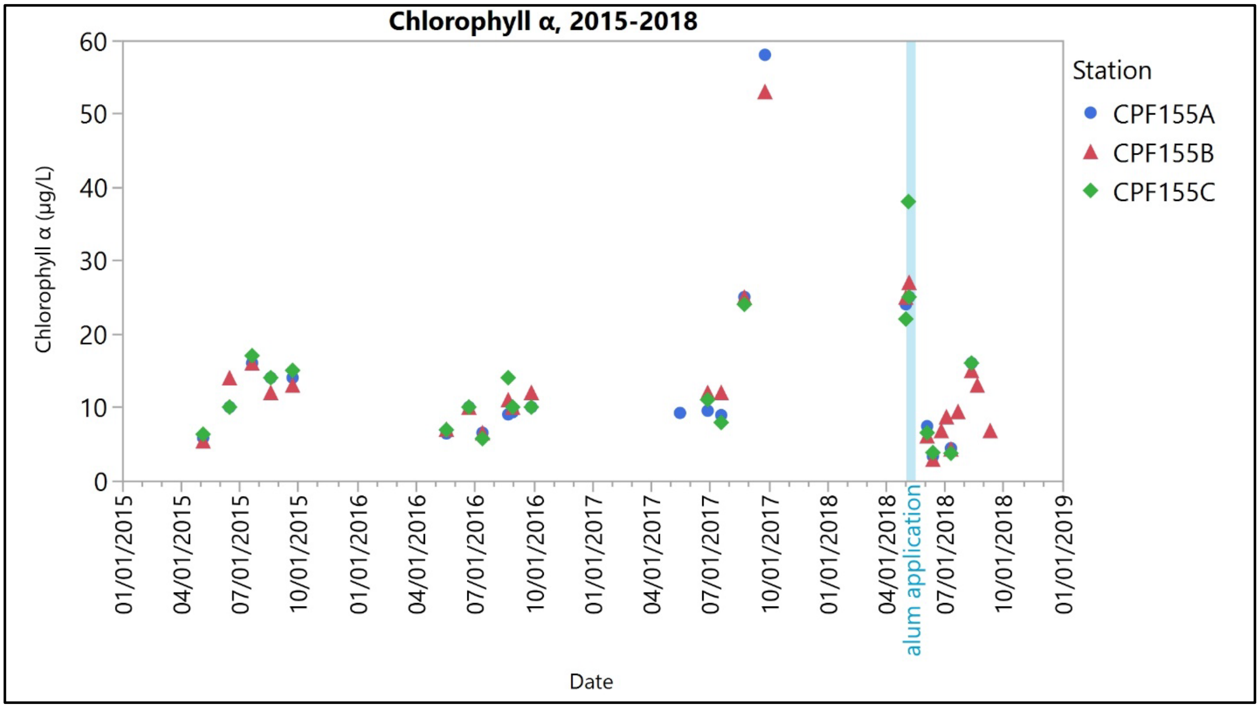

Figure 11 - Chlorophyll *α*a levels in White Lake 2015-2018.

Phytoplankton Densities and Community Structure

One of the more complex components of the special study has been the phytoplankton assemblage assessments. Phytoplankton samples were collected concurrently with other chemical and physical parameters as part of the study but also as part of bloom investigations in response to concerned citizen reports and questions. These assessments provide estimates of density (units/mL and cells/mL), biovolume (mm^3/m^3), and community structure. Algal toxin (microcystin) testing was performed on one occasion in May 2018.

White Lake's phytoplankton assemblages have historically reflected the oligotrophic and low pH conditions. Phytoplankton densities rarely exceeded 10,000 units/ml, considered to be a threshold representing bloom conditions, and were characterized by low pH tolerant chlorophytes (green algae), specifically desmids and chrysophytes (DWR 2017). Beginning in July of 2017, the phytoplankton assemblage shifted to Cyanobacteria. The shift and subsequent increase in biomass not only contributed to water discoloration but also caused health concerns as some forms of cyanobacteria are known to produce toxins. As densities peaked in September 2017 (Figure 12), the assemblage was comprised primarily of *Planktolyngbya*, a small filamentous cyanobacteria not known to produce toxins. Even though the bloom declined into the fall, bloom reports and investigations continued throughout the winter. The bloom reemerged in early Spring 2018 with the highest densities recorded immediately prior to the alum application (the first sampling event of the 2018 special study). In response to the fish kill, microcystin monitoring was conducted. The testing did not find detectable levels of microcystin in White Lake during the peak of the May bloom. Alum treatment is designed to bind to and flocculate available phosphorous and is not approved by the EPA to be used as an algaecide. However, it appears the alum did remove the phytoplankton from the water column as staff noted the post-alum treatment samples contained filaments of *Planktolyngbya* trapped in the alum floc. After the crash of the Cyanobacteria in June, the assemblage returned to being comprised of chlorophytes and chrysophytes (Figure 13).

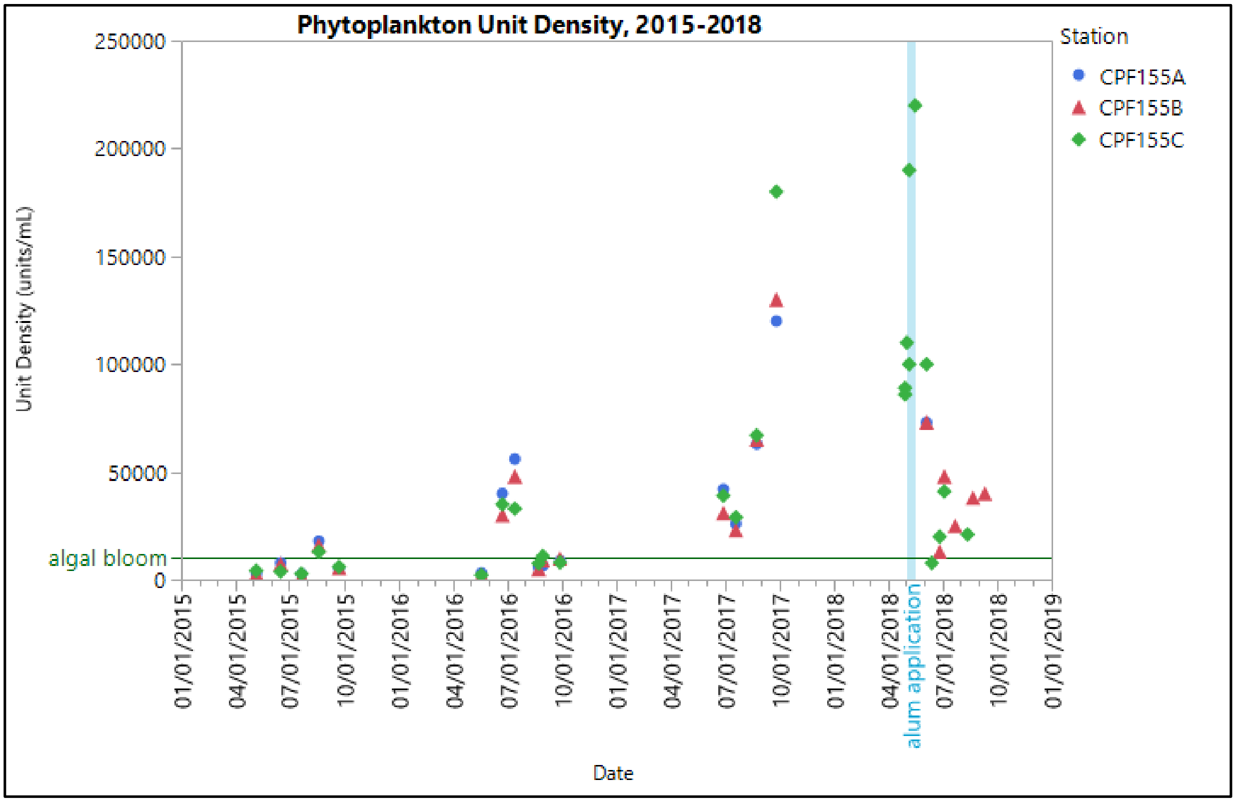

Figure 12 – Phytoplankton unit density at White Lake, 2015-2018.

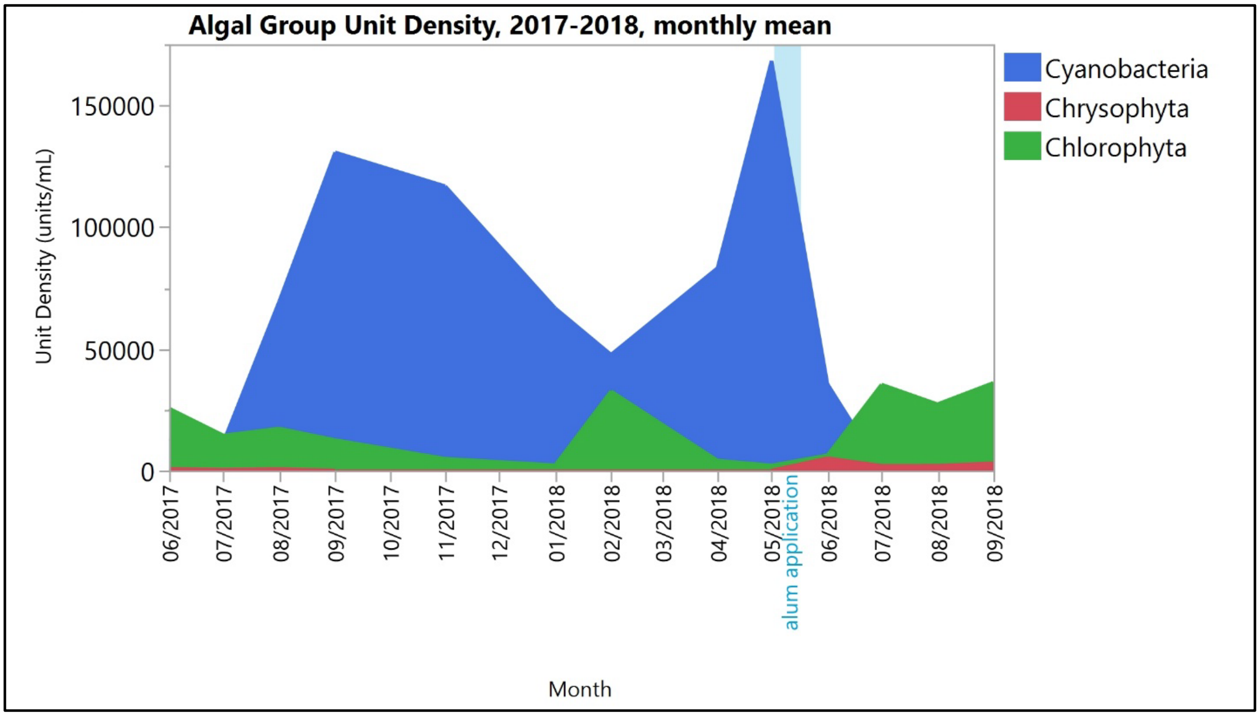

Figure 13 – Monthly mean unit density by algal group at White Lake, 2017-2018.

Monitoring Platform

The continuous monitoring platform was deployed from June 5, 2018 to August 11, 2018. Taking hourly measurements of DO, pH, chl α and phycocyanin for 64 days provided 6,432 data points to evaluate how the lake responded to the alum application. Dissolved oxygen levels ranged from 6.25mg/L to 9.34 mg/L on June 11th and September 4th, respectively. pH ranged from 6.11 S.U. to 8.62 S.U. on June 11th and August 15th, respectively. Algal activity, as measured through chl α, ranged from 2.77 µg/L to 36.59 µg/L on June 10th and September 3rd, respectively. Phycocyanin, expressed as blue-green cells/mL, ranged from 0 cell/mL to 6 cells/mL on June 10th and September 3rd, respectively. Chlorophyll α and blue-green cell density increased over time, peaking in early September just prior to the removal of the platform (Figure 14). As discussed above, chl α and phycocyanin are qualitative measurements and cannot be taken as absolute magnitudes for assessment purposes but are useful for trend analysis over time.

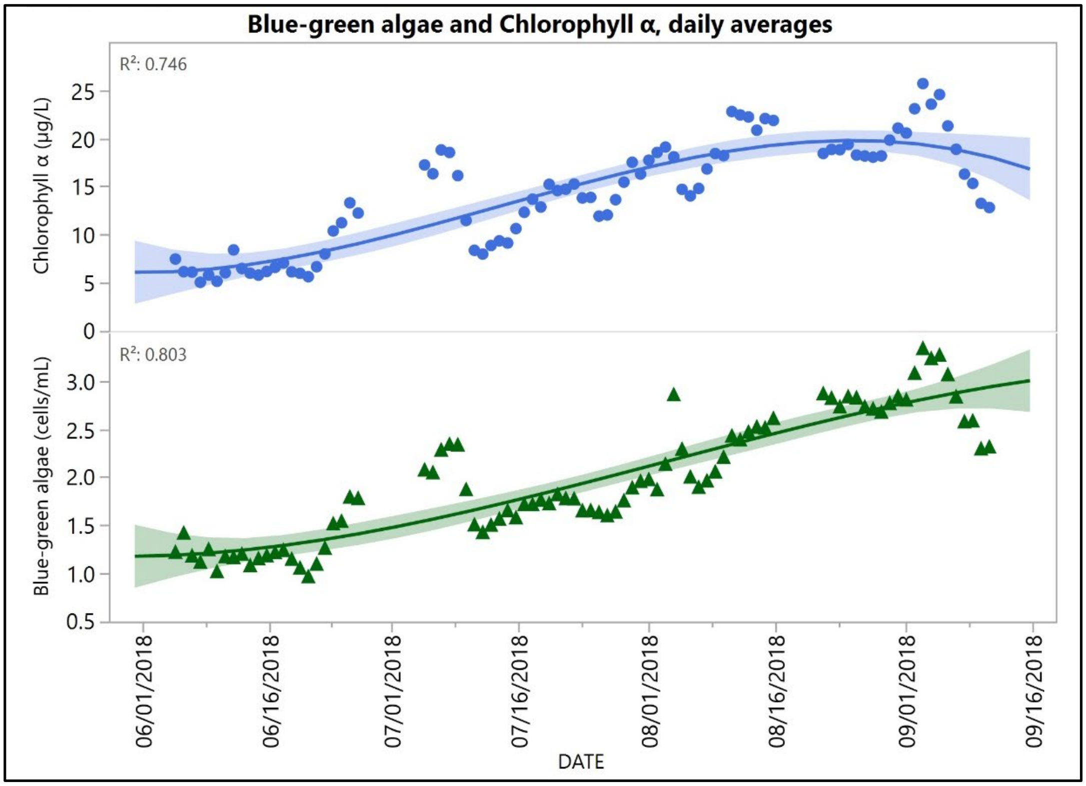

Figure 14 - Chlorophyll α and blue-green cells/mL over time.

Figures 15, 16, and 17 show periods of low, medium, and high algal activity based on chl α measurements over three 48-hour periods. These three date ranges are used as examples and have no significance in their selection. Low, medium, and high algal activity are defined as follows:

- low (<10ug/L),
- medium (>10ug/L but < 20ug/L),
- high activity (>20ug/L but <35ug/L),

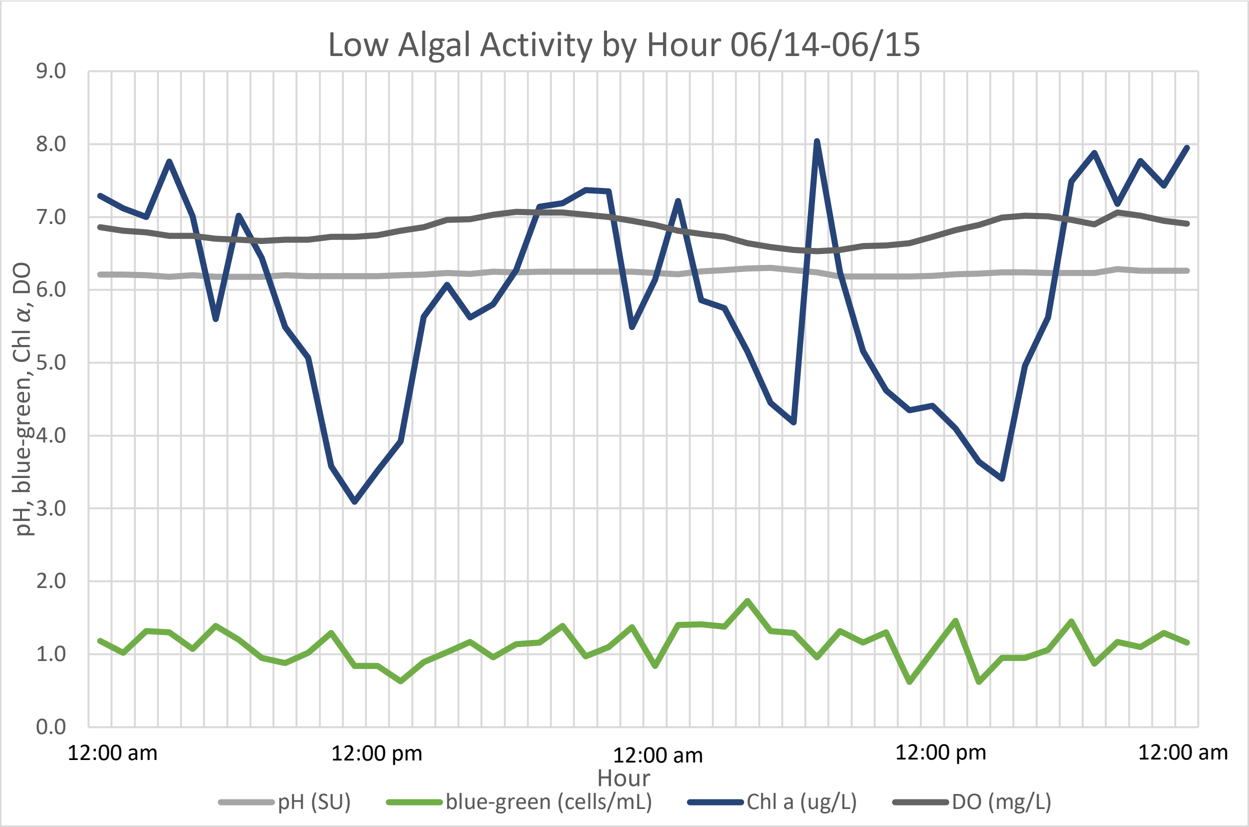

Figure 15 - Monitoring platform data during low (<10ug/L) algal activity.

Note: X axis changes in following graphs due to increase in Chl α

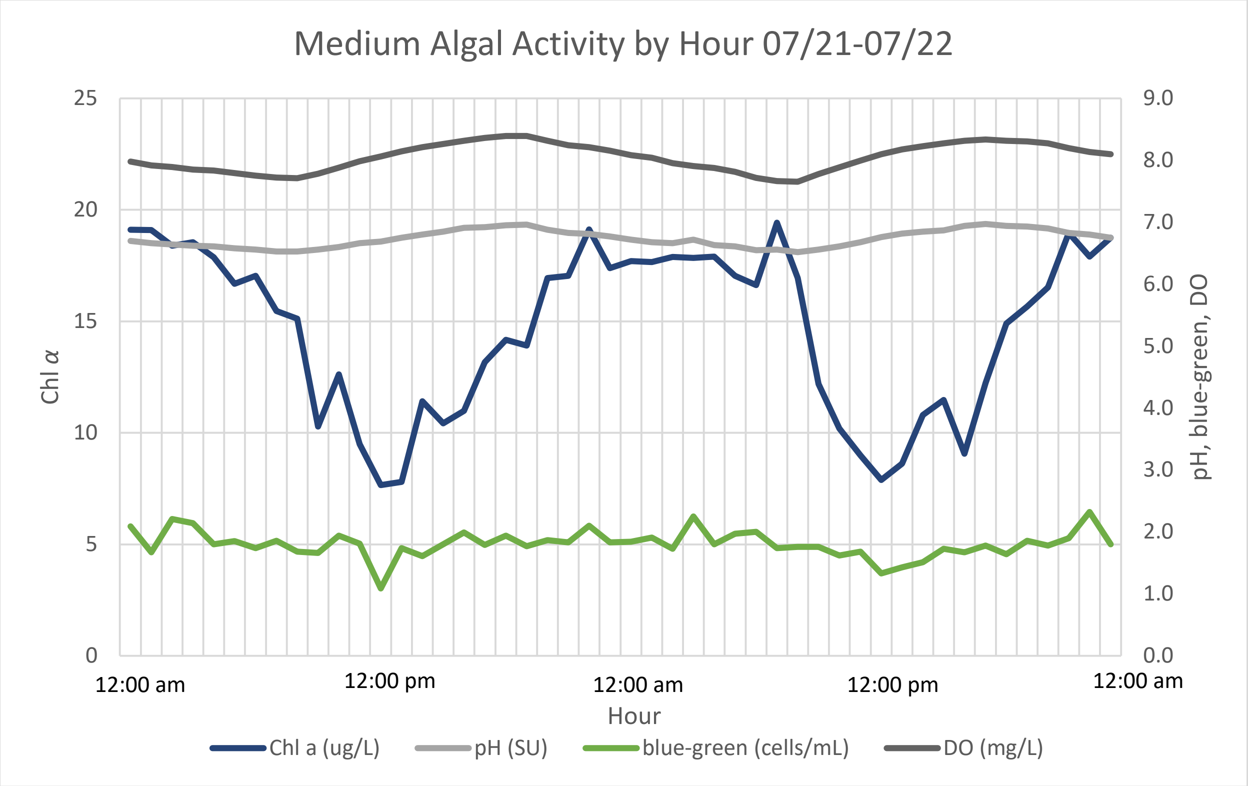

Figure 16 - Monitoring platform data during medium (>10 µg/L but < 20 µg/L) algal activity

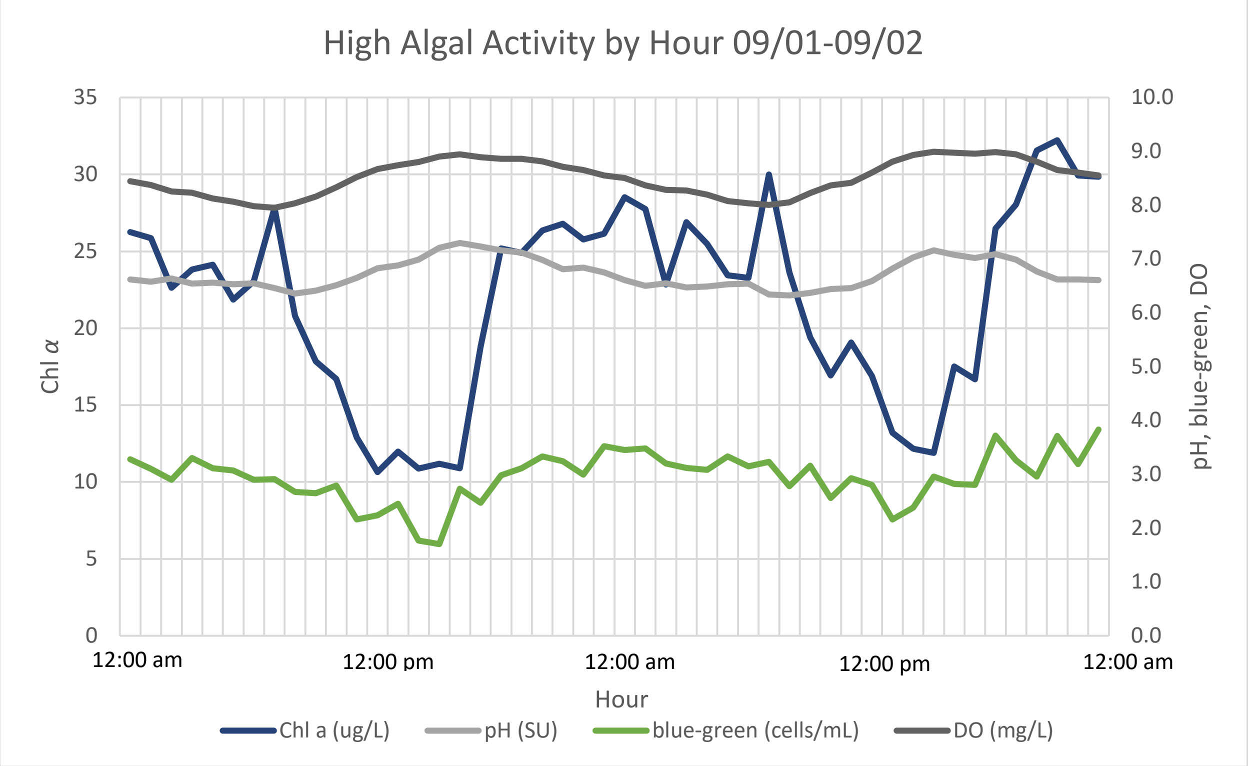

Figure 17 - Monitoring platform data during high (>20 µg/L but <35 µg/L) algal activity

It should also be noted that as algal activity increases (increasing chl *α*), diurnal variation in pH, as well as magnitude and diurnal variation in dissolved oxygen, increases as well (Table 7). This demonstrates some of the complex ecosystem relationships associated with algal productivity.

Table 7 - Parameter minimum, maximum, and range of results during varying algal activity periods.

Algal Activity	**Dates (2018)**	**BG (cells/mL)**	**Chl α (µg/L)**	**pH (S.U.)**	**DO (mg/L)**
Low	June 14-15	1 to 2 (1)*	3.1 to 8.0 (4.9)	6.2 to 6.3 (0.1)	6.5 to 7.1 (0.6)
Medium	July 21-22	1 to 2 (1)	7.7 to 19.4 (11.7)	6.5 to 7.0 (0.5)	7.7 to 8.4 (0.7)
High	Sept 1-2	2 to 4 (2)	10.7 to 32.2 (21.5)	6.3 to 7.3 (1.0)	8.0 to 9.0 (1.0)

*Parameter results shown as "minimum to maximum" and "(range of values)" during given timeframe.

Conclusions

The alum application had significant impacts on the water quality and aquatic life of White Lake, both positive and negative. The pH in the lake was the highest ever recorded prior to the application and returned to pre-2017 levels following the application. The application also brought a subsequent shift in trophic status from hypereutrophic back to mesotrophic. Decreasing nutrients, primarily phosphorus, which was the primary goal in the alum application, did occur. The levels of phosphorus were reduced from 0.06 mg/L to below detection (PQL = 0.02 mg/L) and TON levels also dropped. The drop can likely be attributed to the reduction of algae in the water column. Secchi depth increased and TSS decreased indicating an improvement in water clarity, although an increase in turbidity in August was observed. The alum application also had a large impact on the algae in White Lake. Chlorophyll *α* and phytoplankton unit density both decreased after the application returning to pre-2017 conditions. Algal assemblage structure also changed reflecting mesotrophic and oligotrophic taxa.

On the other hand, levels of aluminum and copper were both acutely and chronically toxic during the first few days of the alum application and subsequent fish kill. Copper values prior to the application were similar to those after application began suggesting that the elevated copper concentrations could be from some other anthropogenic source (e.g., copper-based herbicides used by residents) or naturally occurring. However, pre-application aluminum concentrations were non-detect or at the minimum detection level (50 µg/L). Dissolved aluminum increased dramatically from observed background concentrations after the alum application (1,600-1,700 µg/L). Alum application is safest and most effective at creating a floc between pH values of 6.0 S.U. and 8.0 S.U. (Gensemer and Playle, 1999). At higher pH values (>8.0 S.U.), alum application can result in a higher proportion of free aluminum compounds that are toxic to aquatic life (North American Lake Management Society, 2016). When the alum application began, pH values were recorded by DWR staff as high as 8.5 S.U. This may have caused conditions toxic to aquatic life in a water body with few areas of refuge due to the shallow, well-mixed characteristics of the lake. It is worth noting that concurrent with the fish kill, DO and pH levels remained well within the bounds for aquatic life support absent the alum application (Kyle T. Rachels, WRC, personal communication, May 31, 2019).

Ammonia toxicity was considered as well. The toxicity of NH_3 to aquatic life increases as pH increases (Wetzel, 2001). With pH levels above 8.0 S.U. in a lake that historically has had much lower pH, it was plausible that NH_3 toxicity could be a factor. However, DWR has found no detectable concentrations of NH_3 in White Lake since 2015, so it is unlikely that NH_3 could have attributed to the fish kill. Based on the evidence available to DWR, it was determined that alum application played a major role in the unprecedented fish kill that occurred at White Lake in 2018.

Even though the change from hyper- to mesotrophic may be attributed to the alum application, the removal of over 40,000 pounds of fish, an estimated 40 to 50% of the total population of fish in White Lake at the time (Kyle T. Rachels, WRC, personal communication, May 31, 2019), had a significant impact on the water quality and ecosystem of the lake. Furthermore, data indicates that chl α levels began increasing within a few months of the application and that, coupled with the fact that sources of the nutrients and/or changes in pH have not been fully identified or mitigated, it appears the positive changes may be short lived and the lake's water quality will continue to decline into the foreseeable future. The identification of nutrient sources to this unique system is critical to implement measures necessary to return White Lake to the pristine ecosystem of the past.

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