MOUNTAIN LAKE 2021
WATER QUALITY MONITORING REPORT
TOWNSHIP OF LIBERTY, WARREN COUNTY, NEW JERSEY

PROJECT NUMBER: 2002.001
DECEMBER 2021
UPDATED JANUARY 2022

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1.0 INTRODUCTION

The report that follows has been prepared by Princeton Hydro, LLC for the Mountain Lake Community Association (MLCA). This report presents, reviews, and summarizes the findings of the water quality monitoring program conducted by volunteers from the MLCA for Mountain Lake in 2021.

Due to increasing concerns regarding the water quality and associated algae blooms in Mountain Lake, the Mountain Lake Community Association and Watershed Advisory Group began the development of a comprehensive volunteer water quality sampling program in 2021. The collection of consistent yearly water quality data will assist the MLCA, under the advisement of Princeton Hydro, LLC, in shaping future management recommendations and efforts for restoring and maintaining Mountain Lake's limnological state.

In early 2021, Princeton Hydro reviewed the 2021 water quality monitoring program proposed by the MLCA, as well as the sampling equipment currently possessed by the MLCA, and assisted in developing a sampling plan for a successful community volunteer water quality monitoring program. The program was also assisted by the New jersey Department of Environmental Protection (NJDEP).

The 2021 monitoring program involved the collection of water quality and nutrient (phosphorus) data for three (3) sites on the Lake. Data collected by volunteers on Mountain Lake was collected using monitoring protocols recommended by Princeton Hydro, as based on NJDEP protocol. These protocols mirror those which have been successfully employed on numerous other lakes in the northeast by Princeton Hydro staff. Specifically, the 2021 monitoring program consisted of the following:

- *In situ* (real-time) water quality measurements of dissolved oxygen, temperature, pH, and water clarity,
- Collection of discrete water quality samples for the laboratory analysis of total phosphorus, and
- Collection of cyanobacteria samples and fluorometer data.

The collected data are used by Princeton Hydro to help guide the MLCA in further developing their water quality monitoring program. The overarching objective of a water quality monitoring program is to use the data in a pro-active manner to maximize a lake's recreational usage, aesthetic attributes, and ecological status and function. The monitoring program is focused on the collection of seasonal water quality data from spring to fall, commonly referred to in the Northeast as "the growing season."

The balance of this report reviews the water quality data collected in Mountain Lake by volunteers over the 2021 growing season. This report discusses this data in a streamlined format and concludes with a series of recommendations for the management of the Lake and further development of the water quality monitoring program in 2022.

2.0 METHODS

Water quality monitoring by Mountain Lake community volunteers followed protocols based on the NJDEP and work conducted by Princeton Hydro in numerous lakes in the Northeast. These methods aim to form a consistent long-term dataset that can be examined for trends and patterns useful in aiding the year-to-year management of the Lake. Prior to the beginning of the sampling season, volunteers were trained and advised during a 1-day (May 15th) training session on the collection of water quality data by Princeton Hydro staff.

Mountain Lake was then sampled by the volunteers thirteen (13) times over the course of the 2021 growing season – i.e., biweekly from May 15th through November 17th. This pattern allows for the assessment of changes in conditions such as stratification, bottom anoxia, and vegetation and algae growth. Sampling events consisted of the following:

- ***In Situ* Sampling:** The measurement of temperature, dissolved oxygen, and pH in real-time using calibrated water quality meters. Data for dissolved oxygen and temperature were collected at every 3 feet in depth, from surface to bottom. pH levels were measured using a hand-held meter from water samples brought up from various depths using a depth-sampling device. Additionally, water clarity was measured at each *In situ* station using a Secchi disk.
- **Discrete Sampling:** The collection of water quality samples for specific laboratory analysis. Samples were collected at the mid-lake station at both the surface and just above the bottom sediments to examine important vertical differences in lake water quality. Additional bottom samples were also collected from the north and south stations. All laboratory analyses are conducted by Environmental Compliance Monitoring (ECM) of Hillsborough, New Jersey, a NJDEP certified laboratory (#18630). ECM is the preferred contractor because of their excellent detection limits and focus on natural waterbodies rather than wastewater. Water samples were analyzed for total phosphorus, the most common limiting nutrient for algae, cyanobacteria, and plant growth in New Jersey lakes.
- **Cyanobacteria Analysis:** Cyanobacteria, or "blue-green algae," are microscopic organisms that live in aquatic environments and can form large blooms. These organisms differ from other forms of common freshwater algae in that they have a potential to release harmful toxins into the water column (USEPA, 2014). Surface water samples for cyanobacteria were collected by both volunteers and NJ Department of Environmental Protection (NJDEP) employees at different areas of the lake and delivered to a NJDEP laboratory for enumeration of cyanobacteria cells. In addition, volunteers measured surface concentrations of phycocyanin, a pigment often found in cyanobacteria, using a handheld meter.
- **General Observations:** Information pertaining to the aesthetics and appearance of the lake was recorded during each sampling event. This observational data provides a context and background to better understand the sampling data. These observations also prove useful in identifying correlations between various water quality indicators and such factors as prevailing weather conditions and water color.

3.0 RESULTS

3.1: *IN SITU* DATA

In situ data refers to temperature, dissolved oxygen, and pH data collected directly in the field using a water quality meter. Temperature and dissolved oxygen (DO) in particular drive the main conditions of a lake that can influence nutrient loading and subsequent plant, algae, and cyanobacteria growth. By measuring these parameters at multiple points along the water column, differences between the surface and bottom-most depths of a lake can be determined. For example, thermal stratification is the natural process during which a lake will be divided into two or more layers of differing temperature. This will occur during the summer months, when surface waters warm and become less dense, while water near the bottom of the water column remains relatively cold and dense. The point along the water column at which the temperature drops the quickest between two measured depths is referred to as the thermocline, while the deeper, colder strata of the water column will be referred to as the hypolimnion. A major impact of this process is the depletion of dissolved oxygen (DO) near the bottom of the water column as a product of reduced surface mixing and deep-water microbial activity. Under these conditions, not only is cold-water fish habitat reduced, but a total lack of oxygen at the bottom sediments (referred to as anoxia) may allow for redox reactions to occur, resulting in phosphorus normally bound to the sediment to become soluble in the water column (James et al., 2015, James and Bishoff, 2015, Nurnberg, 1985). The mixing of the water column as a result of temperature decreases at the end of the year or due to a large storm event can allow this phosphorus to move to the top of the water column, where it is available for assimilation by algae and cyanobacteria. For this reason, many lakes experience algae blooms in the fall season, shortly following "lake turnover."

As a relatively deep waterbody (approx. 35' deep), Mountain Lake was thermally stratified throughout most of the growing season (Figure 1). During the May 15th event, thermal stratification was observed to occur approximately halfway through the water column, with a thermocline (the area of sharpest temperature change) occurring between approximately 12' and 15' in depth. It should be noted that the lake was already experiencing a degree of dissolved oxygen reduction at depth, with the bottom-most approximately 3-5' measuring below 1 mg/L at the mid-lake station (Figure 2). Thermal stratification followed similar patterns during the two June events, although bottom dissolved oxygen concentrations, while reduced, were mostly measured above 1 mg/L. By mid-July, thermal stratification had strengthened, with the mid-lake station showing a difference of almost 10°C between the 12' and 15' deep measurements. It should be noted that, at this point in time, the dissolved oxygen profile shows a large increase to approximately 13 mg/L at the thermocline. This degree of super saturation at the thermocline usually suggests that a large population of deep-water algae or cyanobacteria are suspended at this depth. This is further suggested by higher pH and fluorometer readings from these depths. The July 30th sampling event yielded similar conditions, although the bottom of the water column, while still somewhat reduced, measured higher dissolved oxygen readings than 1 mg/L. Similar patterns were measured throughout August. By September 14th, surface water temperatures began to cool and stratification became weaker, with the thermocline dropping to between 18' and 21'. Bottom dissolved oxygen reduction was still prevalent during this time, however, while the supersaturated readings near the thermocline had largely ceased. The lake remained thermally stratified and yielded low bottom dissolved oxygen readings to some extent through the October 18th event. By Mid-November, the water column had become mostly thermally mixed, with only an approximately 3°C difference between the bottom and the top of the water column. The mid-lake station still showed evidence of dissolved oxygen reduction at depth; however, this was only within the bottom-most 3'-6'. The three stations were largely very similar in regard to temperature and dissolved oxygen concentrations; however, the southern station typically featured slightly lower dissolved oxygen concentrations near the surface during the summer months.

Mountain Lake was measured to feature overall relatively high pH values. These usually measured over 8 at the surface of each station, and, at times, over 9. This is typical of a highly productive systems, where a large amount of photosynthesis may be occurring due to plant, algae, and/or cyanobacteria growth. Samples from deeper in the water column typically measured closer to neutral and, at times, somewhat acidic (approximately 6.5-7.5). This is natural for many lakes that stratify, as rates of photosynthesis and dissolved oxygen become lower towards the bottom of the water column.

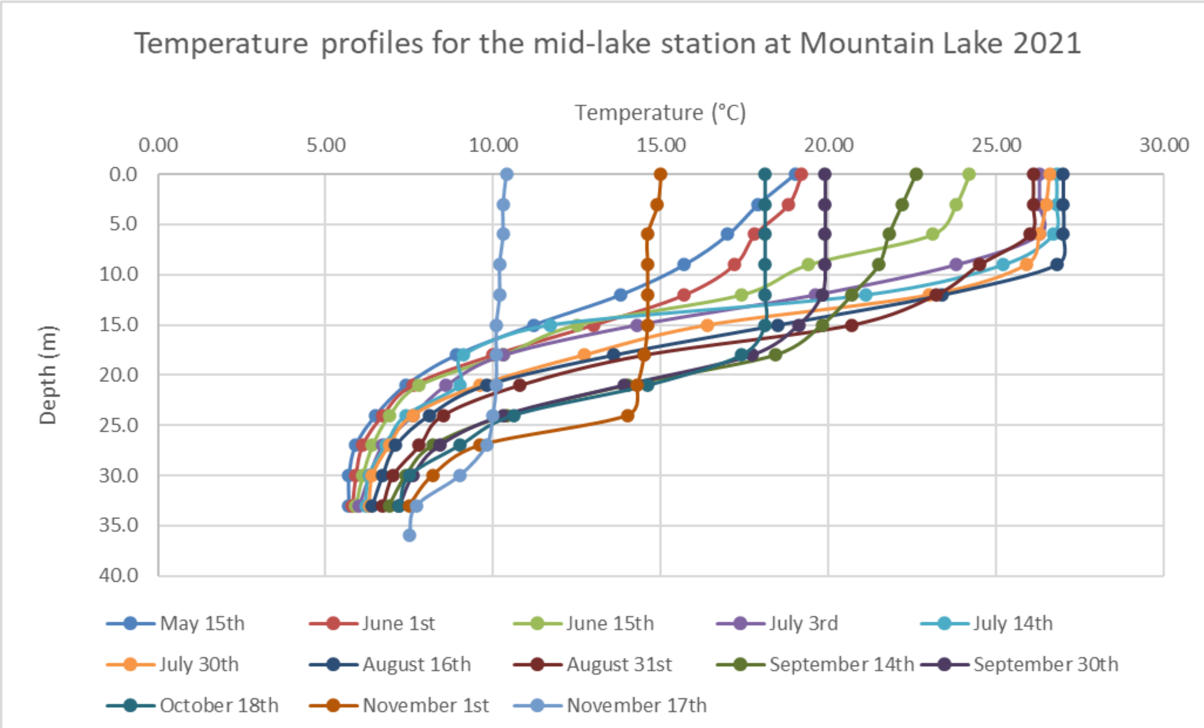

Figure 1. Temperature profiles at the mid-lake station at Mountain Lake - 2021 growing season.

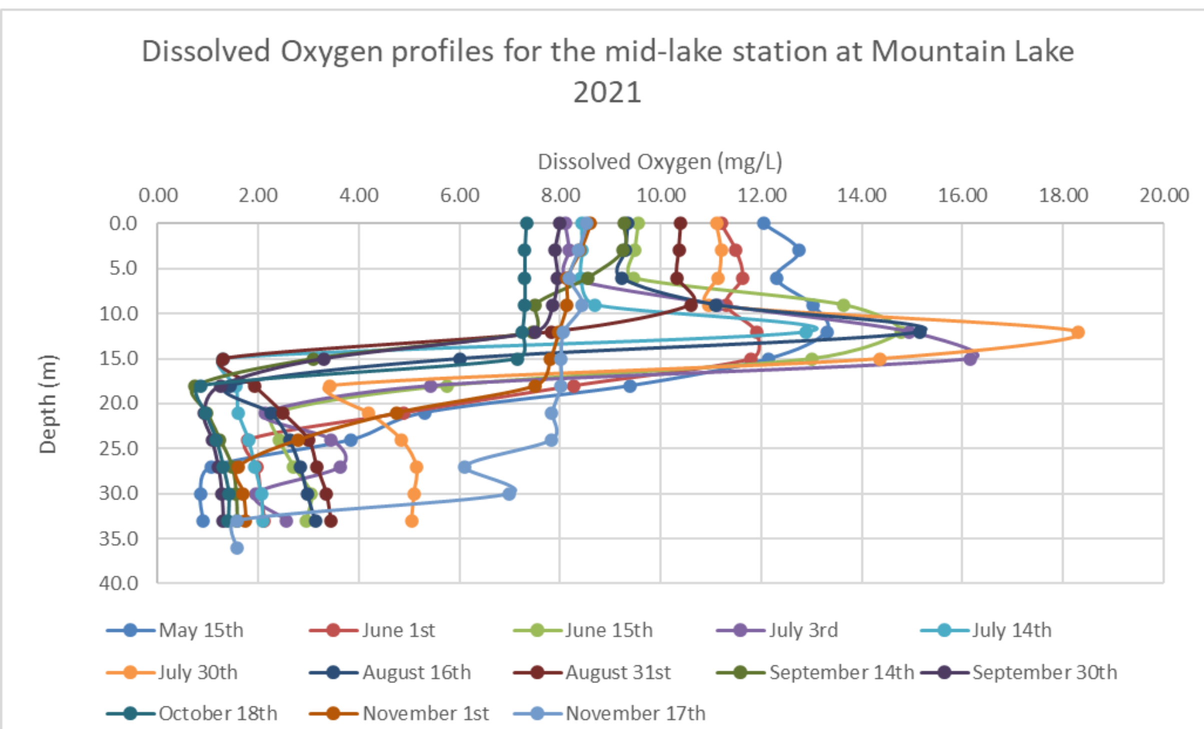

Figure 2. Dissolved Oxygen profiles at the mid-lake station at Mountain Lake - 2021 growing season

Flourometer readings for phycocyanin varied over the course of the season, with surface readings featuring an upward trend through August. Also of note were higher readings from samples at approximately mid-depth during the mid- and late-July events, as well as at the end of August. This suggests that Mountain Lake may harbor populations of algae or cyanobacteria that inhabit the area of the water column adjacent to the thermocline, as mentioned above.

Water clarities, represented by Secchi Depths, were acceptable throughout the growing season (Figure 3). Princeton Hydro usually uses 1 meter, or approximately 3', as what is considered an "acceptable" water clarity in most Northern NJ lakes. Water clarity was at this threshold during the May 15th sampling event, before increasing to the seasonal high of 6' in June. By the end of July, however, clarity had decreased to 3.5', before increasing to 5' in mid-August and remaining between 4'-5' throughout the remainder of the season. Variations throughout the season were likely due to changes in algae and cyanobacteria densities. Cloudy and/or windy conditions during individual sampling events can also lead to lower clarity measurements, as can sampling after a large rain event.

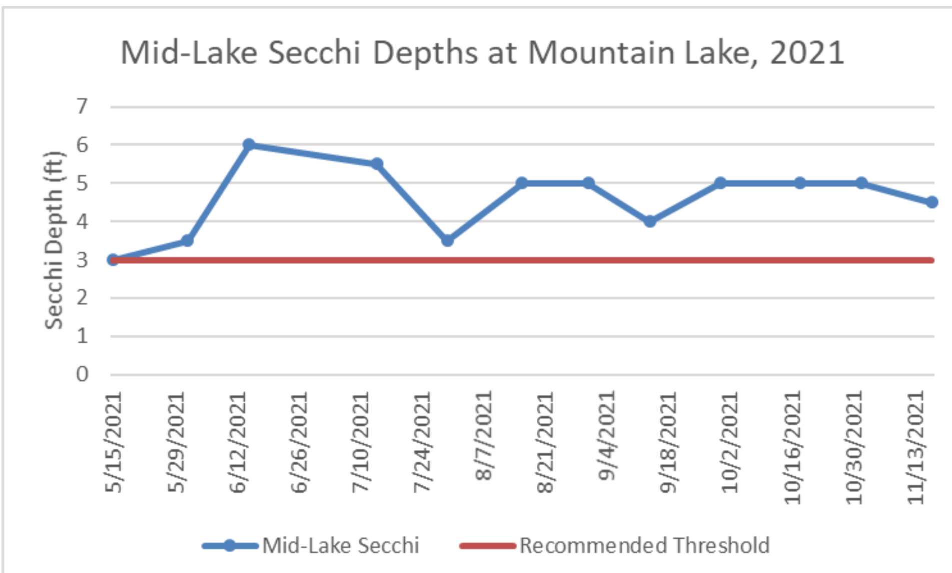

Figure 3. Water clarities as measured by a Secchi disk at the mid-Lake station at Mountain Lake - 2021 growing season.

3.2: DISCRETE SAMPLING

In many Northeastern lakes, algae, cyanobacteria, and plant growth is often the result of increases in nutrient loads, particularly phosphorus. This element is usually the limiting nutrient, or the nutrient that is in low supply relative to others. Even a small increase in phosphorus can result in a noticeable increase in plant, algae and cyanobacteria growth. Phosphorus can enter the water column from outside the system as organic debris and pollutants are washed into a waterbody during runoff events (Dennis et al., 1989), or through the groundwater/surface water interface. Additionally, as described above, phosphorus can enter the water column from the Lake's bottom sediments at an increased rate during periods of bottom anoxia. In 2021, surface and deep water samples collected in Mountain Lake were analyzed for total phosphorus (TP). The NJDEP surface water quality standard (7:9B) for TP is 0.05 mg/L, however concentrations as low as 0.03 mg/L can start to show an impact with regard to cyanobacteria densities.

While surface concentrations of TP in Mountain Lake were all below the 0.05 mg/L surface water quality standard, deep samples were highly elevated, suggesting that internal loading of phosphorus in the hypolimnion was occurring (Figure 4, Table 1). Because very little phosphorus can result in a disproportionately large growth in plant, algae and/or cyanobacteria biomass, a goal of management for many lakes in the Northeast, including Mountain Lake, is to maintain relatively low concentrations of phosphorus throughout the year. According to the NJ Surface Water Quality Standards, lakes should maintain phosphorus concentrations of 0.05 mg/L or less. At the mid-lake station, surface samples measured this value of 0.03 in mid-May and mid-June, with deep samples already measuring much higher than this, at 0.12 mg/L and 0.22 mg/L, respectively. While mid-lake surface samples decreased somewhat during the peak of the summer, deep-water concentrations continued to climb, yielding values as high as 0.46 mg/L during the mid-September and mid-October events.

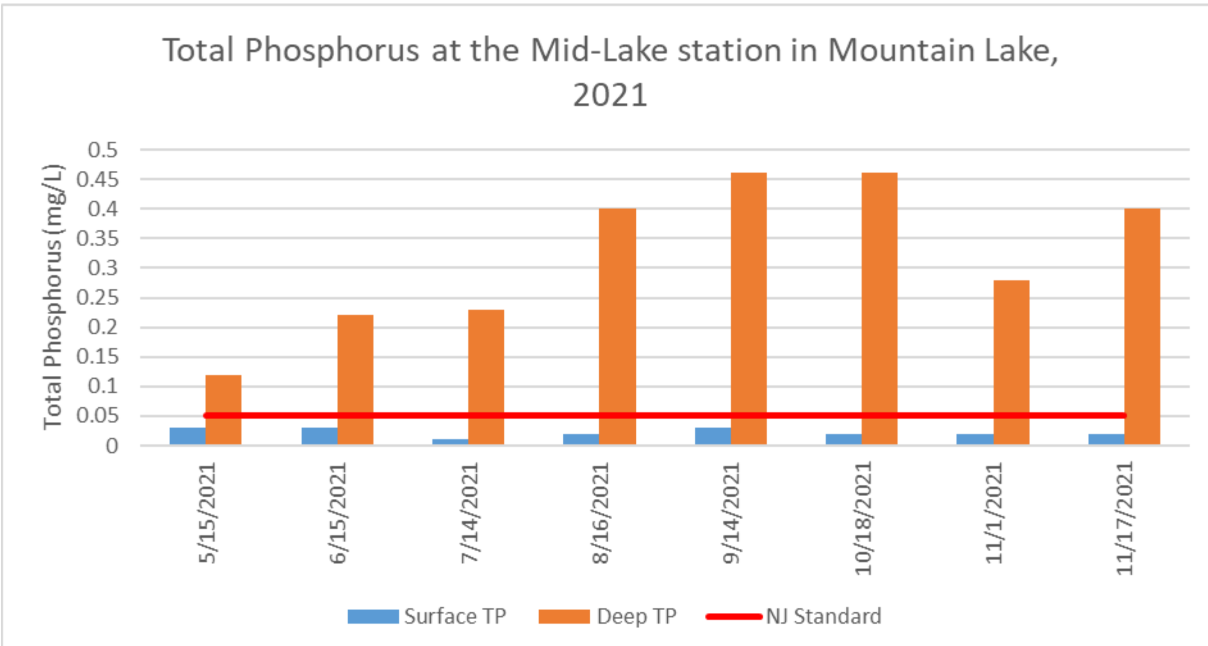

Table 1. Total Phosphorus concentrations in Mountain Lake, 2021			
Date	Sampling Location	Total Phosphorus (mg/L)	
		Surface	Deep
5/15/2021	Midlake	0.03	0.12
6/15/2021	South	-	0.04
6/15/2021	Midlake	0.03	0.22
6/15/2021	North	-	0.05
7/14/2021	North	-	0.04
7/14/2021	South	-	0.03
7/14/2021	Midlake	0.01	0.23
8/16/2021	South	-	0.08
8/16/2021	Midlake	0.02	0.4
8/16/2021	North	-	0.05
9/14/2021	South	-	0.05
9/14/2021	Midlake	0.03	0.46
9/14/2021	North	-	0.12
10/18/2021	South	-	0.05
10/18/2021	Midlake	0.02	0.46
10/18/2021	North	-	0.06
11/1/2021	Midlake	0.02	0.28
11/17/2021	South	0.04	0.02
11/17/2021	Midlake	0.02	0.4
11/17/2021	North	0.02	0.02

Because Mountain Lake remained thermally stratified throughout the summer season, most of the deep-water phosphorus remained in the hypolimnion, rather than mixing to the top of the water column where it would be available for use by algae and cyanobacteria. However, a very heavy rainstorm and/or wind event could result in a premature mixing event that brings some of this phosphorus to the surface of the waterbody. Additionally, many cyanobacteria genera, including most species of *Aphanizomenon*, a taxa that dominated some samples throughout the season, feature gas vacuoles that allow them to move up and down throughout the water column. Because of this, these organisms can move deep to uptake free phosphorus from around the thermocline (as is described above regarding an increase in dissolved oxygen at this depth) before moving to the top of the water column to conduct photosynthesis. This may explain the relatively high counts of cyanobacteria throughout the season in Mountain Lake, despite surface concentrations of total phosphorus being somewhat manageable and below the NJDEP surface water quality standard.

3.3: CYANOBACTERIA

The data discussed above is primarily the means by which each lake's water quality conditions are documented and are used to determine the severity of episodic or seasonal trophic state impacts. The density and composition of the phytoplankton community, including cyanobacteria, represent the extent of the trophic state impact caused by or associated with changes in water quality data. Greater amounts of cyanobacteria, other algae, and macrophytes are in turn directly linked to greater dissatisfaction amongst lake users, as well as ecological impacts.

While many phytoplankton genera produce chlorophyll *a*, a commonly measured parameter in many lake sampling programs, the pigment phycocyanin is only produced in some genera of cyanobacteria. As such, recent efforts have taken place in New Jersey to corroborate cyanobacteria cell counts with measured concentrations of phycocyanin. In many lakes, this allows for the development of regression equations that can be used to obtain approximate estimates of cyanobacteria densities using only a measurement of phycocyanin using a small hand-held meter. The connection between cell counts and phycocyanin, however, are stronger in some lakes than they are in others, and as such, need to be originally assessed by conducting cell counts in conjunction with phycocyanin readings.

Phytoplankton samples collected by both NJDEP staff and Mountain Lake volunteers were assessed in an NJDEP laboratory. Additionally, water samples were collected for the assessment for cyanotoxins. These are compounds produced by some cyanobacteria taxa under certain conditions and can be a cause of health issues in swimmers and other lake users who come in contact with the toxins.

In April of 2021, the NJDEP released updated guidelines for establishing harmful algae bloom (HAB) alert levels at recreational lakes. These alerts are established based on cyanobacteria cell counts and lab-tested cyanotoxin results. A cell count of 20,000 – 80,000 cells/mL constitutes a "Watch," while cell counts greater than 80,000 cells/mL or toxin concentrations over the recommended public health thresholds constitute an "Advisory," at which point public bathing beaches are closed and primary-contact recreational activities such as swimming are recommended to be avoided. Further advisory tiers occur after higher concentrations of the cyanotoxin microcystin are measured.

Cell counts from Mountain Lake triggered an Advisory-level status in Mid-May with high cyanobacteria counts, at times in excess of 200,000 cells/mL (Figure 5), with the genus *Pseudanabaena* being the dominant taxa. The lake's status was lowered to Watch-level after a lower count later in the month of 21,500 cells/mL. Further Watch-level cyanobacteria cell counts occurred at least once a month through November, with the September event yielding one advisory level count at the northern end of the lake. Despite a frequent presence of high cyanobacteria cell counts, cyanotoxins were never over health thresholds, with the cyanotoxin microcystin only reaching a seasonal high of 1.9 µg/L, falling just under the public health guideline of 2 µg/L or greater.

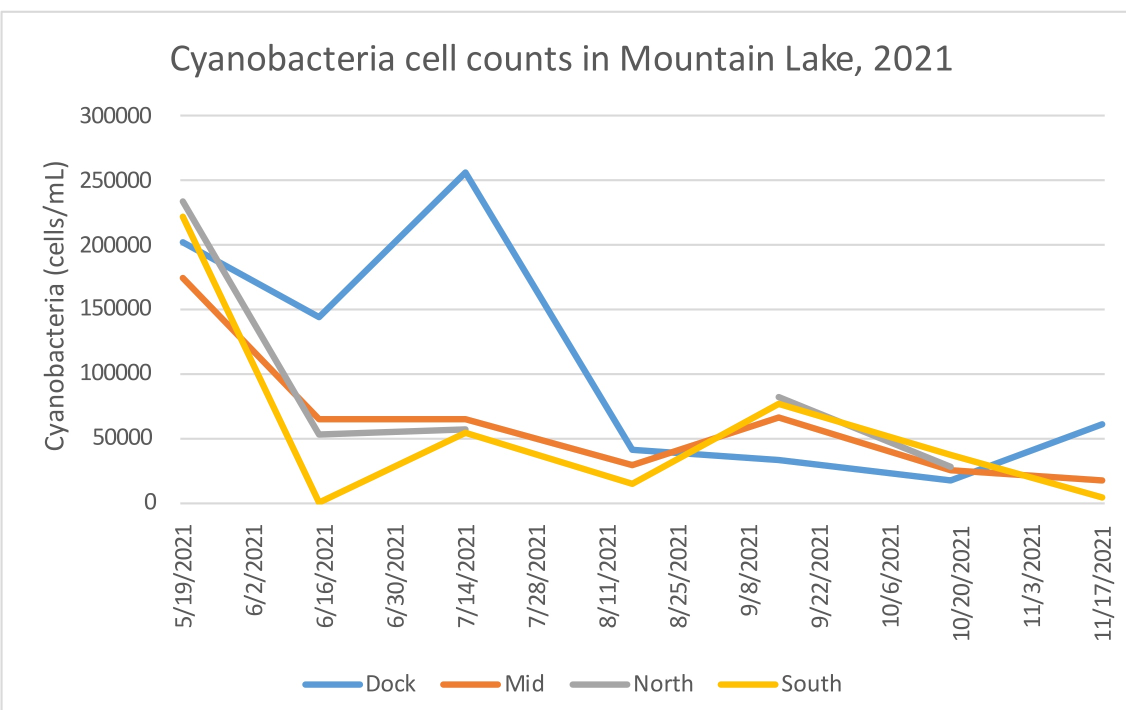

Figure 5. Cyanobacteria cell counts in Mountain Lake over the course of the 2021 season

Figure 6 below displays a regression analysis of phycocyanincollected by the MLCA and NJDEP and cyanobacteria cell counts. Phycocyanin concentrations did not strongly predict cyanobacteria cell counts (R^2 = 0.0396) in Mountain Lake in 2021, and in fact displayed a very slight downward trend as cell counts increased. A number of factors may have influenced this; for example, the exact species of cyanobacteria prevalent in Mountain Lake may not produce high levels of phycocyanin, instead producing another pigment. During the NJDEP's collection of cyanobacteria samples, measurements were also collected of Chlorophyll *b*. While chlorophyll *a* is found in all photosynthetic organisms, chlorophyll *b* is an additional pigment that is **not** typically present in most of the cyanoabcteria genera that are found during lake surveys. As such, a measurement of high chlorophyll *b* with very little phycocyanin would indicate that a bloom is more likely caused by green algae or another group. This parameter varied throughout the season, with a large spike occurring during the November sampling from the boat ramp dock. This was accompanied by a relatively high phycocyanin reading, however, suggesting that both high amounts of cyanobacteria and other taxa were present.

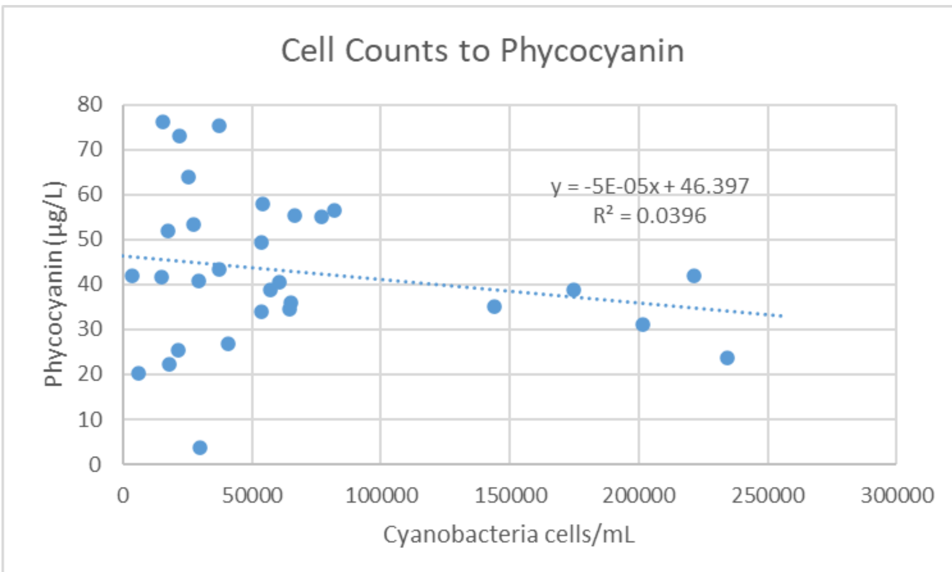

Figure 6. Cyanobacteria cell counts and corresponding phycocyanin concentrations collected in Mountan Lake, NJ, 2021

4.0 SUMMARY AND RECOMMENDATIONS

Based on the data collected in 2021, Mountain Lake typically stays thermally stratified through the entirety of the growing season and appears to experience significant internal loading, based on comparisons between surface and deep phosphorus concentrations. Cyanobacteria cell counts were often high enough to constitute at least Watch-level HAB status throughout most of the growing season, while cyanotoxin levels remained consistently below the public health standard throughout the growing season.

The volunteer monitoring program conducted in 2021 should be considered a success in that it led to the identification of some of the issues that should be addressed at Mountain Lake. Princeton Hydro recommends the following actions for 2022; these may assist in further assessing the issues identified in 2021 or in identifying any newer issues.

4.1: CONTINUATION OF THE WATER QUALITY MONITORING PROGRAM

2021 saw the collection of sufficient data and observations to make some important initial inferences about Mountain Lake. Princeton Hydro therefore recommends that this program continue in future years. This will also allow for the continuation of a long-term database that can allow the MLCA and Princeton Hydro to track the condition of the lake over time and assess the effectivity of any future management efforts.

A continued program in 2022 would likely follow a similar schedule and methodology; however, some changes and/or additions may aid in the collection of further useful data or in an increased sampling efficiency. For example, in 2021, MLCA volunteers collected *In-situ* data using a dissolved oxygen probe with a built in thermometer. pH was taken using a different meter and had to be measured for each depth using a depth sampler and bringing the sample into the boat. Further efforts might be made less time consuming by the purchase or rental of a newer multi-probe water quality meter, such as those used by Princeton Hydro, while monitoring. While these devices can be very expensive, they are essential tools for those conducting frequent lake monitoring. Additionally, additional field gear may be useful in future years for collecting additional data, such as phytoplankton and zooplankton tow nets. Lastly, the MLCA may wish to collect additional samples for the assessment of other discrete water quality parameters, such as chlorophyll *a* and nitrogen. Each additional analysis would be associated with a higher cost; however, more informative data can be collected in Mountain Lake and allow for further analysis, such as the calculation of Carlson's Trophic State Index (TSI), a measurement of the general productivity of the lake, with the additional collection of chlorophyll *a*. Chlorophyll *a* is typically measured as a generally proxy for algae productivity, and can also be an indicator of a high presence of cyanobacteria.

The timing and frequency of sampling performed in 2021 was effective, and should be mirrored in future sampling programs. If desired, the MLCA may wish to start a monitoring season slightly earlier, such as during mid-April. Lastly, the MLCA may benefit from the collection of weather data. Frequency of rain storms and dry, still periods during the summer can have a large impact on cyanobacteria blooms in some lakes; collection of this data from the area around Mountain Lake may help further track the lake's response to different weather patterns.

4.2 DEVELOPMENT OF A NUTRIENT BUDGET

Data collected in Mountain Lake in 2021 suggests that the lake likely has a relatively high rate of internal phosphorus loading. In order to further assess the rate of internal phosphorus loading and its relative contribution to the Lake's full nutrient load, Princeton Hydro recommends performing a nutrient budget analysis. Such an analysis factors several sources of phosphorus entering the lake, from both internal loading and watershed-based loading, as well as from other sources, such as carp populations (if present), atmospheric deposition, and septic tank loading. This can be paired with morphometric lake data to calculate the phosphorus retention capabilities of the lake, if paired with a bathymetric survey. Information obtained through such an analysis can assist with developing solutions for reducing the amount of phosphorus that enters the lake each year. If the MLCA is interested in further pursuing these analyses, Princeton Hydro can provide a proposal to conduct these services.

4.3 ASSESSMENT OF ZOOPLANKTON POPULATIONS

As mentioned above, an element the MLCA should consider adding to the water quality modeling program is the sampling of the lake's zooplankton populations. Conversations with members of the community indicate that the lake is known to harbor a large population of alewife. These fish typically live in limnetic (open-water) habitat and feed heavily on zooplankton populations. In many instances, too large of a population of these and other similar fish species can result in a decreased population of large-bodied herbivorous zooplankton, such as the water flea *Daphnia*. These zooplankton graze on green algae populations and often can prevent them from forming nuisance populations or blooms. While a study of these elements of the lake would eventually require a fisheries survey and assessment, the MLCA would benefit from first assessing the lake's zooplankton populations. While the equipment needed is associated with an initial cost, sampling zooplankton can be relatively simple, particularly if done with a zooplankton tow net. If desired, zooplankton samples can be assessed by Princeton Hydro, either for a general community assessment, or for a quantitative analysis of organisms per liter of water.

While an assessment of the lake's apparent internal phosphorus load should be initially prioritized, as this may be a very large source of nutrients for cyanobacteria, the MLCA will also benefit from the collection of periodic zooplankton samples. It should be noted that zooplankton do not typically graze selectively on cyanobacteria; however, the collection of these organisms would nonetheless be value in assessing the state of the lake's overall ecology and food-web. They may also provide indication as to whether the lake is also susceptible to green algae blooms. Should the MLCA wish to further pursue this option, Princeton Hydro can recommend sampling equipment, provide initial sampling training and/or guidance, and/or provide sample analysis services.

4.4 DEVELOPMENT OF A LAKE AND WATERSHED PLAN

The lack of a comprehensive Lake and Watershed Plan can create difficulties in both short and long-term management. This is especially true in assessing the impacts that can be attributed to altered hydrology, climate variations, pollutant loading, internal nutrient generation, and general trophic state analyses. Princeton Hydro recommends the MLCA implement a comprehensive Lake and Watershed Management Plan.

A Lake and Watershed Management Plan process consists of three basic parts: bathymetric study, hydrologic modeling, and nutrient load modeling. A bathymetric study is the mapping of water depths and basin morphometry. This data is crucial for determining lake water volume which is fundamental to the understanding of the hydrology of the system as well as the feasibility of projects such as dredging, aeration, fishery manipulation, and even algae and vegetation control. Through the hydrologic modeling element of the study, the MLCA would be able to accurately quantify the water budget of the lake on a monthly scale. This data would allow for better evaluation and prediction for the effects of rainfall on water quality and the implications of flushing rates and the influence of hydraulic retention times on water quality. The pollutant load analysis quantifies watershed and internal nutrient loads and what these loads (or load increases/reductions) mean with respect to the lake's overall trophic state.

The data generated through the Lake and Watershed Management Plan process is then used to prepare a detailed management plan. A Lake and Watershed Management Plan establishes the feasibility of various water quality management strategies and guides the implementation of projects designed to improve or protect water quality and to improve or enhance recreational use. The Lake and Watershed Management Plan would include specific measures that should be taken in the management of the lake. The management recommendations account for the disparate driving factors affecting the lake. This avoids any "cookie cutter" management approach and moves beyond managing only the lake's vegetation and algae issues. Overall, such a plan will provide the MLCA with a blueprint for managing the lake. Funding for such a plan may be available from the NJDEP through the 319(h) program, however the MLCA would need to partner with Liberty Township in this approach.

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