Pilot Harmful Algal Bloom Monitoring Project:
Lackawanna Lake, Lackawanna County, PA

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INTRODUCTION AND BACKGROUND

Harmful algal blooms (HABs) are a topic of ever-increasing interest to aquatic scientists, particularly as they are related to a changing climate. HABs can occur when algae species grow out of control and can produce toxins in the water that can lead to harmful effects on people, fish, birds, and pets. The human illnesses caused by HABs are rare but can be debilitating or even fatal. Harmful algal blooms do not have to be producing toxins to be harmful, however. Additional impacts of excessive algal growth that are non-toxic but nonetheless detrimental include depleted oxygen levels in the water as the algae decay, clogging of gills in fish and invertebrates, the smothering of submerged aquatic vegetation, and fish kills.

Monitoring for HABs outbreaks in a waterbody is crucial so that recreational water contact (swimming, wading, or fishing) can be limited or banned to protect human and animal health. This type of monitoring has been underway by a variety of regulatory groups such as state health departments and environmental agencies. The Susquehanna River Basin Commission (Commission) is working with the Pennsylvania Department of Environmental Protection (PADEP) and the Pennsylvania Department of Conservation and Natural Resources (PADCNR) through the PA HABS Task Force to assist in gathering data and sharing research and monitoring strategies. Because of the lag time between sampling and results and how rapidly HABs can materialize, warnings can be delayed and people exposed unknowingly.

In recent years, scientists have been evaluating potential methods of predicting the occurrences of HABs. With partial funding support from the U.S. Environmental Protection Agency (USEPA) through a Water Pollution Control (Section 106) grant, the Commission initiated HABs studies in two waterbodies in the Susquehanna River Basin: Lackawanna Lake (Lackawanna County, PA) and Octoraro Lake (Lancaster County), PA.

Lackawanna Lake, in Lackawanna State Park in northeastern Pennsylvania, is a manmade, mesotrophic reservoir that covers 198 acres within Lackawanna State Park. While Lackawanna Lake has had historic HABs, none have been observed in recent years. Octoraro Lake is a 650-acre manmade eutrophic reservoir that receives a higher nutrient influx.

The data being collected in these studies will be used to pursue two objectives:

1. Monitor water quality conditions and document potential HABs in these waterbodies, and
2. Link in-lake conditions with remote sensing technologies to develop a predictive tool to anticipate HABs occurrences.

This technical report has two purposes:

1. To summarize the first year of data collected in Lackawanna Lake in 2021, and
2. To introduce efforts for the second year of data collection that occurred in Octoraro Lake in 2022.

The Commission intends to continue collecting HAB and associated environmental data to develop a robust dataset that will serve to address HAB issues in the Susquehanna River Basin.

METHODS

Commission field crews followed the field methods outlined in the USEPA-approved Quality Assurance Project Plan (SRBC, 2021). Sampling occurred within Lackawanna Lake and also in the streams draining to the lake.

A continuous monitoring sonde was deployed on a buoy in Lackawanna Lake, in 30 feet of water on the south end of the lake near the dam (Figures 1 and 2). The sonde operated from May 5 through October 21, 2021, and collected water temperature, dissolved oxygen, specific conductivity, pH, turbidity, and chlorophyll-a measurements every 30 minutes from a fixed point approximately one meter below the surface. Two HOBO sensors were also affixed to the buoy to also measure air temperature and sunlight intensity.

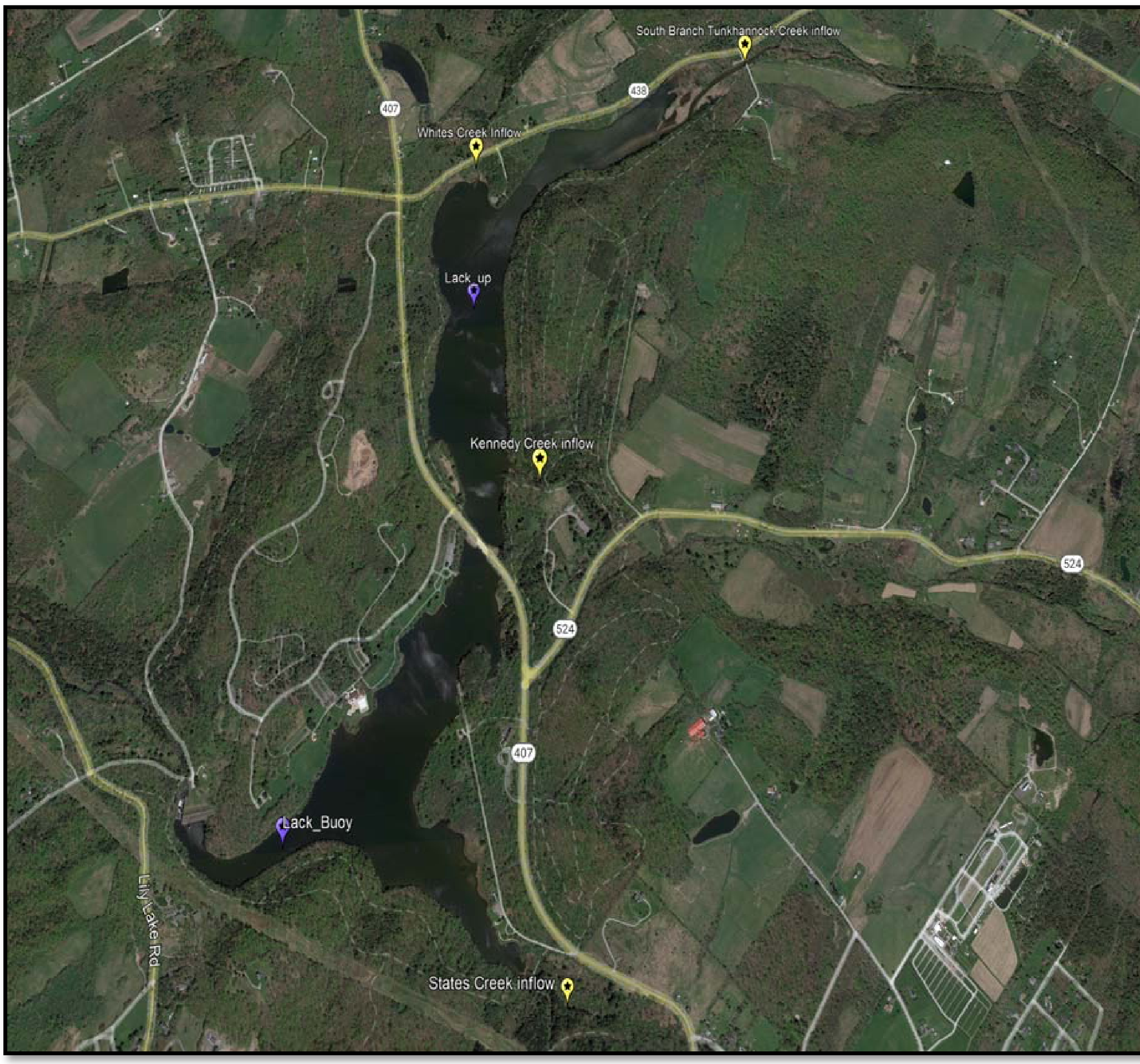

Figure 1. Map of Lackawanna Lake Showing Sampling Locations

Figure 2. SRBC Staff Deploying Water Quality Monitoring Sonde Into the Buoy

Sampling events occurred twice monthly at two locations in the lake, one at the same location as the monitoring sonde and the second at the northern part of the lake. During each sampling event, Commission field crews recorded depth profiles of temperature, pH, dissolved oxygen, and conductivity at regular depth intervals and secchi depth, and collected nitrate, phosphorus, suspended sediment, and chlorophyll-a samples for laboratory analysis. These twice-monthly sampling events were conducted concurrently with the overpass of Sentinel 2A and Sentinel 2B satellites to allow for validation of imagery-derived chlorophyll-a and max chlorophyll-a values. During each sampling visit, algal samples were taken in support of PADEP HABs monitoring efforts using PADEP protocols at 3 boat launches and both lake sampling sites. These samples were analyzed for potential toxin-producing cyanobacteria and then algal toxins if cell count thresholds were met (PADEP, personal communication).

Once monthly, nitrate, phosphorus, and suspended sediment samples were collected from each of the four inflow tributaries to Lackawanna Lake (Figure 1), including South Branch Tunkhannock Creek, Whites Creek, Kennedy Creek, and States Creek. Precipitation data were obtained from the Binghamton, NY, airport rainfall gage data.

Table 1. Summary of Sampling Activities

Waterbody	**Site**	**Sampling Frequency**	**Parameters Sampled**
Lackawanna Lake, buoy site	Lack_buoy	Twice monthly	Temperature, pH, dissolved oxygen, conductivity, secchi depth, nitrate, phosphorus, suspended sediment, chlorophyll-a. Algal counts and algal toxins (PADEP)
Lackawanna Lake, northern/uplake site	Lack_up		
South Branch Tunkhannock	SBTK 14.0	Once monthly	Temperature, pH, dissolved oxygen, conductivity, nitrate, phosphorus, suspended sediment
Kennedy Creek	KENN 0.3		
States Creek	STAT 0.2		
Whites Creek	WHITE 0.2		
3 boat launches		Twice monthly	Algal counts and algal toxins (PADEP)

RESULTS AND DISCUSSION

Nutrients

Not surprisingly, about 80 percent of the inflow to Lackawanna Lake comes from South Branch Tunkhannock Creek, which is dammed to form the lake. An additional 10 percent of flow comes from Kennedy Creek. States and Whites Creeks contribute 6 and 3 percent of the flow, respectively.

Nitrate and phosphorus concentrations were relatively consistent at each stream site throughout the sampling period (Figures 2-3). Nitrate concentrations were generally highest at States and Kennedy Creeks (between 0.44 and 0.66 mg/l), which drain more proximate agricultural lands on the east and southeast side of the lake. Nitrate concentrations at South Branch Tunkhannock and Whites Creek ranged between 0.22 and 0.36 mg/l. Land use around these two tributaries is more low intensity development and the agricultural land is not as close to stream corridors.

Total phosphorus concentrations were below 0.1 mg/l at all stream and lake sites with the exception of one sampling event, taken after a major rain event (outlier in Figure 3). Phosphorus concentrations in the lake were similar to the concentrations documented at the stream sites.

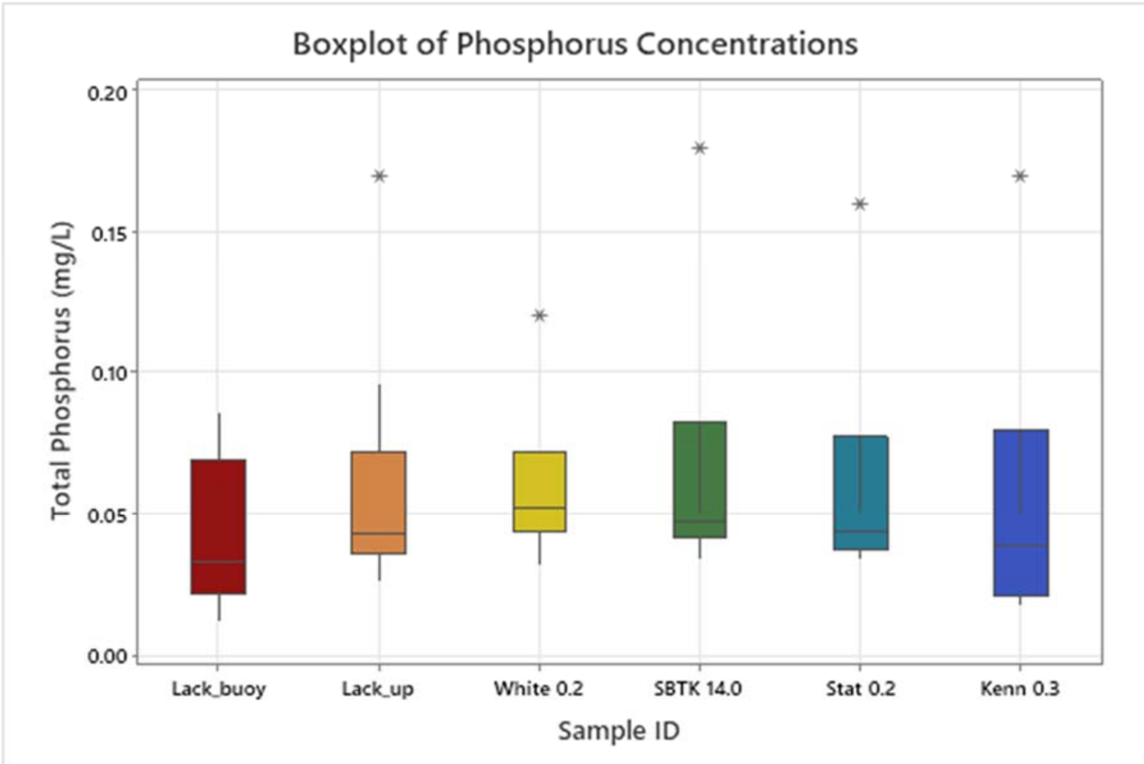

Figure 3. ***Box Plot of Phosphorus Concentrations for Each Lackawanna Lake Sampling Sites, May-October, 2021***

Not unexpectedly, nitrate concentrations were lower at the lake sites than the stream sites. Nitrate concentrations were slightly higher at the uplake site than at the buoy site, but the uplake site experienced more outlier concentrations after storm events (Figure 4).

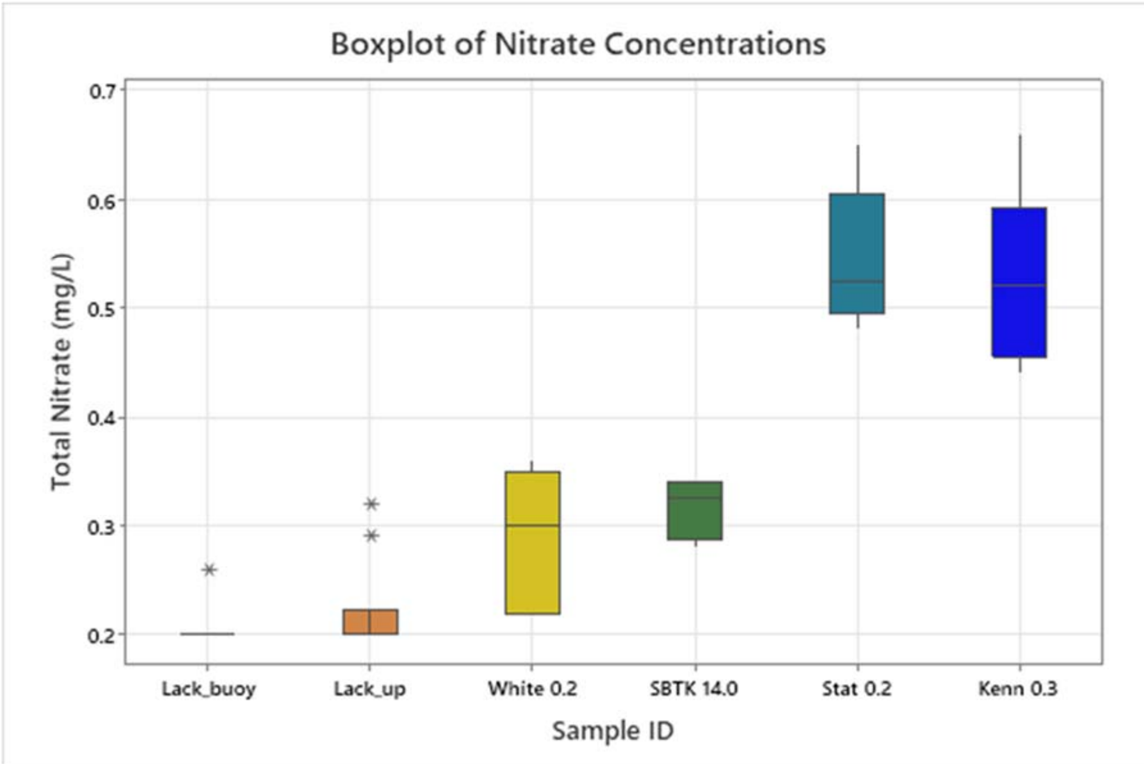

Figure 4. Box Plots of Nitrate Concentrations at Lackawanna Lake Sampling Sites, May-October 2021

Continuous chlorophyll was collected by the water quality sonde in two ways: one as a relative reflective unit (RFU) and one as an estimated concentration (µg/L) based on lab studies correlating RFU to known concentrations of chlorophyll. Data were collected every 30 minutes but there was a sensor malfunction for a short period of time in June and those data are missing from the time series plots. Relationships between estimated chlorophyll concentrations from the sonde and corresponding discrete water samples taken for lab analysis of chlorophyll showed a lot of variation that may be linked to the location of the sonde in the water column not corresponding with maximum chlorophyll. More study and improved sampling methods are needed to get at this issue, particularly in systems with relatively low chlorophyll concentrations.

<u>Precipitation</u>

Understanding how rainfall affects lake water quality is critical to understanding how and when a HAB event may occur. Average daily rainfall data were plotted against daily max chlorophyll concentrations (Figure 5). Results show that chlorophyll-a spikes after rain event are evident, although the lag time between precipitation and chlorophyll-a spikes was not consistent. Generally a 2-3 day time lag between rainfall and chlorophyll spike was observed. This pattern, coupled with the spike in phosphorus in the inflow tributaries documented after one rain event, points to potential factors for increased chlorophyll. Monthly views of chlorophyll concentrations also generally reflect wetter and drier months, with July showing the greatest monthly rainfall total (Table 2) and one event over 3.5 inches in one day (Figure 6).

Table 2. Summary of Recorded Rainfall Per Month

Month	Mean Rain/Day (inches)	Monthly Rainfall (inches)
June	0.1	3.0
July	0.36	11.21
August	0.11	3.43
September	0.14	4.3
October (21 days)	0.09	1.84

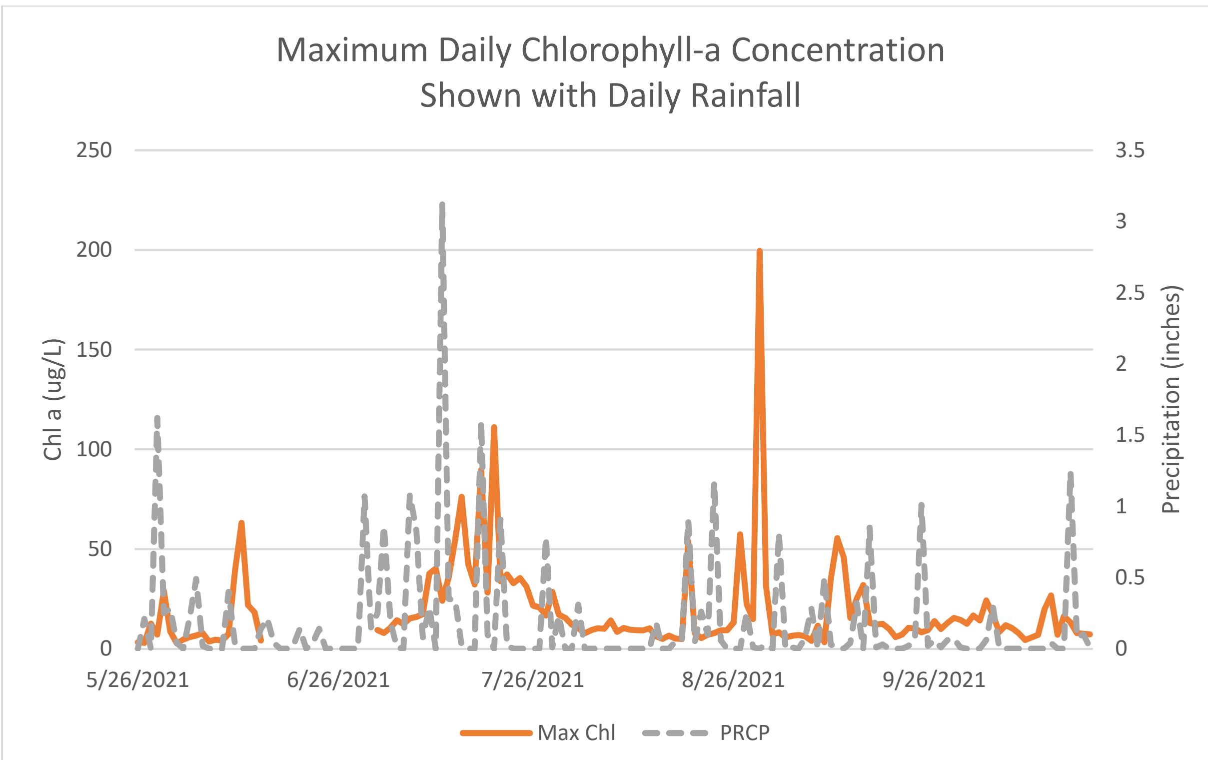

***Figure 5.** Time Series Plot of Average Daily Rainfall and Daily Maximum Chlorophyll-a Concentrations at Lack_buoy*

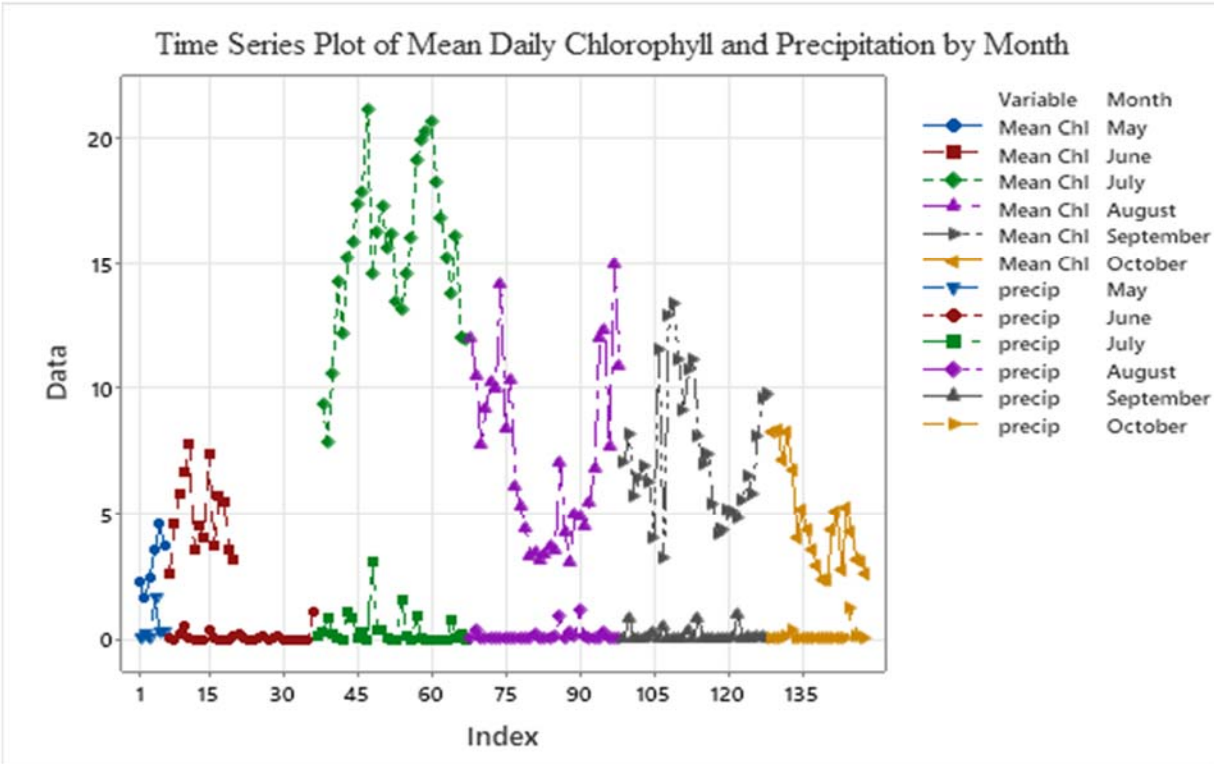

Figure 6. Mean Chlorophyll-a and Precipitation by Month at Lackawanna Buoy Site

<u>Algal Toxins</u>

Algal samples were collected for PADEP during every sampling event. If potential toxin-producing cyanobacteria genera were present above a threshold of 300 cells then a toxin screen was completed on that sample. Although no blooms were observed in Lackawanna Lake in 2021, algal toxins were present four different times in samples taken at 1-meter depth in the water column at the buoy location. These toxins all occurred later in the summer and were not consistent with peaks in maximum daily chlorophyll-a (Figure 7). When these toxin-containing samples were collected, Commission field crews did not observe any algae or difference in the color or condition of the lake compared to other sampling events.

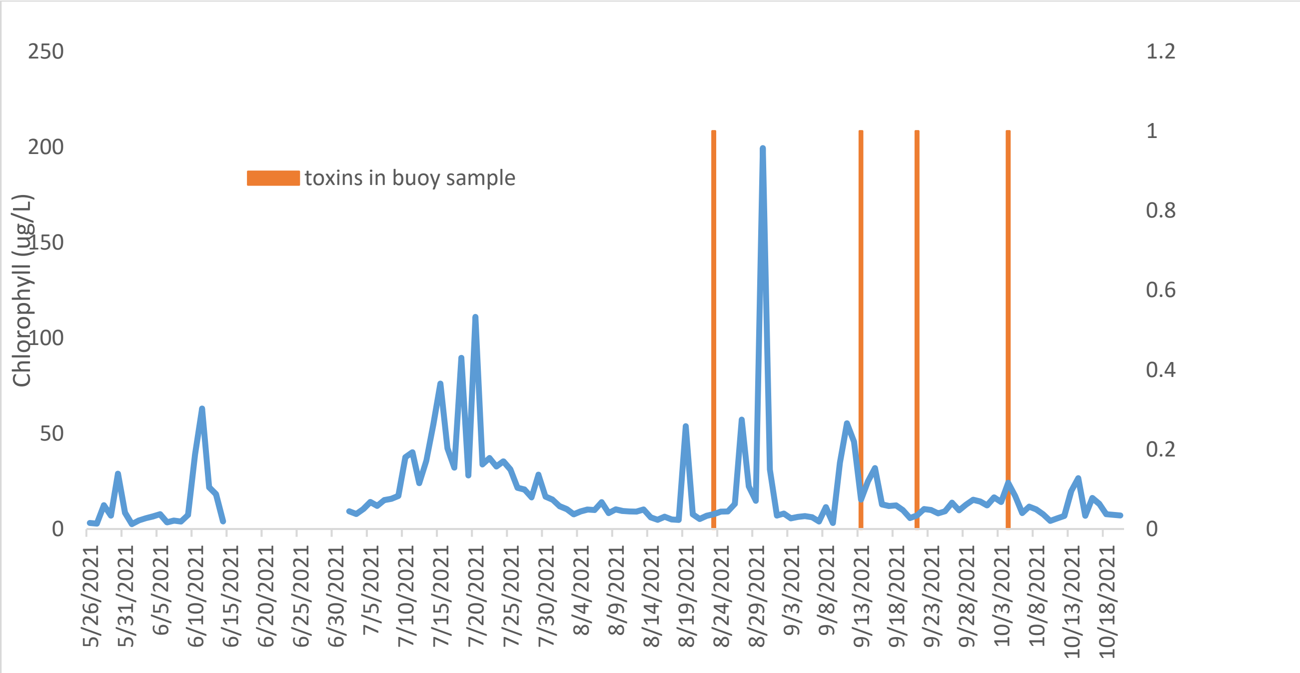

Figure 7. Time Series Plot of Maximum Daily Chlorophyll-a Shown with Discrete Positive Detections of Toxins at Lack_buoy (Toxin observation is presence/absence, not concentration)

Water Clarity

Secchi depth is a typical parameter measured during a lake sampling event to measure water clarity. Since secchi depth can only be measured during a discrete sampling event, a light intensity sensor was installed to see if measurements could function as a continuous surrogate for water clarity. Unfortunately, a chlorophyll-a sensor malfunction occurred throughout the month of June that overlapped with the period of greatest light intensity recorded during the study period (Figure 8). While additional light intensity data were collected throughout the rest of the study period, more data are needed to better evaluate the effectiveness of light intensity as a continuous water clarity parameter and an important variable in monitoring and predicting algal blooms. It was difficult to correlate discrete secchi depth measurements with light intensity as secchi depths were only taken every two weeks at about the same time of day and secchi depth did not vary more than 0.1 meters at any sampling event.

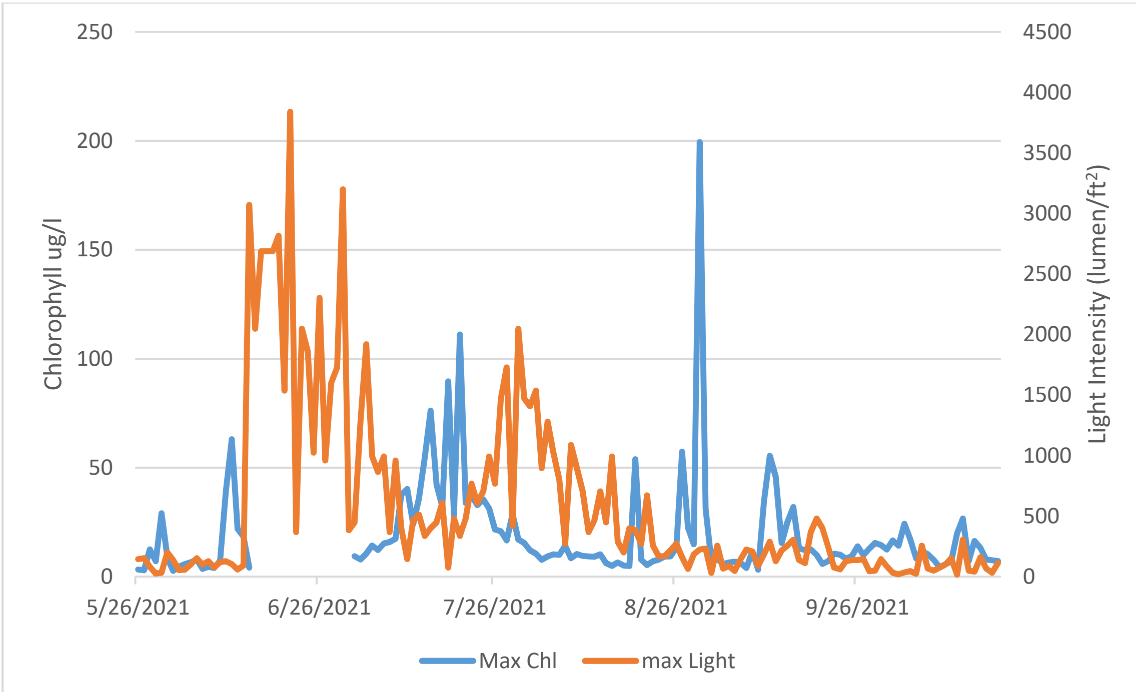

Figure 8. Time Series Plot Showing Maximum Daily Chlorophyll and Maximum Daily Light Intensity at Lack_buoy

Depth Profiles

Temperature Depth Profiles

Field crews measured temperature and dissolved oxygen at Lack_buoy in one-meter intervals during each sampling event from the surface to a depth of 9 meters. Temperature and dissolved oxygen measurements (Figures 9 and 10, respectively) show strong lake stratification through most of the summer until fall turnover occurred between September 22 and October 4 sampling events. Both of these depth profiles show how a storm that occurred just before the August 23rd sampling event caused mixing of shallower depths of the lake. This mixing might also have had an impact on the way cyanobacteria and any associated toxins disperse across the lake horizontally and vertically.

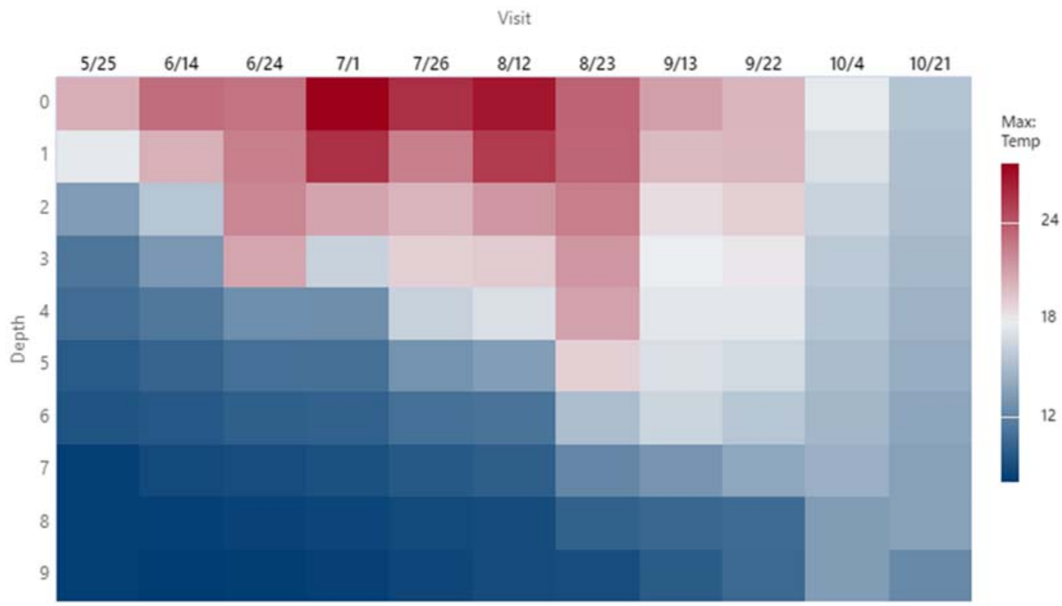

Figure 9. Heat Map Showing Temperature Depth Profile Data for 2021 Sampling Events (Temperature in C; depth in m) at Lack_buoy

Dissolved oxygen stratification was more pronounced than temperature. In mid-July, dissolved oxygen at 2 meters from the surface was already down to nearly 2 mg/l. In the bottom 3 meters it was typical for dissolved oxygen to be less than 0.5 mg/L (Figure 10).

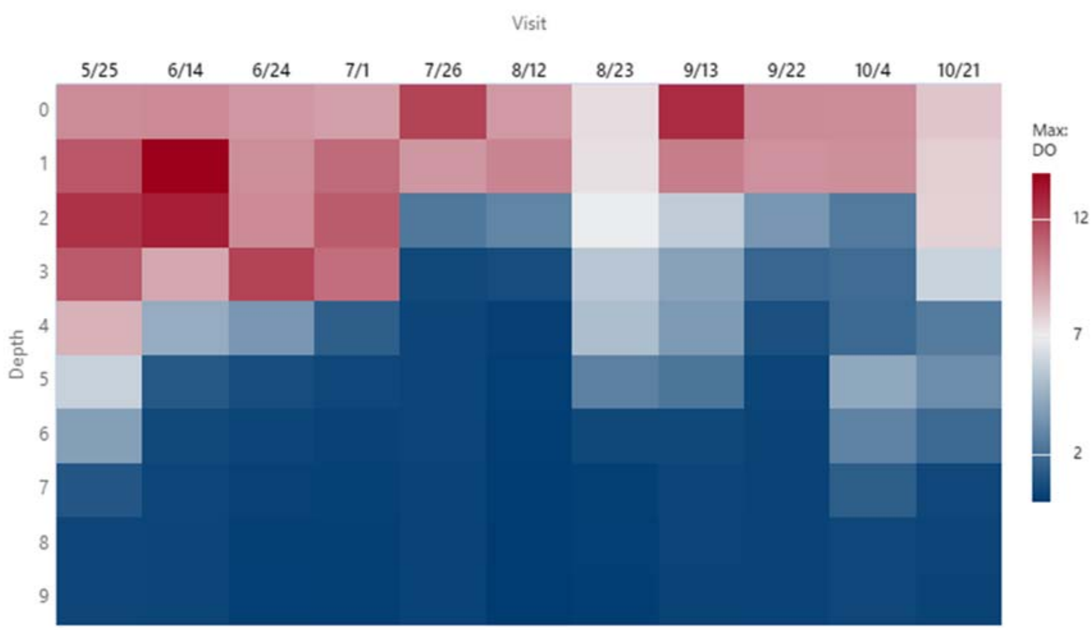

Figure 10. Heat Map Showing Dissolved Oxygen Depth Profile For All 2021 Sampling Events (Dissolved oxygen in mg/l; Depth in m) at Lack_buoy

Continuous Measurements

Continuous measurements were also recorded at Lack_buoy at a depth of 1.3 meters throughout the study period. All the continuously measured in-lake parameters were relatively stable across the study period (Figure 11). Continuously measured maximum daily values follow generally consistent patterns of dissolved oxygen, stable pH, predictable seasonal temperature shifts, and infrequent peaks in chlorophyll and turbidity which are also short in duration. There was no obvious correlation between pH and chlorophyll spikes and turbidity spikes followed rain events and were more influenced by rainfall than by algae or other biomass in the water.

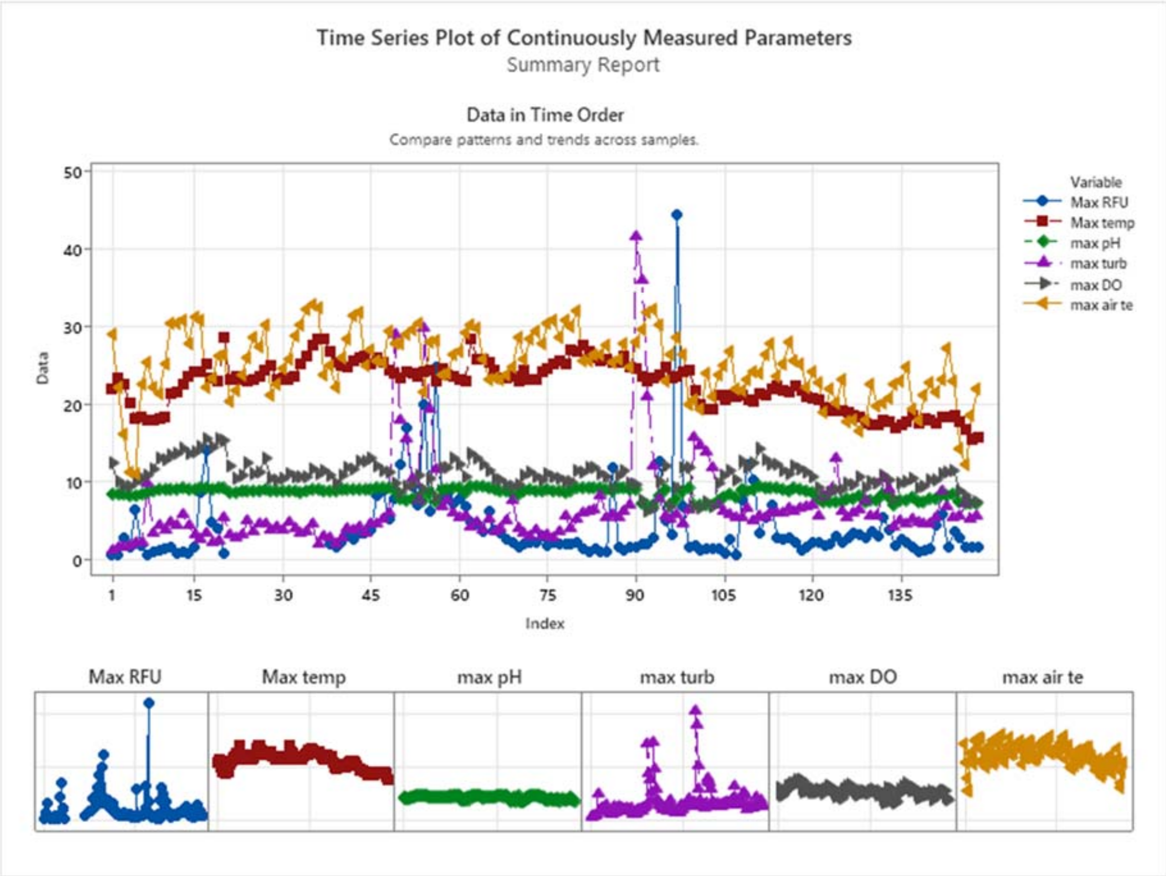

Figure 11. Time Series Plot of Continuously Measured Daily Maximum Values at Lack_buoy (Y axis reads in RFU for chlorophyll, degree Celsius for temperature, pH units for pH, NTU for turbidity and mg/L for dissolved oxygen; X-axis reflects sampling days)

<u>Comparison Between Two Lake Sites</u>

Spatial heterogeneity is a key factor that needs to be examined as patterns and indictors of harmful algal blooms are researched. Depth profiles were mapped and chlorophyll-a samples were also taken at the second lake site (Lack_up). No consistent patterns were observed in chlorophyll-a concentrations between the two lake sites. Chlorophyll-a values were higher at Lack_buoy than Lack_up at 70 percent of the paired sampling events from May to October. However, at one sampling event in September, the chlorophyll-a value at Lack_up was nearly 4 times higher (Figure 12).

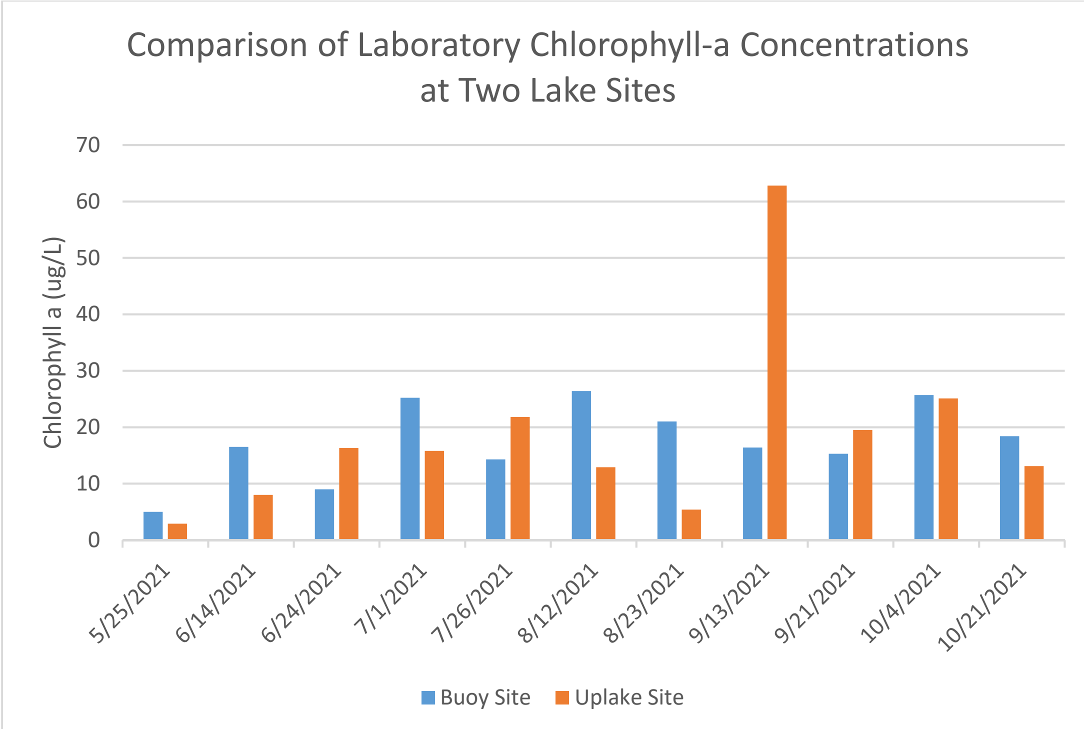

Figure 12. Comparison of Laboratory Chlorophyll-a Concentrations (ug/L) at Two Lake Sampling Locations

Satellite Correlations

Concurrently with this data collection effort, colleagues at Harrisburg University are working on interpreting Sentinel-2 imagery and indexes derived from that imagery to assess the potential use of satellite data to supplement HABs monitoring of small inland lakes. Initial research pairing Lackawanna Lake data were promising, but in the end, results were limited given cloud cover, a narrow range of low chlorophyll-a concentrations, and a short study period.

To improve the analytical success of satellite correlation, the second year of data collection in 2022 was instead conducted in Octoraro Lake using the same sampling framework. Octoraro Lake is a eutrophic lake that has more productivity and higher chlorophyll concentrations. Preliminary results from Octoraro Lake monitoring in 2022 revealed a greater range in chlorophyll concentrations as well as a very different lake chemistry, both of which will complement the data collected in 2021 and improve the strength of any observed relationships.

Discussion and Next Steps

The 2021 monitoring effort in Lackawanna Lake represented the Commission's first attempt at continuous monitoring in a lake setting, as well as the first HAB-focused monitoring. Through this project, Commission scientists became proficient in new water quality monitoring technologies, learned which data were most valuable to collect and interpret, and refined the sampling design to improve the outcome of the project.

While no actual algal blooms were observed during either year of sampling, toxins were present in low concentrations a few times. Questions surrounding toxin formation, duration of toxic conditions, meaningful algal counts, and the lag time between environmental change and bloom all need to be better understood.

The total algal sensor on the YSI EXO includes a measure of chlorophyll reflective units (RFU) as well as an estimated concentration (ug/L) based on an internally programmed relationship between RFU and concentration. In order to validate that concentration in the specific waterbody where data are being collected, chlorophyll samples are taken and the laboratory results are compared to sonde readings for RFU and concentration to create a correction factor if needed. The results of this exercise in 2021 ended with mixed results and moving forward, additional data need to be collected to better understand the inconsistencies between the sonde reading and laboratory measured values.

Other studies have shown high levels of HABs heterogeneity (i.e., highly variable concentrations of chlorophyll, pockets of algal blooms) in shallow eutrophic lakes in particular. A second lake site was sampled in each lake in an attempt to understand spatial variances. Additional work needs to be done to get a handle on those differences and how they impact bloom potential. At this time, the second lake site did not have continuous monitoring which limits the potential for detailed comparability.

Commission staff are involved in Pennsylvania's statewide HABs Task Force groups, both technical and policy. Continued coordination with state agencies tasked with regulating HABS advisories and monitoring recreational and drinking water sources for human health concern is critical. Because the Commission does not directly regulate water quality or issue advisories, these meetings provide opportunities for us to fill in research gaps, provide monitoring support, and share results outside of the regulatory arena.

REFERENCES

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