FINDLEY LAKE NUTRIENT STUDY REPORT

TOWN OF MINA, CHAUTAUQUA COUNTY, NY

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OVERVIEW

Findley Lake is a 296-acre dimictic lake with a mean depth of approximately 11 feet (3.3 meters) and a maximum depth of approximately 40 feet (12.1 meters). It is a public lake located in the Town of Mina, within Chautauqua County, New York. Findley Lake has a Total Maximum Daily Load (TMDL) for phosphorus (NYSDEC, 2008) and has experienced degraded water quality in recent decades, often manifesting as harmful algal blooms (HABs). Although the TMDL report recognizes the need for phosphorus reduction in Findley Lake, the analysis did not include an internal phosphorus load component due to lack of data; the report did recognize the need to further investigate the potential role of internal phosphorus loading.

In recognition of the degraded water quality as a result of phosphorus loading, the NYSDEC awarded Findley Lake a grant to assess the benefits of implementing in-waterbody controls for nutrients in Findley Lake. This report is a feasibility study that assesses various strategies to reduce the internal phosphorus load in Findley Lake. Mitigating internal nutrient loading typically occurs in lake management via one of two means; aerating the deep portions of the lake to maintain the iron-phosphorus bond during the summer or chemically treating the lake sediments with an aluminum sulfate (alum) or other compound that creates a stronger bond with phosphorus than iron, thereby maintaining sequestration of phosphorus in the sediments under anoxia. However, the use of alum for internal load control are currently not permissible in New York; thus, this report focuses on the various forms of lake aeration.

The first section of this report summarizes the water quality data collected over the course of the 2023 summer (July – September). Next, an internal phosphorus loading study is provided that quantifies the amount of phosphorus released from the sediments during the growing season. Finally, multiple aeration technologies are reviewed and a recommended approach for Findley Lake is provided.

SUMMARY OF 2023 WATER QUALITY DATA

Findley Lake was sampled on 6 July, 8 August, and 12 September. During each event, various *in—situ* and discrete parameters were measured at three sampling stations: ST-1 (south), ST-2 (mid-lake), and ST-3 (north). Phytoplankton and zooplankton samples were also collected at each station. At the deep, mid-lake station (ST-2) phytoplankton and zooplankton were enumerated.

The lake was stratified and anoxic (DO < 1.0 mg/L) in the hypolimnion at ST-2 and ST-3 during each monitoring event. The shallow south station (ST-1) was mixed and oxygenated during each monitoring event. Water clarity was excellent in July, with Secchi depth's > 3.5 meters at both deep stations. Water clarity remained above 4.0 meters at ST-2 in August but declined significantly at ST-3; however, water clarity was still good and remained above 1.5 meters. Water clarity declined significantly at both deep stations in August with Secchi depths of 1.1 meters. This decline in water clarity was attributed to a significant increase in phytoplankton growth, mainly in the form of cyanobacteria.

Surface total phosphorus (TP) concentrations remained low to moderate throughout the season, ranging between 0.01 mg/L and 0.05 mg/L, with a mean concentration of 0.03 mg/L. However, deep TP concentrations were very high at times at the two deep stations. Deep TP concentrations at ST-3 ranged between 0.06 mg/L and 0.10 mg/L, with a seasonal mean of 0.08 mg/L. ST-2 had elevated deep TP concentrations all summer, ranging between 0.19 mg/L in July and 0.39 mg/L in September; the seasonal mean deep TP concentration at ST-2 was 0.27 mg/L. Thus, it's evident that phosphorus was being released from the sediments at ST-2 and ST-3 from at least July through September while the hypolimnion remained anoxic, suggesting an elevated rate of internal loading.

Surface and deep soluble reactive phosphorus (SRP) concentrations were low for most of the season with only one slightly elevated sample; ST-3 had a deep SRP concentration of 0.006 mg/L in August. Given the significant increase in deep TP concentrations as anoxia persisted, SRP concentrations would also be expected to be elevated if internal loading was the cause of the elevated TP; SRP is the dissolved form of phosphorus that is released from anoxic sediments. However, the excellent water clarity in July and August resulted in the photic zone, or area within the water column with enough sunlight to permit photosynthesis, extending down as far as approximately 8.6 meters at ST-2. With a photic zone extending deep into the hypolimnion, phytoplankton were able to assimilate the bioavailable phosphorus in these deeper waters and photosynthesize without moving back into the epilimnion. Thus, it's possible that TP concentrations were extremely elevated in the deeper waters as a result of particulate phosphorus that may have included a large portion of cell-bound organic phosphorus. This could explain why deep TP concentrations were extremely elevated while deep SRP concentrations were low; the dissolved bioavailable phosphorus was likely assimilated by phytoplankton as it was released from the sediments.

Chlorophyll *a* concentrations increased as the summer progressed, reaching a seasonal maximum of 34 µg/L in August. Chlorophyll *a* and cyanobacteria densities increased significantly as the internal phosphorus load increased. Findley Lake had a cyanobacteria-dominated plankton community at all three stations from July through September. The three dominant cyanobacteria genera, *Planktothrix, Dolichospermum,* and *Aphanizomenon* all possess gas vacuoles and have the ability to regulate their position in the water column. Additionally, *Dolichospermum* and *Aphanizomenon* possess heterocysts and akinetes, making them hardy organisms with great potential to produce nuisance blooms. Given the fact that the photic zone extended down into the hypolimnion in July and August, even species without gas vacuoles were likely able to assimilate phosphorus in the nutrient-rich hypolimnion and photosynthesize at depth.

The pertinent *in-situ*, discrete, and biological data all support the claim that the internal phosphorus load is contributing to increased algal densities in the surface waters, and managing this internal load should improve water quality in Findley Lake.

INTERNAL PHOSPHORUS LOADING ANALYSIS

The anoxic internal load was calculated on an event basis across the 2023 season using measured *in-situ* and discrete data. Only stations ST-2 and ST-3 were utilized in this analysis because both stations were anoxic in the hypolimnion during all three sampling events. For each event, the anoxic internal load was calculated by multiplying the average measured deep TP concentration from ST-2 and ST-3 by the volume of water that corresponds to the average anoxic depth interval at ST-2 and ST-3 using the hypsographic data generated from the bathymetric map.

The highest event-based internal phosphorus load calculated was then used as the internal phosphorus load because it represents the actual internal load of the lake as phosphorus accumulated in the hypolimnion over the course of the entire season. After calculating the total anoxic zone phosphorus load on an event basis, net anoxic sediment TP loading rates between events were also calculated.

The annual internal phosphorus load at Findley Lake is estimated to be 130 kg/yr (287 lbs/yr). The daily areal TP loading rates for August and September are 1.3 mg TP/m^2/d and 8.1 mg TP/m^2/d, respectively. The average daily loading TP rate from 6 July – 12 September, which represents the peak of the growing season, is 4.7 mg TP/m^2/d. For reference, 6.0 mg TP/m^2/d is a common internal phosphorus loading coefficient used for lakes in the northeast based on values reported in a 1985 paper (Nürnberg, 1985). The seasonal average daily loading rate in Findley Lake would have likely been higher than 4.7 mg TP/m^2/d if sampling was conducted from the onset of thermal stratification, as we would have been able to account for the initial increase in the internal phosphorus load.

The 2008 TMDL reported a total phosphorus load of 436 kg/yr (929 lbs/yr) for Findley Lake, with a targeted load of 99 kg/yr (218 lbs/yr). Adding the estimated 2023 internal phosphorus to this existing load, the updated total phosphorus load for Findley Lake is 566 kg/yr (1,238 lbs/yr); please note that this does not account for any watershed or other management measures that may have been implemented since the development of the TMDL. Assuming a total phosphorus load of 566 kg/yr (1,238 lbs/yr), the internal phosphorus load accounts for 23% of this load. Reducing the internal phosphorus load through in-lake management has the potential to significantly reduce the total phosphorus load in Findley Lake.

PROPOSED FINDLEY LAKE AERATION SYSTEM

There are three main aeration strategies used for internal phosphorus load control: full air-lift (destratification), partial air-lift (hypolimnetic aeration and Layer-Air), and direct oxygen injection systems. However, there are a multitude of technologies available for each of those strategies. All of the major classifications were reviewed extensively relative to Findley Lake before a specific strategy was recommended.

A destratification system is not the primary recommendation because it would alter the thermal regime of the lake, increase water temperatures throughout the water column, and potentially reduce fish refuge during the summer months. Partial air-lift systems are also not recommended due to the large size of the in-lake structures and the fact that they are much more logistically complicated, requiring frequent monitoring and adjustments throughout the growing season. A direct oxygen system is therefore recommended as the best option to restore oxygen to the hypolimnion and preclude the internal release of phosphorus while maintaining the natural thermal structure of the lake.

Based on the relatively shallow maximum depth of Findley Lake compared with other dimictic systems, an Oxygen Saturation Technology (OST) system is recommended as the most cost-effective and efficient system for Findley Lake for a number of reasons:

1. The built in DO sensors and automation of the system allow for the maintenance of a specific DO range while only generating enough oxygen to meet the demand.
2. The relatively small size of the in-lake infrastructure will not impede recreation.
3. The positioning of the pumps and oxygen mixing chamber in the hypolimnion reduces operational costs by eliminating the need to pump the oxygen-poor water from the hypolimnion to the shoreline, then back into the hypolimnion.
4. The oxygenated water is discharged into the hypolimnion, directly over the sediments, without any bubbles, effectively preserving thermal stratification.
5. The potential to address the legacy sediment oxygen demand (SOD), which could reduce the hypolimnetic oxygen demand over time, resulting in reduced operational costs.

However, before moving forward with the design of an OST system, or any oxygenation system for that manner, it is recommended that an additional SOD analysis be conducted to calculate the exact oxygen demand in Findley Lake. It would also be practical to utilize updated bathymetric data in determining the specific direct oxygen system design. Conducting these additional tasks would be prudent to design the most efficient system for Findley Lake.

In addition to the efficiency of these systems in oxygenating the hypolimnion without disrupting stratification, the annual operating costs are typically lower than destratification systems due to the use of smaller compressors, potentially shorter period of operation, and higher oxygen transfer efficiencies (OTE) and reoxygenation capabilities.

The OST system would be designed specific to the thermal properties present in Findley Lake so that thermal stratification is preserved. There is less risk of disrupting thermal stratification with an OST system, which makes this technology a prime candidate for Findley Lake.

The physical location of the land-based components of the OST system can greatly affect the system's design, capital cost, and operational cost. In short, the compressor buildings should be as close to the targeted areas of oxygenation as possible to reduce the length of wire and piping and improve efficiency. In Findley Lake, the two deep pockets of the lake (ST-2 and ST-3) represent the areas of greatest oxygen demand and would require OST units. Compressor building locations should also be on publicly owned land and located as close to the shoreline as possible, with easy access for regular maintenance.

The two locations that seem most feasible at Findley Lake include the Findley Lake Waterway Access at the north end of the lake and the DEC cartop/kayak boat launch along the southwest shoreline. Based on these two locations, the most cost-effective scenario would be to locate a compressor building at both of these locations; the northern location would generate oxygen for the northern deep pocket and the southwest location would generate oxygen for the mid-lake pocket. This would place a compressor building in relative proximity to each of the two deep pockets that needs to be oxygenated, significantly reducing the length of wire and piping that would be required if only one compressor building is used. Under this scenario and based on our current estimate of oxygen demand in each deep pocket, this would require an 8' x 8' compressor building at the north end of the lake (Findley Lake Waterway Access) and a 12' x 12' compressor building at the southwest location (DEC boat launch). If one of these locations is not a feasible option, one larger (12' x 12') compressor building could be used to generate the oxygen for both sites. However, this could increase the cost of electrical and piping by an estimated 60 – 70%. If any alternative shoreline locations can be secured closer to the mid-lake deep pocket, capital and operational costs will decrease even further.

Without knowing the exact SOD that would be measured during the SOD analysis under EPA approved methods, and with only one summer's worth of monthly full water column *in-situ* profiles, the oxygen demand can only be estimated. However, based on similar projects throughout New York and New Jersey in recent years, a relatively accurate oxygen demand can be deduced based on existing data. It is estimated that the hypolimnetic oxygen demand in Findley Lake is in the range of 300 kg/d. This can be further broken down by basin, with an estimated oxygen demand in the range of 50 kg/d in the north basin and 250 kg/d in the deeper mid-lake basin.

The primary recommendation for the Findley Lake OST system would include separate compressor buildings for the two deep pockets in the lake. This would include an OST unit that generates 150 GPM situated in the smaller, northern deep pocket (ST-3) and a second OST unit that generates 300 GPM situated in the deeper, mid-lake pocket (ST-2). The smaller unit in the north would require a compressor building approximately 8' x 8'; this building would be situated at the Findley Lake Waterway Access. The in-lake component for the northern basin would be one 4' x 4' x 7' OST chamber with approximately 100' of combined suction and discharge piping along the lake bottom. The larger unit in the deeper mid-lake basin would require a compressor building approximately 12' x 10' located at the DEC cartop/kayak boat launch. The in-lake component for the mid-lake basin would be two 5' x 5' x 8' OST mixing chambers with approximately 200' of combined duction and discharge piping each. The size of the electrical wire needed to run power from the compressor buildings to the OST mixing chambers under this scenario is 6 AWG. Opinions of cost for the two-compressor building OST system components is in the range of $800,000 - $1,000,000 while all other costs (compressor buildings, installation of 3-phase power, permitting, design, installation) are estimated between $350,000 - $450,000. Thus, it is estimated that the capital cost for the system would be in the range of $1,150,000 - $1,450,000.

A secondary option for the Findley Lake OST system would include one compressor building, most likely located at the Findley Lake Waterway Access lot at the northern end of the lake. The in-lake OST chambers would be the same as the primary design option described above; one unit that generates 150 GMP situated in the smaller, northern deep pocket (ST-3) and a second OST unit that generates 300 GPM situated in the deeper, mid-lake pocket (ST-2). All of the land-based components would be housed in a 12' x 12' compressor building. The primary difference between the two designs, in addition to the size and number of compressor buildings, is the size of the electrical wire, and the length of both electrical wire and piping that would need to run from the compressor building to the mid-lake unit. This scenario would require 2 AWG wire, which is significantly more expensive than the 6 AWG required for the primary recommendation, and the length of wire required would also be much longer. Opinions of cost for the one compressor building OST system components is in the range of $1,100,000 - $1,300,000 while all other costs are estimated between $350,000 - $450,000. Thus, it is estimated that the capital cost for the system would be in the range of $1,450,000 - $1,750,000.

Annual operation and maintenance costs are anticipated to be in the range of $20,000 - $40,000, depending on the final design. These costs will be very dependent on how close the compressor building(s) are to the two deep basins.

If cost is a significant limiting factor, a destratification (full air-lift / full water column mixing) system would likely have a lower capital cost, although it would still be a significant investment. It's also important to recognize the limitations relative to increased water temperatures and reduced fish habitat during the summer months. If the main goal is strictly to reduce the internal phosphorus load, a destratification system would be a less efficient alternative. Based on available water quality data and bathymetric data, diffusers would likely be placed in all areas of the lake that are ≥ 4.0 meters, or an approximate area of 87 acres. This would likely require at least 30 diffusers to be dispersed throughout the lake. All diffusers would be connected via weighted airline tubing to shoreline compressor buildings similar in size to the compressor buildings required for the OST system. Because it appears that available shoreline locations in proximity to the deepest section (mid-lake) of the lake is limited, a destratification system would require long runs of airline which would increase capital and operational costs. An opinion of cost for all capital costs, including design, permitting, materials, shoreline compressor building(s), and installation is in the range of $600,000 - $900,000.

1.0 INTRODUCTION

Findley Lake is a public Lake located in the Town of Mina, within Chautauqua County, New York. The lake has a surface area of 296 acres and respective mean and maximum depths of 11 feet (3.3 meters) and 40 feet (12.1 meters) (NYSDEC, 2008). The lake has experienced degraded water quality in recent decades, resulting in the loss of recreational opportunities. Findley Lake has a Total Maximum Daily Load (TMDL) for phosphorus (NYSDEC, 2008). Phosphorus is the limiting nutrient, or the nutrient that is naturally lowest in supply relative to the amount required for plant and algal primary productivity, in most freshwater aquatic ecosystems (Schindler, 1977). Currently, the TMDL report notes that internal phosphorus loading was not considered in the development of the TMDL due to the lack of confirmation. Still, this document identifies that the New York State Department of Environmental Conservation (NYSDEC) acknowledges the need for additional monitoring to determine if phosphorus release from the sediments plays a significant role in the phosphorus loading of Findley Lake. Historic data collected by the New York Citizens Statewide Lake Assessment Program (CSLAP) shows intermittent deep-water sampling. However, the majority of the data was collected from the surface and the dissolved oxygen profile data required to accurately assess the potential role of internal phosphorus load was lacking.

In recognition of the degraded water quality as a result of phosphorus loading, the NYSDEC awarded Findley Lake a grant to assess the benefits of implementing in-waterbody controls for nutrients in Findley Lake. The focus of this grant is in developing a feasibility report for projects that reduce internal nutrient loading for Findley Lake. Princeton Hydro and Barton and Loguidice determined the first step in providing a robust feasibility report is to develop a base water quality database with particular focus on the documentation of internal anoxia and subsequent phosphorus release into the water column.

The objective of this project is to develop a preliminary aeration system design customized for Findley Lake based on lake science and engineering principles. Operation of the aeration system shall prevent deep-water anoxia, control/decrease internal phosphorus loading, and decrease the occurrence and intensity of cyanobacteria harmful algal blooms (HABS). The first section of this report will summarize the water quality data collected over the course of the 2023 growing season. Next, an internal phosphorus loading study will be provided that quantifies the amount of phosphorus released from the sediments during the growing season. Finally, multiple aeration technologies will be reviewed and a recommended approach will be provided specific to Findley Lake.

2.0 SUMMARY OF 2023 WATER QUALITY DATA

The following section will discuss the water quality parameters measured in Findley Lake during the 2023 season. This includes data analysis of the *in-situ*, discrete, and plankton data collected from July – September. The data collected was an important component of the larger project and was necessary to assess the potential role of internal phosphorus loading. In particular, current measurements regarding hypolimnetic anoxia and the associated phosphorus dynamics of the lake were necessary to compute the lake's internal phosphorus load, which is a crucial element in evaluating the feasibility of in-lake management strategies. Thus, while all of the data collected in 2023 will be discussed, emphasis will be given to the data pertinent to the internal phosphorus load and the specific biological parameters most affected. Additionally, the 2023 monitoring program provides a current assessment of the plankton community of Findley Lake. This data can also be utilized to document shifts in water quality in response to future in-lake and watershed management efforts.

2.1 SAMPLING METHODOLOGY

The 2023 monitoring program consisted of three in-lake water quality monitoring events. Water quality monitoring was conducted at three monitoring stations during each sampling event: ST-1 (south), ST-2 (mid-lake), and ST-3 (north). A map with approximate locations of sampling stations is provided in Appendix I. The lake was sampled on 6 July, 8 August, and 12 September.

Various *in-situ*, discrete, and biological parameters were monitored. The *in-situ* data were collected in profile, at approximately 1.0 m increments, and consisted of temperature, specific conductance, dissolved oxygen (DO) concentration, DO percent saturation, and pH. *In-situ* data were collected with an In-Situ Aqua TROLL 500 water quality meter. This meter was calibrated according to manufacturer's specifications prior to sampling. Princeton Hydro is a certified lab in the State of New Jersey for the measurement of these *in-situ* parameters (State ID #10006). In addition, Princeton Hydro monitored transparency with a Secchi disk.

Discrete samples were collected at the surface of the deep, mid-lake station (ST-2) for chlorophyll *a*, nitrate-N (NO_3-N), ammonia-N (NH_3-N), total Kjeldahl nitrogen (TKN), total phosphorus (TP), soluble reactive phosphorus (SRP), total dissolved phosphorus (TDP), and total suspended solids (TSS). Deep water samples were collected 0.5 meters above the sediment and analyzed for the same parameters with the exception of chlorophyll *a*. At the other two shallower stations, samples were collected at the surface and bottom for TP, SRP, and TSS. All samples were collected in appropriately preserved containers, placed on ice to 4°C (39.2°F), and transported under chain-of-custody procedures to Environmental Compliance Monitoring (ECM) of Hillsborough, NJ for analysis.

Plankton samples were also collected. At the deep, mid-lake station (ST-2), surface and mid-depth grab samples were collected and taxonomically analyzed to genus level and cells enumerated (cells/mL); these samples were collected with a Van Dorn sampling device. Surface and depth dependent samples were also collected for zooplankton utilizing a Schindler-Patalas trap. These samples were also identified to genus and enumerated. At the two shallow stations, water column plankton tow samples were collected and analyzed to genus and semi-quantitatively described.

2.2 RESULTS

The following section provides detailed information on the parameters measured for Findley Lake. Information pertaining to the scientific definition, recommended levels and concentrations, and general causes for variation from baseline conditions are highlighted as they pertain to the water quality of the lake.

Tables with all water quality data collected throughout the 2023 season are provided in Appendices II - IV.

2.2.1 *IN-SITU* PARAMETERS

TEMPERATURE

The water temperature of a lake influences many biological and chemical reactions. Primarily dependent upon solar radiation and secondarily by ambient air temperatures, thermal diffusion is generally aided through wind driven or artificial mixing. Changes in water temperature with depth are primarily dependent upon the degree of light attenuation, water clarity, lake depth, and the topography and vegetative cover surrounding a lake.

The morphology of the lake basin is the primary factor that determines temperature distributions throughout the water column. Shallow basins have less spatial variation in temperature throughout the water column than deeper basins. Water density also plays an important role in vertical temperature distribution. Many deeper lakes (>8' max depth) within the North American temperate zone experience strong variation in temperature throughout the water column due to seasonality.

Summer thermal stratification results when increasing solar radiation and air temperatures, aided by a few days of little wind activity, combine to thermally stratify the water column. Thermal stratification consists of a relatively warm upper water layer (epilimnion), a transition zone (metalimnion or thermocline), and a cold, deep water layer (hypolimnion). The density differences imparted through thermal stratification serve to inhibit wind driven mixing of the water column, thereby sealing off the hypolimnetic layer from contact with the atmosphere. This phenomenon often results in the depletion of oxygen in the hypolimnion due to excessive bacterial decomposition of organic matter and a lack of atmospheric replenishment of dissolved oxygen through diffusion.

As surface water temperatures begin to decrease in the late summer and early fall, convection currents erode the metalimnion until the water column exhibits a uniform temperature, and therefore uniform density; this is known as fall turnover. The transition from the final stages of weak summer thermal stratification to fall turnover are often times abrupt, and can occur over a period of a few hours, especially if associated with the high wind velocities of a storm.

Another important impact of temperature is its effect on the solubility of gases, as colder can hold more dissolved gases, such as oxygen, than warmer water. This phenomenon has important implications in lakes, as primary productivity and organism respiration increase during the late summer months when water temperatures are warmest. While algal and plant photosynthesis produces oxygen as a byproduct during daylight hours, respiration dominates at night thereby consuming dissolved oxygen to metabolize those carbohydrates produced through photosynthesis. As such, increasing algal densities during the day in concert with warm water temperatures may combine to exhaust dissolved oxygen in the secluded hypolimnion.

Figure 2.1 below presents the temperature profiles at the deep, mid-lake station (ST-2) across the 2023 growing season. All *in-situ* figures in this section of the report will only include data from ST-2. ST-2 is located in the central, deep basin in Findley Lake and thus is the best representation of conditions throughout the lake. If conditions at either of the other two stations vary considerably, it will be noted in the text analysis.

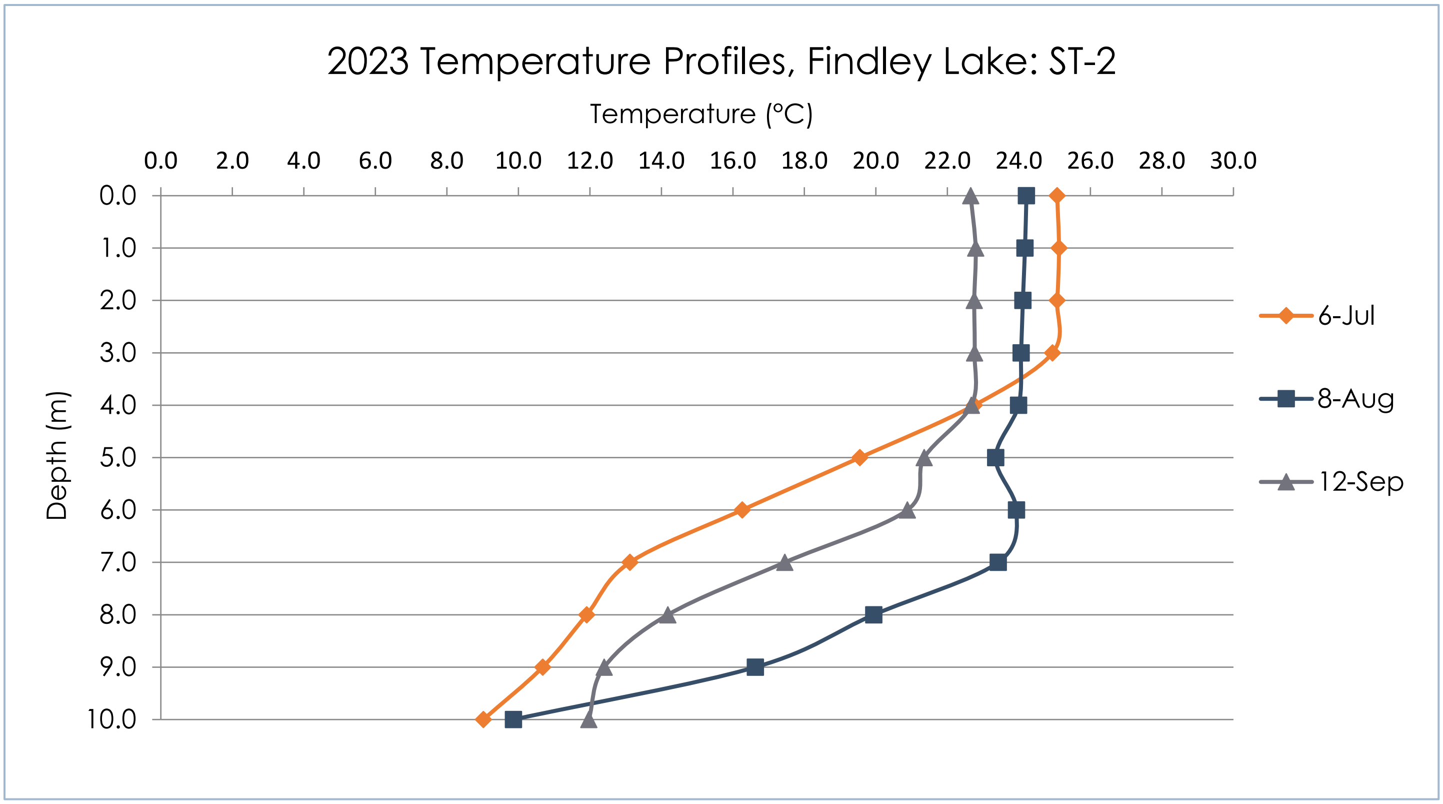


Figure 2.1: Temperature profiles at ST-2 throughout the 2023 season

The water column was thermally stratified at ST-2 and ST-3 during the first monitoring event on 6 July, with an epilimnion present in the upper 3.0 meters and a large thermocline extending down to the bottom at both stations (Figure 2.1). Surface water temperatures were at a seasonal maximum on 6 July, with a temperature of 25.07 °C at ST-2. The surface water temperature cooled slightly by 8 August, resulting in an expansion of the epilimnion at ST-2 and ST-3; surface temperatures were 24.21 °C and 23.97 °C at ST-2 and ST-3, respectively. Strong winds made it difficult for the boat to anchor during the August event, which may have disrupted the profile at ST-2, but the epilimnion was present in at least the upper 4.0 meters. Water temperatures continued to cool by the last monitoring event on 12 September, with respective surface temperatures of 22.65 °C and 22.29 °C at ST-2 and ST-3. The lake remained stratified at ST-2 and ST-3 in September, with an epilimnion present in the upper 4.0 meters.

DISSOLVED OXYGEN

DO is crucial to almost all biochemical reactions occurring in freshwater ecosystems. The primary sources of DO in a lake are diffusion from the atmosphere and photosynthesis. Biological respiration and bacterial decomposition of organic matter are the primary sources of consumption. The abundance and distribution of DO in a lake system is predicated on the relative rates of these producers and consumers; producers include aquatic macrophytes and phytoplankton. As the producers photosynthesize, they utilize water, carbon dioxide, and sunlight to create oxygen and glucose. This process increases DO concentrations in the sun-lit zone of a lake; this active area of the lake is known as the photic zone. As such, DO concentrations are generally higher in photic zone and lower in the deeper water, where a lack of photosynthetic activity in conjunction with organism respiration results in a decrease. DO is also influenced by the thermal properties of the water column. This includes both lake stratification and the varying degree of oxygen retention capacity of water at different temperatures; colder water holds more oxygen than warmer water.

When lakes thermally stratify, there is generally a correlated stratification of DO levels. The hypolimnion usually has lower DO concentrations, as this water cannot mix with the epilimnion, whereby DO concentrations would be replenished with atmospheric sources. In highly productive lakes, the hypolimnion may become devoid of oxygen due to bacterial decomposition of excessive inputs of organic material. The source of this material may either be from excessive phytoplankton production in the upper water layers that then sink to the bottom when they die (autochthonous), from excessive watershed derived sediment loading (allochthonous), or more likely a mixture of the two. Also, as DO concentrations are generally measured during the daytime when concentrations are highest, concentrations are lower at night when photosynthesis ceases but respiration continues.

An important consequence of anoxic (DO < 1.00 mg/L) conditions in the hypolimnion includes both reduced fish habitat and the release of metals and phosphorus, a process termed internal loading. Internal loading occurs when tightly bound iron and phosphate sediment complexes are reduced, thereby dissociating phosphorus from iron, and making it available for diffusion into the water column. This process has been documented to contribute to the overall eutrophication of many lakes, as this internal source of phosphorus is pulsed into the photic zone during strong storm events whereby it may serve as fuel for excessive algal growth. A general guideline for DO concentrations in lakes is that a concentration of greater than 1.0 mg/L is needed to preclude internal nutrient and metal release while concentrations of 4.0 mg/L and greater should be kept in order to sustain proper warm-water fisheries habitat.

Figure 2.2 below presents the DO profiles at the ST-2 station across the 2023 growing season.

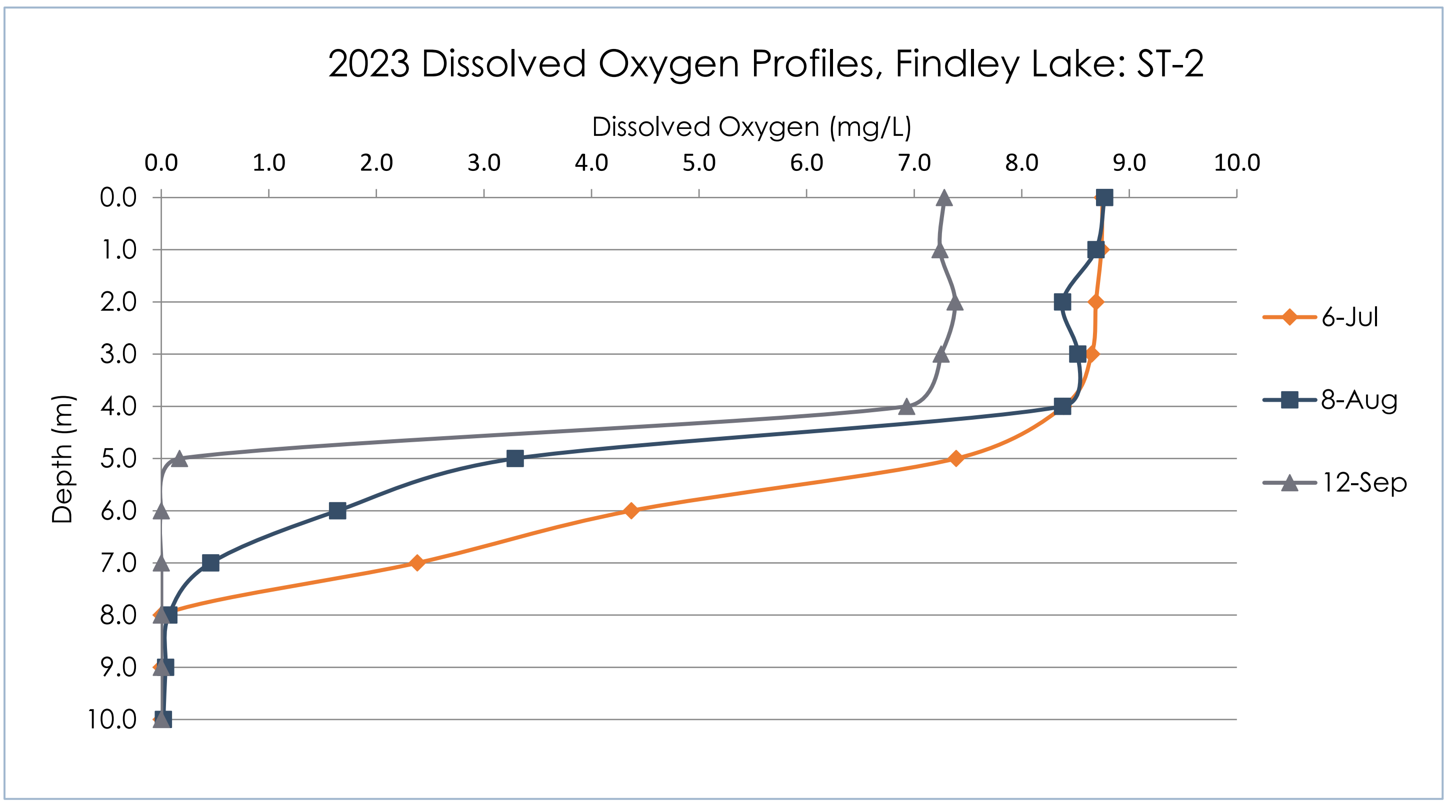


Figure 2.2: Dissolved oxygen profiles at ST-2 throughout the 2023 season

DO concentrations remained above 7.0 mg/L at ST-1 and in the epilimnion of ST-2 and ST-2 throughout the season but declined rapidly with depth below the epilimnion (Figure 2.2). Anoxic conditions (DO < 1.0 mg/L) were present below a depth of 7.0 meters at ST-2 and below a depth of 4.0 meters at ST-3 in July. In August, anoxia was present below a depth of 6.0 meters at ST-2 and below a depth of 5.0 meters at ST-3. Anoxia became more widespread by the final monitoring event in September, present below a depth of 4.0 meters at ST-2 and below a depth of

4.0 meters at ST-3. Thus, it's apparent from the *in-situ* temperature and DO profiles that Findley Lake has a high oxygen demand, and anoxia likely persists in the deeper areas of the lake until the lake undergoes a fall mixing event.

PH

pH is a unitless measurement of the hydrogen ion concentration in water. Expressed on a negative logarithmic scale from 0 to 14, every change of 1 pH unit represents a 10-fold change in hydrogen ion concentration. The pH of pure water is 7 and is termed neutral. Any value less than 7 is termed acidic, while any value greater than 7 is termed basic. Baseline pH values in aquatic systems are primarily determined by the ionic constituency of the surrounding geology. Watersheds draining soils of easily erodible anionic constituents are generally well buffered, and as such have runoff waters with basic pH values (pH above 7). Spatial variations in pH throughout the water column are largely due to relative rates of photosynthesis versus respiration. As plants and algae photosynthesize and carbon dioxide is removed from the water, pH values increase. Conversely, respiration releases carbon dioxide into the environment which results in a reduction in pH. Given these relationships, pH values may differ substantially in the epilimnion and hypolimnion. The optimal range of pH for surface waters, as recognized by the NYSDEC is between 6.5 and 8.5.

pH ranged between a minimum of 6.95 at the bottom of ST-3 and a maximum of 9.69 at the surface of ST-1 on 6 July. Eurasian watermilfoil (*Myriophyllum spicatum*) growth was extensive in the shallow southern cove in July which likely caused the elevated pH, as photosynthetic activity raises the pH of the water. In August, pH ranged between a minimum of 7.14 at the bottom of ST-3 and a maximum of 8.88 at the surface of ST-2. While the surface values were slightly above the optimal range recognized by NYSDEC, these values are not excessive and likely reflect phytoplankton present in the photic zone. pH values were lower throughout the lake in September, ranging between a minimum of 7.07 at the bottom of ST-2 and a maximum of 8.37 at the surface of ST-1.

SPECIFIC CONDUCTANCE

Specific conductance is defined as the ability of water to conduct an electrical current. Increases in specific conductance are due to an increase in ionic constituents from watershed soils and biological reactions and are temperature dependent. Specific conductance is normalized for the effects of temperature on conductivity values.

Watershed geology, pH, and the dissolved solids loads in runoff play an important part in determining conductance values for a particular lake. Some rocks and soils release ions very easily when water flows over them; for example, if water of low pH flows over calcareous rocks then ions of calcium (Ca^{2+}) and carbonate (CO_3^{2-}) ions will dissolve in water and raise the conductance values. Some rocks such as quartz are very resistant to weathering and in a predominately quartz geology conductance values would be low.

Two other important sources of ionic constituents in suburban watersheds are salts from road de-icing and salts derived from fertilizer runoff. As such, increases in specific conductance are often used as proxy measures of increased pollutant loading from the surrounding watershed.

Specific conductance values were low to moderate in Findley Lake throughout the 2023 season. In July, values ranged from a minimum of 161.4 µS/cm at the surface of ST-1 up to a maximum of 250.1 at ST-2. In August, values varied between 196.3 at the surface of ST-2 and 284.9 at the bottom of ST-2. Specific conductivity increased slightly in September, with a minimum of 199.9 at the surface of ST-1 and a maximum of 286.6 at the bottom of ST-2. Specific conductance values increased with depth during each sampling event at the two deeper stations, and the bottom of ST-2 consistently had the highest values. As the bottom layer of the lake is continually thermally separated from the surface layer as the summer progresses, ionic constituents released from the sediment accumulate in the hypolimnion, raising the conductivity.

WATER CLARITY

Transparency in lakes is generally determined through the use of a Secchi disk. The Secchi disk is a contrasting white and black disk that is lowered into the lake until it is no longer visible, then retrieved until visible again. The average of those two lengths is termed the Secchi depth. This depth may be influenced by algal density, suspended inorganic particles, organic acid staining of the water, or more commonly a combination of all three. This parameter is often times used to calculate the trophic status (productivity) of a lake, and as such is a critical tool in lake evaluation. Secchi depths less than 1.0 m are generally associated with reduced water quality due to high concentrations of algae or suspended inorganic sediments and is generally associated with impaired quality.

Figure 2.3 below presents water clarity at all three stations in Findley Lake across the 2023 growing season. The red line represents the 1.0 m threshold that Princeton Hydro recommends for maintaining adequate water clarity.

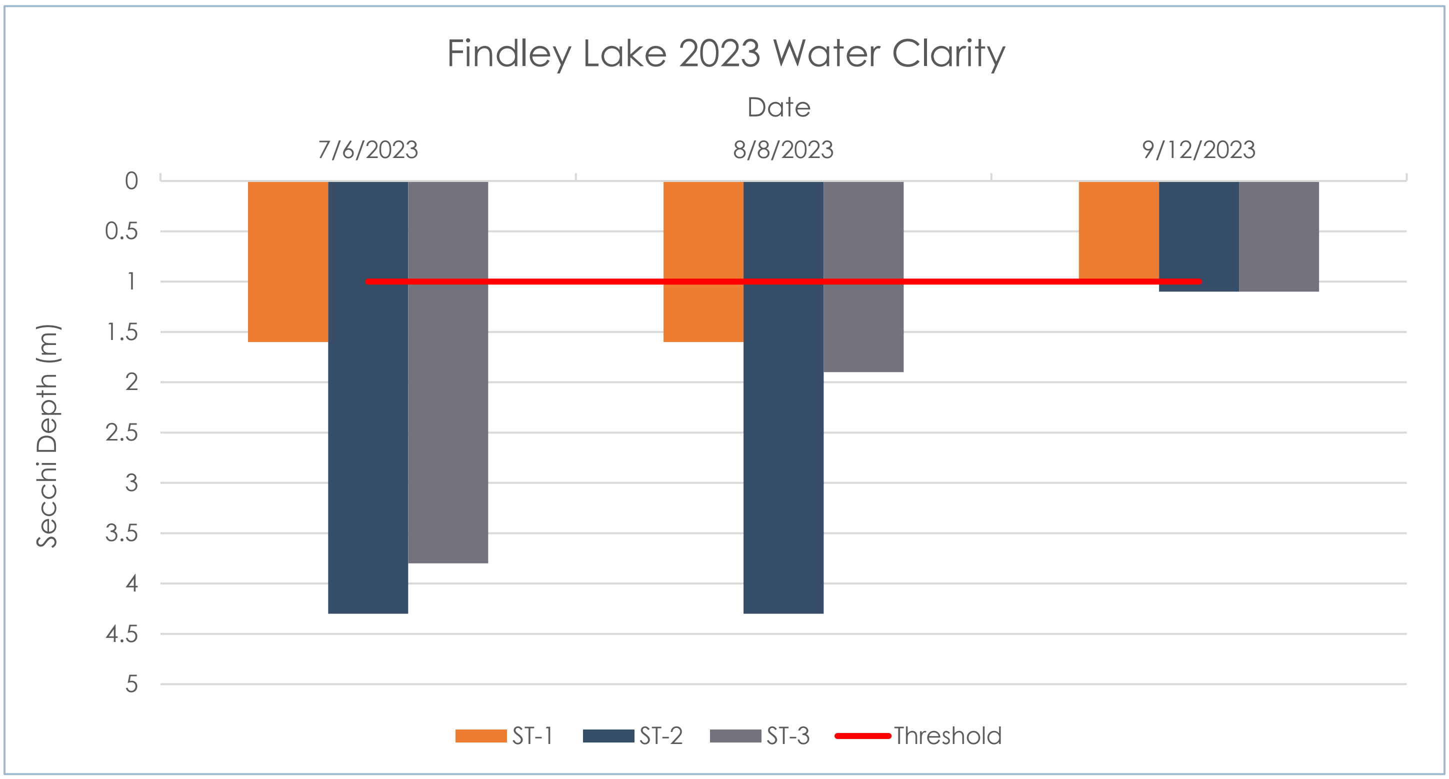


Figure 2.3: Water Clarity in Findley Lake throughout the 2023 season

Water clarity was excellent in Findley Lake in July and August; submerged aquatic vegetation (SAV) growth at ST-1 prevented the Secchi disk from being visible at the bottom of the lake (Figure 2.3). Water clarity varied between 3.8 meters at ST-3 and 4.3 meters at ST-4 in July. In August, water clarity varied between 1.9 meters at ST-3 and 4.3 meters at ST-2. Water clarity was significantly reduced throughout the lake in September, ranging between 1.0 meter at ST-1 and 1.1 meters at ST-2 and ST-3. An increase in phytoplankton growth near the surface was likely the main cause of the reduced water clarity in September; chlorophyll *a* concentrations reached a seasonal maximum of 34 µg/L at ST-2 in September and cyanobacteria densities were high.

2.2.2 DISCRETE PARAMETERS

TOTAL PHOSPHORUS

Phosphorus is often the limiting nutrient in lake ecosystems, or the nutrient in which abundance is lowest relative to demand by plants and algae. As a result, phosphorus is often the primary nutrient driving excessive plant and algal growth. Given this nutrient limitation, only relatively small increases in phosphorus concentration can fuel algal blooms and excessive macrophyte production. By monitoring TP concentrations, the current trophic status of the lake can be determined and future trends in productivity may be predicted. The current concentration threshold recommended by Princeton Hydro for TP concentrations in lakes and ponds to preclude nuisance algal and macrophyte growth is 0.03 mg/L. The NYSDEC guidance level for TP is 0.02 mg/L to protect contact recreation in Class B and higher lakes.

It is important to note that TP concentrations account for all species of phosphorus, including organic, inorganic, soluble, and insoluble. Therefore, this measure accounts not only for those dissolved, inorganic species of phosphorus that are readily available for algal assimilation, but also for those species of phosphorus either tightly bound to soil particles or contained as cellular constituents of aquatic organisms which are generally unavailable for algal assimilation.

Figure 2.4 below presents the TP concentrations at all three stations throughout the 2023 season. The red line represents the 0.02 mg/L NYSDEC guidance level to protect contact recreation. Please note that this threshold is more applicable for surface TP and does not necessarily account for internal phosphorus loading in the deeper waters.

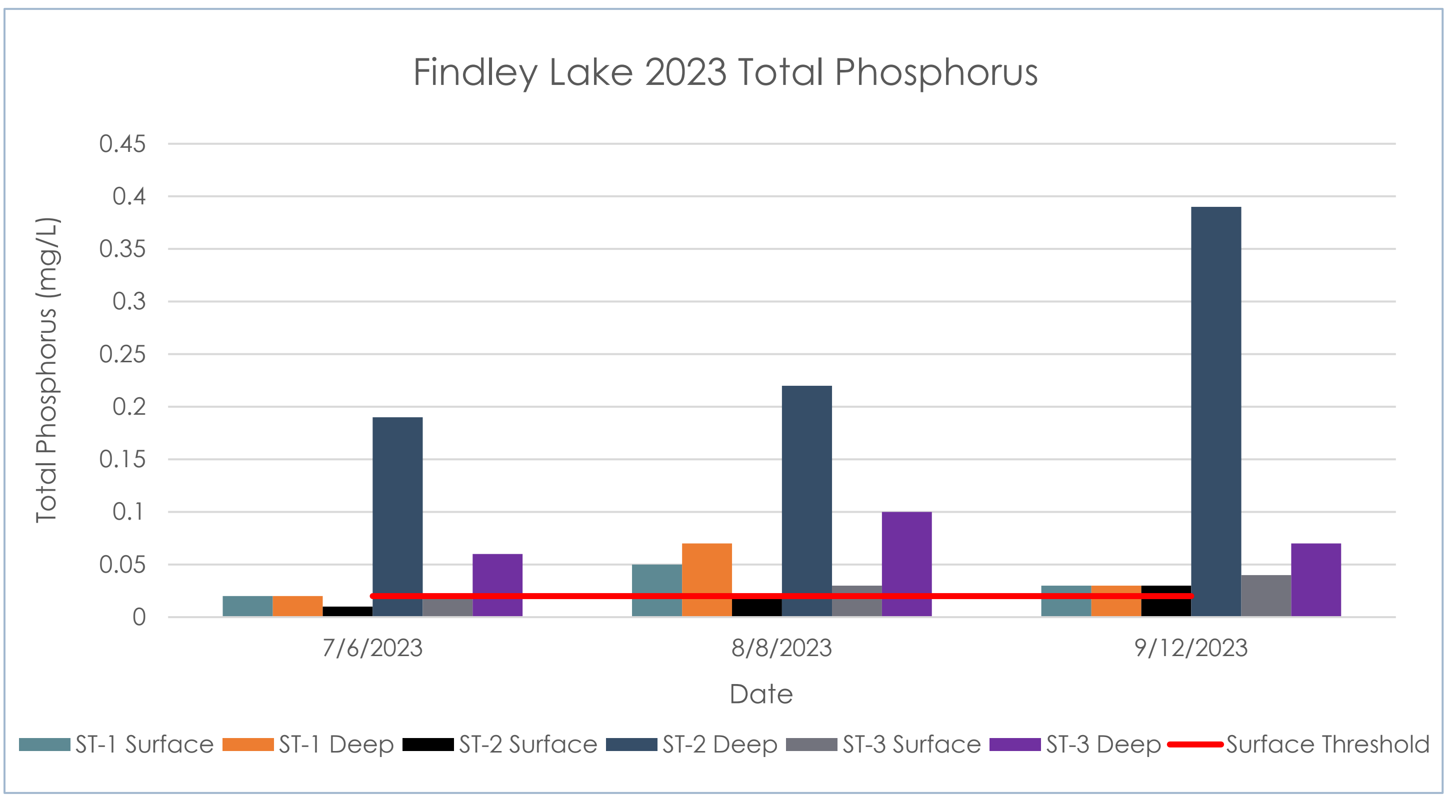


Figure 2.4: Total phosphorus concentrations in Findley Lake throughout the 2023 season

Surface TP concentrations remained low to moderate throughout the season, ranging from 0.01 mg/L at ST-2 in July to 0.05 mg/L at ST-1 in August (Figure 2.4). The mean surface TP concentration in Findley Lake was 0.03 mg/L.

Deep TP concentrations were much more variable throughout the season. Deep TP concentrations were the lowest at the shallow ST-1, ranging between 0.02 mg/L in July and 0.07 mg/L in August, with a seasonal mean of 0.04 mg/L. ST-3 had higher deep TP concentrations, ranging between 0.06 mg/L in July and 0.10 mg/L in August, with a seasonal mean of 0.08 mg/L. ST-2 had elevated deep TP concentrations from July through September, ranging between 0.19 mg/L in July and 0.39 mg/L in September; the seasonal mean deep TP concentration at ST-2 was 0.27 mg/L. The seasonal mean deep TP concentration at all three stations was 0.13 mg/L.

It's evident that phosphorus was being released from the sediments at ST-2 and ST-3 from at least July through September while the hypolimnion remained anoxic. The deep, mid-lake station (ST-2) had the highest concentration during each event, indicating that the rate of phosphorus release increased with depth. The shallow ST-1 did not show any indication of significant internal phosphorus loading, although the July deep TP concentration of 0.07 mg/L is slightly elevated; however, the DO data from this date shows that ST-1 remained oxic, and this slightly elevated deep TP concentration was likely not the result of anoxic internal phosphorus loading.

TOTAL DISSOLVED PHOSPHORUS

TDP represents all forms of dissolved phosphorus, including both inorganic and organic dissolved phosphorus. While SRP represents the dissolved form of phosphorus that is immediately available for algal assimilation, TDP represents the SRP in addition to any dissolved organic phosphorus (DOP).

Figure 2.5 below presents the surface and deep TDP concentrations at ST-2 throughout the 2023 growing season. Please note that no deep sample was collected in July due to a logistical error.

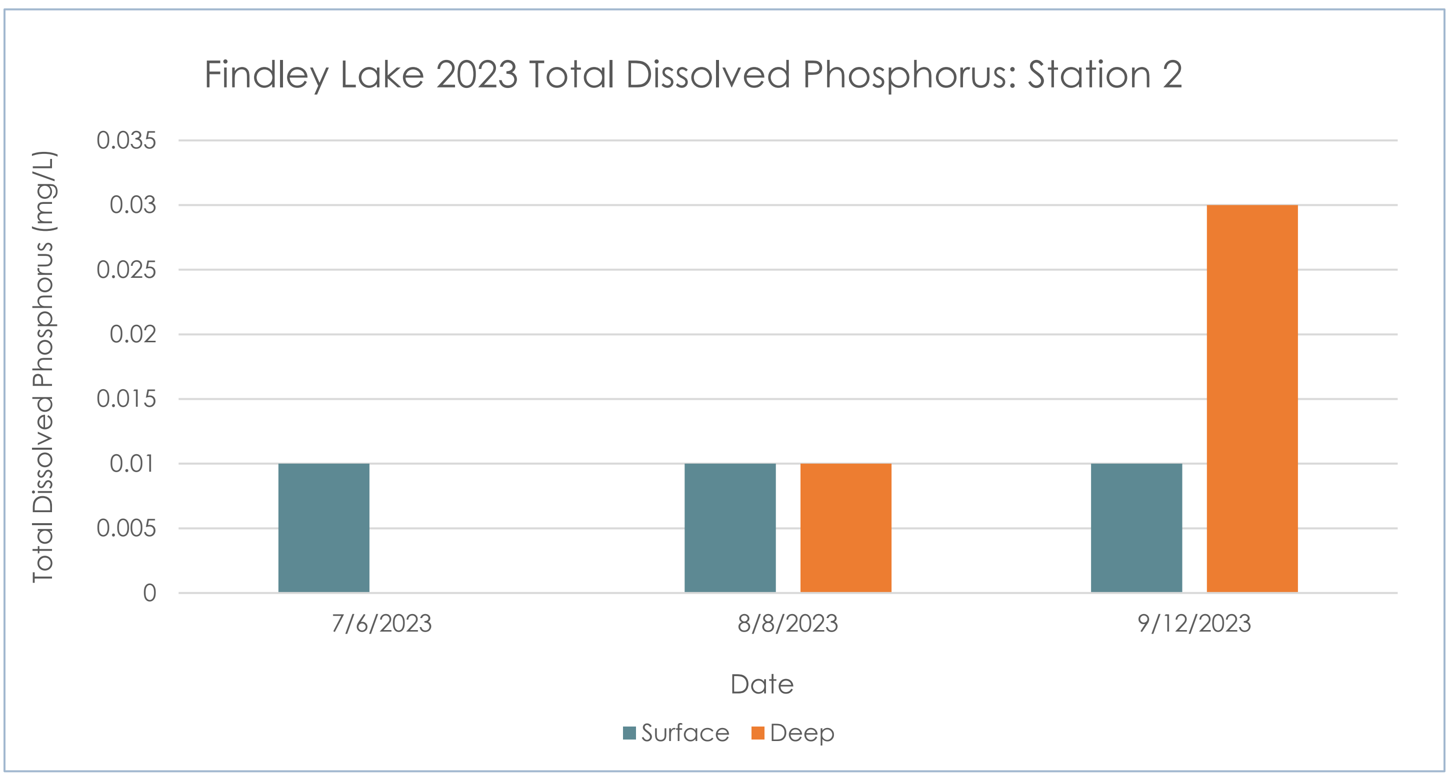


Figure 2.5: Total dissolved phosphorus concentrations in Findley Lake throughout the 2023 season

Surface TDP concentrations at ST-2 remained low from July through September, never exceeding 0.01 mg/L (Figure 2.5). The deep TDP concentration was low in August before increasing slightly in September, with respective concentrations of 0.01 mg/L and 0.03 mg/L. The deep concentrations were low relative to the deep TP concentrations at ST-2, indicating that only a small portion of the phosphorus in the hypolimnion was in the dissolved form.

SOLUBLE REACTIVE PHOSPHORUS

SRP represents the dissolved inorganic portion of phosphorus. This species of phosphorus is readily available for assimilation by all algal forms for growth and is therefore normally present in limited concentrations except in very eutrophic lakes. Princeton Hydro recommends concentrations to not exceed 0.005 mg/L to prevent nuisance algal blooms.

Figure 2.6 below presents the SRP concentrations at all three stations throughout the 2023 growing season.

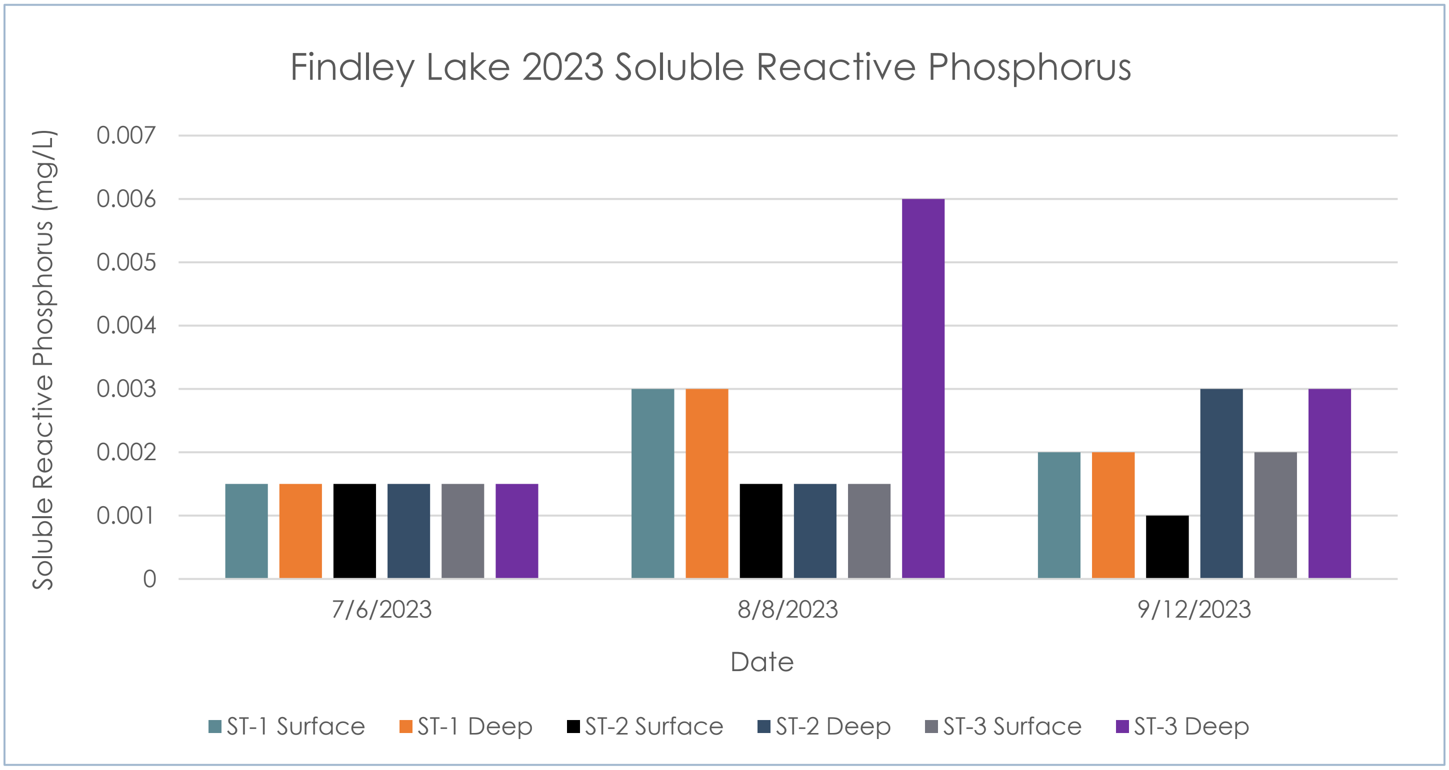


Figure 2.6: Soluble reactive phosphorus concentrations in Findley Lake throughout the 2023 season

Surface SRP concentrations remained low at all three stations in 2023, never exceeding 0.003 mg/L (Figure 2.6). The seasonal mean SRP concentration in Findley Lake from July through September was 0.002 mg/L. Deep SRP concentrations also remained relatively low, with only one slightly elevated sample; ST-3 had a deep SRP concentration of 0.006 mg/L in August. The deep concentrations were low relative to the deep TP concentrations at ST-2, indicating that only a small portion of the phosphorus in the hypolimnion was in the dissolved form. However, it's possible that deep SRP concentrations at the two deeper stations were elevated at times in between sampling events. SRP is the preferred form of phosphorus for algal growth and is often assimilated relatively quickly when it's available.

A review of the Secchi depth data indicates excellent water clarity in July and August, exceeding 4.0 meters at ST-2 during both events. With a Secchi depth of 4.3 meters, the photic zone, or area within the water column with enough sunlight to permit photosynthesis, can extend down as far as approximately 8.6 meters. With a photic zone extending deep into the hypolimnion, phytoplankton were able to assimilate the bioavailable phosphorus in these deeper waters and photosynthesize without moving back into the epilimnion. Thus, it's possible that TP concentrations were extremely elevated in the deeper waters as a result of particulate phosphorus that may have included a large portion of cell-bound organic phosphorus. This could explain why deep TP concentrations were extremely elevated while deep SRP concentrations were low; the dissolved bioavailable phosphorus was likely assimilated by phytoplankton as it was released from the sediments.

CHLOROPHYLL A

Chlorophyll *a* is the primary photosynthetic component of all algae and is often used as a proxy indicator of total algal biomass. Increases in chlorophyll *a* concentration are generally attributable to increases in total algal biomass and are highly correlated with increasing nutrient concentrations. As such, elevated chlorophyll *a* concentrations are a visible indicator of increased nutrient loading within a waterbody. Chlorophyll *a* concentrations above 6 µg/L are generally associated with eutrophic conditions. Through analysis of many regional waterbodies, Princeton Hydro has determined that concentrations above 20 µg/L are generally perceived as a water quality issue by those who utilize the lake for recreation. Concentrations above 20 µg/L are generally attributed to excessive phosphorus loading and are therefore a visible sign of nutrient impairment. There are no current water quality standards or guidance values for chlorophyll *a* in New York State, however the NYSDEC utilizes 25 µg/L as a starting threshold for harmful algal blooms.

Chlorophyll *a* samples were only collected at the surface of ST-2. The chlorophyll *a* concentration was extremely low in July, with a concentration of 1.4 µg/L. Chlorophyll *a* increased to a moderate concentration of 15 µg/L in August, indicating an increase in algal growth in the surface waters. Chlorophyll *a* reached a seasonal maximum of 34 µg/L in September. Thus, algal productivity in the surface waters increased from July through September.

NITROGEN (NITRATE-N, AMMONIA-N, AND TOTAL KJELDAHL NITROGEN-N)

Nitrate is the most abundant form of inorganic nitrogen in freshwater ecosystems. Common sources of nitrate in freshwater ecosystems are derived from bacterial facilitated oxidation of ammonia and through groundwater inputs. The molecular structure of nitrate lends it poor ability to bind to soil particles but excellent mobility in groundwater.

Nitrate is often utilized by algae, although to a lesser extent than ammonia, for growth. Nitrate distribution is highly dependent on algal abundance and the spatial distribution of dissolved oxygen concentrations. In many eutrophic lake systems nitrate concentrations show temporal and spatial variability due to algal productivity and relative concentrations of dissolved oxygen.

Excessively high concentrations of nitrate are primarily attributable to either wastewater inputs or excessive organic matter decomposition in oxygenated hypolimnion. Typically, lakes with concentrations above 0.30 mg/L indicates nitrogen-loading; however, concentrations below 0.50 mg/L are still considered acceptable surface water quality. For comparison purposes, the US drinking water standard for nitrate is 10 mg/L.

In lakes, ammonia is naturally produced and broken down by bacterial processes while also serving as an important nutrient in plant growth. In a process termed ammonification, bacteria break down organically bound nitrogen to form NH_4^+. In aerobic systems bacteria then break down excess ammonia in a process termed nitrification to nitrate (NO_3^-). These processes provide fuel for bacteria and are generally kept in balance to prevent accumulation of any one nitrogen compound.

Ammonia is generally present in low concentrations in oxygenated epilimnetic layers of lakes due to the rapid conversion of the ammonium ion to nitrate. In addition, most plants and algae prefer the reduced ammonium ion to the oxidized nitrate ion for growth and therefore further contribute to reduced concentrations of ammonia in the upper water layer. In the anoxic hypolimnion of lakes ammonia tends to accumulate due to increased bacterial decomposition of organic material and lack of oxygen which would otherwise serve to oxidize this molecule to nitrate.

Increased surface water concentrations of ammonia may be indicative of excessive non-point source pollution from the associated watershed. The ammonium ion, unlike that of nitrate, may easily bind to soil particles whereby it may be transported to the lake during storm events. Another likely source of excessive ammonia in suburban watersheds is runoff from lawn fertilizer which is often highly rich in nitrogenous species. Increases in ammonia concentrations in the hypolimnion of lakes are generally associated with thermal stratification and subsequent dissolved oxygen depletion. Once stratification breaks down a pulse of ammonia rich water may be mixed throughout the entire water column whereby it will cause undue stress to aquatic organisms, as well as possible toxicity.

Toxicity of ammonia to aquatic species generally increases with increasing pH (>8.5) and decreasing temperature (<5°C). The general guideline issued by the EPA is that ammonia should not exceed a range of 0.02 mg/L to 2.0 mg/L, dependent upon water temperature and pH, to preclude toxicity to aquatic organisms.

TKN represents total organic nitrogen + total ammonia. Thus, subtracting ammonia from TKN provides total organic nitrogen, which is mostly associated with organic debris and algal cells. Nitrogen is a major component of proteins.

Figure 2.7 presents all three forms of nitrogen at ST-2 throughout the 2023 season. Please note that no deep sample was collected in July due to a logistical error.

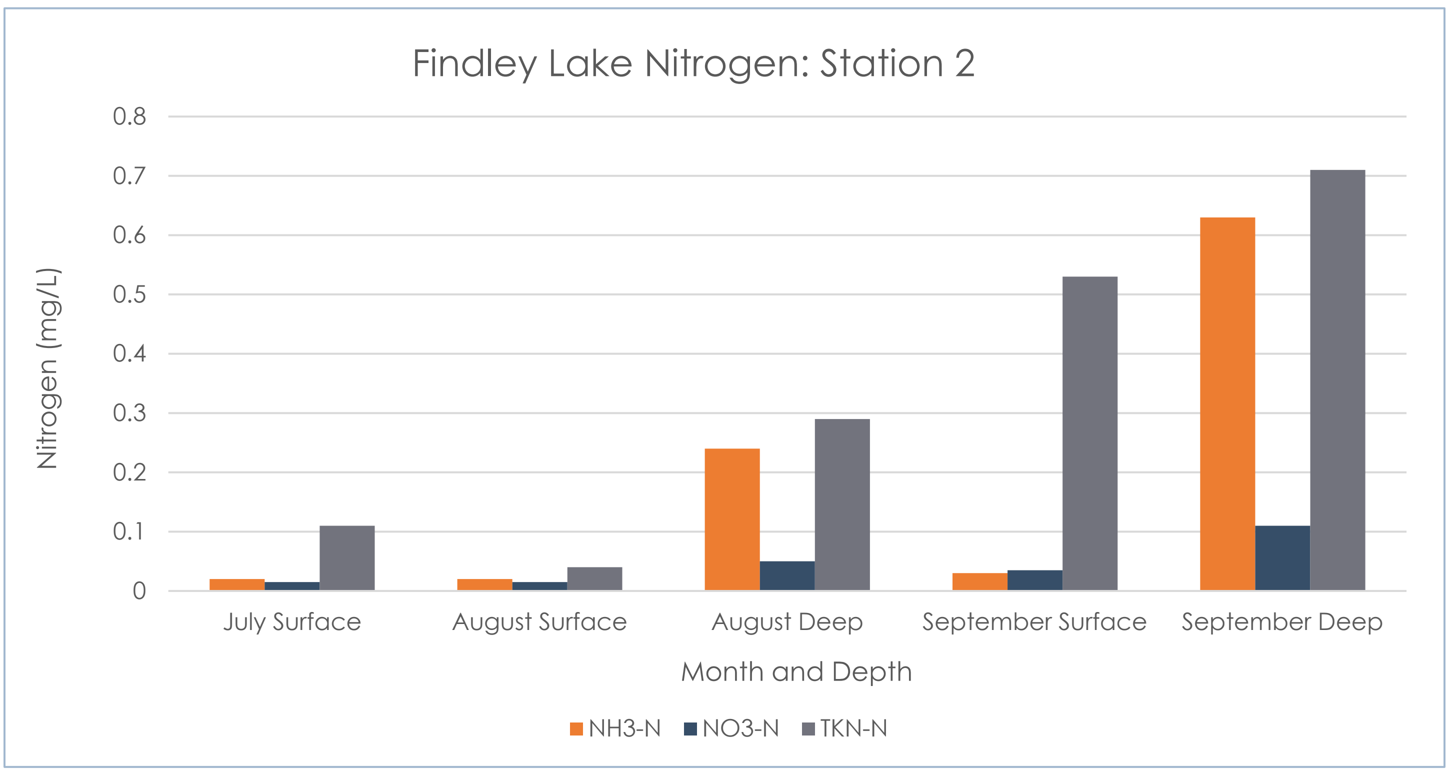


Figure 2.7: Nitrogen concentrations at ST-2 throughout the 2023 season

Nitrogen concentrations were variable by station from July through September (Figure 2.7). Surface nitrate-N and ammonia-N concentrations remained low during each event, never exceeding 0.035 mg/L. Surface TKN-N concentrations were consistently higher and increased as the season progressed, but organic nitrogen is typically present in higher concentrations. The seasonal maximum surface TKN-N concentration of 0.53 mg/L in September coincided with the seasonal maximum chlorophyll *a* concentration and was likely influenced by the higher algal densities at the surface.

Deep nitrate-N concentrations remained low to moderate, ranging from 0.05 mg/L in August up to 0.11 mg/L in September. Deep ammonia-N concentrations were much higher, ranging between 0.24 mg/L in August and 0.63 mg/L in September. It is not uncommon for deep water ammonia concentrations to increase during the summer stratification period due to the absence of oxygen; under oxic conditions, ammonia is converted to nitrite and nitrate by bacteria in the environment which can then be assimilated by plants and algae. Finally, deep TKN-N concentrations were the highest of the three parameters, increasing from 0.29 mg/L in August up to 0.71 mg/L in September. Thus, the elevations in deep-water nitrogen concentrations as the season progressed further supports the *in-situ* data that showed a stratified water column and an anoxic hypolimnion from at least July through September.

TOTAL SUSPENDED SOLIDS

The concentration of suspended particles in a waterbody that will cause turbid or "muddy" conditions, TSS is often a useful indicator of sediment erosion and stormwater inputs into a waterbody. Because suspended solids within the water column reduce light penetration through reflectance and absorbance of light waves and particles, suspended solids tend to reduce the active photic zone of a lake while contributing a "muddy" appearance at values over 25 mg/L. TSS measures include suspended inorganic sediment, algal particles, and zooplankton particles.

Figure 2.8 below presents the TSS concentrations in Findley Lake throughout the 2023 growing season.

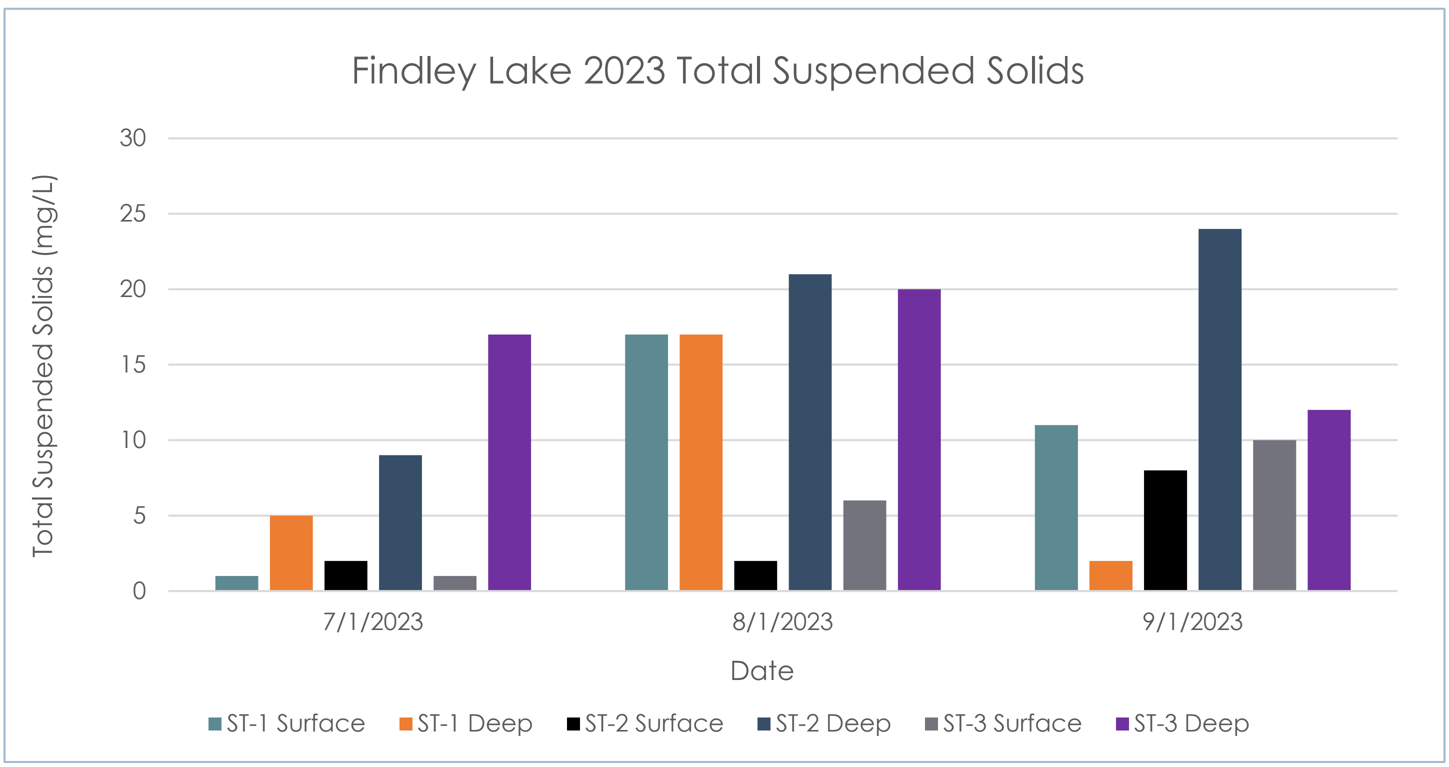


Figure 2.8: TSS concentrations throughout the 2023 season

TSS concentrations were variable by station and depth from July through September. Surface TSS concentrations were low at all three stations in July, ranging from 1 mg/L to 2 mg/L. Surface TSS concentrations increased significantly at ST-1 in August but remained relatively low at the two deeper stations; ST-1 had a surface concentration of 17 mg/L. Surface TSS concentrations decreased slightly at ST-1 in September but increased slightly at the two deeper stations; concentrations ranged from 8 mg/L at ST-2 up to 11 mg/L at ST-1.

Deep TSS concentration were typically higher than their surface counterparts. Deep TSS concentrations in July varied between 5 mg/L at ST-1 and 17 mg/L at ST-3. In August, deep concentrations varied between 17 mg/L at ST-1 and 21 mg/L at ST-2. During the final sampling event in September, deep TSS concentrations ranged between 2 mg/L at ST-1 and 24 mg/L at ST-2. Increases in the deep TP concentrations at the deeper ST-2 and ST-3 are likely the result of internal loading under anoxic conditions.

2.2.3 PLANKTON SAMPLING

Full plankton results can be found in Appendix IV.

PHYTOPLANKTON

Phytoplankton form the base of the trophic web in lake systems and largely determine the quality of the waterbody from ecological, recreational, and aesthetic perspectives. Phytoplankton are described herein as single celled and colonial algae, forming surface and benthic (bottom) colonies that act as primary producers. Phytoplankton growth is largely a function of nutrient concentrations, specifically phosphorus and nitrogen as discussed above, and available light intensity. Excessive nutrient levels can cause undesirable phytoplankton blooms that negatively impact water clarity and may form dense, floating surface mats. In addition to limiting phytoplankton biomass, nutrient levels can directly affect the phytoplankton assemblage, most notably low N:P (nitrogen to phosphorous) environments favor the growth of the undesirable cyanobacteria division (blue-green algae). These are the algae that commonly form surface scums that are not only aesthetically unpleasant but can produce toxins and noxious odors.

Cyanobacteria thrive in warm, nutrient rich lakes, and thus typically bloom during the warmer months, primarily from the end of the spring season through the beginning of the fall season. However, certain species may bloom in low nutrient, cool water environments, making the predictability and management of cyanobacteria and cyanotoxins a difficult task. Further complicating matters, cyanobacteria do not always produce cyanotoxins when they are present in a waterbody, but always have the potential to and must be treated as such. Given the variety of conditions that cyanobacteria blooms and cyanotoxins may arise under, it's important to proactively monitor cyanobacteria densities. When cyanobacteria produce toxins, or when cyanobacteria densities are high enough that the risk for cyanotoxin production increases, the blooms are referred to as harmful algal blooms (HABs).

Figures 2.9 and 2.10 below present phytoplankton community proportions and densities at the surface and mid-depth at the deep, mid-lake station (ST-2) across the 2023 growing season.

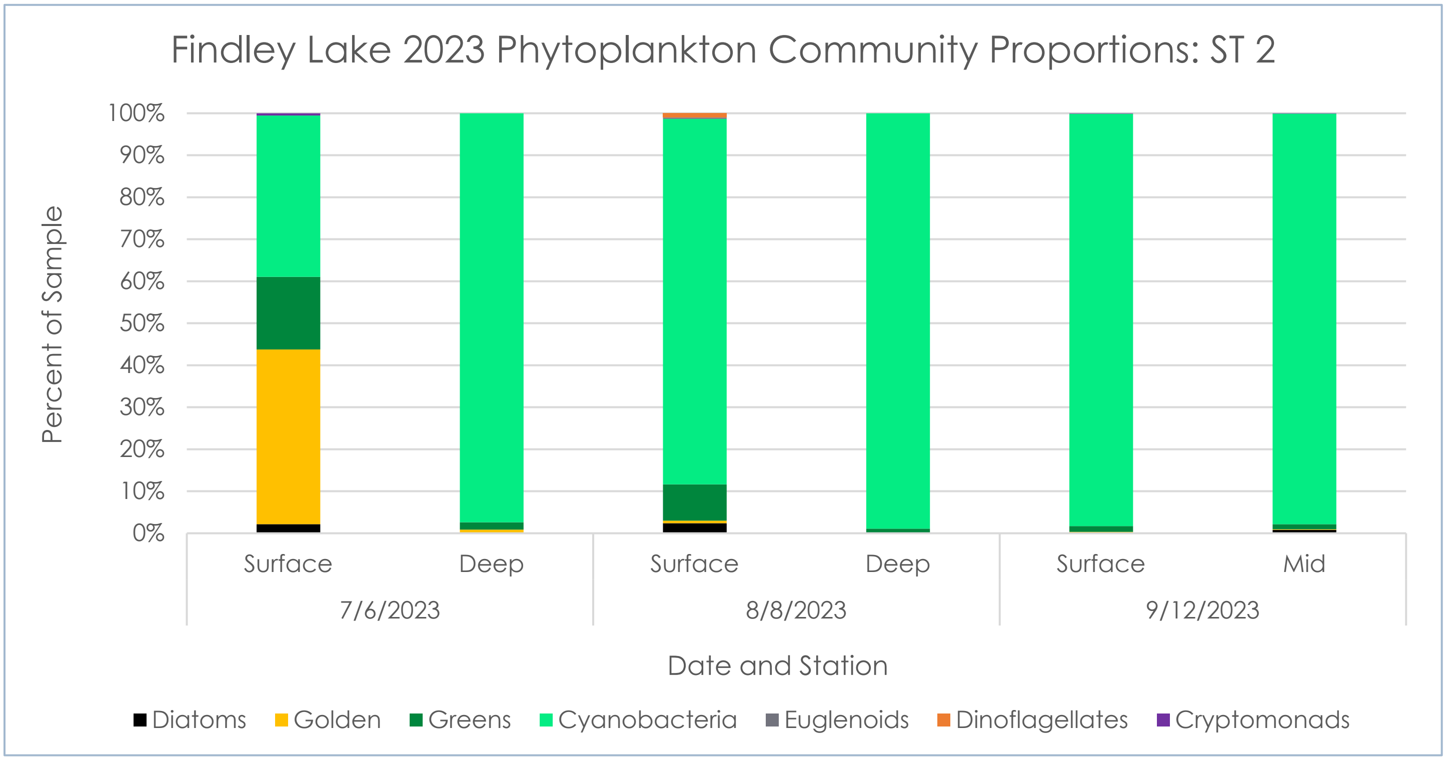


Figure 2.9: Surface and mid-depth phytoplankton community composition at ST-2 throughout the 2023 season

The surface sample on 6 July was co-dominated by chrysophytes (golden-brown algae) and cyanobacteria (blue-green algae), with a minor representation by the chlorophytes (green algae). However, the deep sample collected from the hypolimnion during the same event was dominated by cyanobacteria, which represented over 97% of the sample. The surface sample collected on 8 August was also dominated by cyanobacteria, representing 87% of the sample, but green algae represented approximately 9% of the sample. The deep sample collected from the hypolimnion during the same event was 99% cyanobacteria, with the remaining 1% comprised of just two green-algae genera. Cyanobacteria represented over 97% of the plankton community in the surface and mid-depth (4.5 meters) samples during the final sampling event in early September. Thus, the plankton community in the grab samples collected during the three sampling events was dominated by cyanobacteria, with little representation from the other groups. The deep samples were consistently dominated by cyanobacteria, which is important to note considering the deep-water phosphorus concentrations were significantly higher than the surface concentrations as a result of internal phosphorus loading.

Figure 2.10 below presents total phytoplankton cell counts at the surface and mid-depth of the deep, mid-lake station (ST-2) across the 2023 growing season.

The Environmental Protection Agency (EPA) developed recommended recreational ambient water quality criteria / swimming advisories for the two cyanotoxins microcystins and cylindrospermopsin in 2019. Unfortunately, the EPA has not developed any "action levels" or health advisory guidelines based on cyanobacteria cell counts and / or concentrations for some of the more toxic cyanotoxins. However, the EPA recognizes that many state agencies have recently been developing guidance levels based on cyanobacteria cell densities. Many of these cyanobacteria cell density guidelines are adapted from guidelines developed by The World Health Organization's (WHO), "Recreational Guidance/Action Levels for Cyanobacteria, Chlorophyll *a,* and Microcystin (Table 2.1)."

The risks to public health continue to be explored and recognized, and many regulatory agencies, including the NYSDEC through the HABs Program, are devoting major resources to their management, regulation, and mitigation. Table 2.1 below presents the WHO guidance levels, which were used in part to develop the HABs Program criteria.

Table 2.1: WHO Guidance

Relative Probability of Acute Health Effects	Cyanobacteria cells/mL	Microcystin-LR µg/L	Chlorophyll-a µg/L
Low	< 20,000	< 10	< 10
Moderate	20,000 - 100,00	10 - 20	10 - 50
High	100,000 - 10,000,000	20 - 2,000	50 - 5,000
Very High	> 10,000,000	> 2,000	> 5,000

The NYSDEC HABs Program has established four levels of bloom status based in part on visual evidence, plankton composition, chlorophyll concentration, and microcystins concentration. These levels are:

- No Bloom – Low likelihood of a bloom including at least one of the following criteria: (1) visual evidence not consistent with a cyanobacteria bloom; (2) BG chlorophyll levels ≤ 25 µg/L; (3) Plankton composition not dominated by cyanobacteria and not in bloom concentration; (4) microcystins concentrations ≤ 4 µg/L.
- Suspicious Bloom – NYSDEC HABs Program or NYSDOH determination based on digital photographs, field reports from professional/trained staff, or closure of a regulated swimming area, which may require follow-up and verification through sampling and analysis.
- Confirmed Bloom – Laboratory analysis indicates at least one of the following: (1) BG Chlorophyll concentrations ≥ 25 µg/L; (2) microscopy indicates dominance of cyanobacteria at bloom concentrations in samples; (3) absent other data, microcystins concentrations ≥ 4 µg/L but less than high toxin thresholds and ancillary evidence of a recent bloom.
- Confirmed with High Toxins Bloom: (1) microcystins concentrations ≥ 20 µg/L (shoreline samples only); (2) microcystins concentrations ≥ 10 µg/L (open waters); (3) known risks of exposure to cyanotoxin.

For the sake of comparison, the cyanobacteria cell counts from the 2023 sampling events will be compared with the WHO thresholds. > 20,000 cells/mL is recognized by the WHO as having a moderate relative probability of acute health effects. > 100,000 cells/mL is recognized by the WHO as having a high relative probability of acute health effects.

Cyanobacteria densities remained low at the surface of ST-2 during the 6 July sampling event, with a cell count of 8,403 cells/mL; the colony of the golden-algae genus *Synura* had a cell count of 8,994 cells/mL. The deep sample had a cyanobacteria cell count of 21,751 cells/mL which just exceeds the 20,000 cells/mL threshold that the WHO recognizes as having a moderate relative probability of acute health effects. The deep sample was dominated by the cyanobacteria *Planktothrix,* a filamentous genus with gas-vacuoles and the potential to produce cyanotoxins.

Cyanobacteria densities increased at the surface and bottom of ST-2 in August, with respective cell counts of 18,302 cells/mL and 40,001 cells/mL. Thus, the surface sample remained just below the 20,000 cells/mL threshold while the deep sample exceeded it. The surface sample was dominated by the cyanobacteria *Dolichospermum*, a common filamentous genus that also contains gas-vacuoles and has the potential to produce cyanotoxins. The gas vacuoles allow the cyanobacteria to position themselves in the water column where conditions are ideal, including the hypolimnion to assimilate the available phosphorus and near the surface where water temperatures are warmer and there is more light availability. *Dolichospermum* also contain specialized cells called heterocysts, which allow them to fix atmospheric nitrogen into ammonium that can be used for cell growth, and akinetes, which are thick-walled resting cells that are resistant to cold temperatures and unfavorable conditions and can overwinter in the sediments. The deep sample was dominated by *Planktothrix* again.

Cyanobacteria densities more than doubled at the surface and bottom of ST-2 in September and coincided with a significant reduction in water clarity and increase in chlorophyll *a* concentrations. The surface sample had a cyanobacteria cell count of 87,676 cells/mL and the deep sample had a cell count of 90,098 cells/mL. The surface and deep samples were both dominated by the cyanobacteria *Aphanizomenon*, another genus that possesses heterocysts and akinetes and can form dense planktonic blooms at-depth or at the surface.

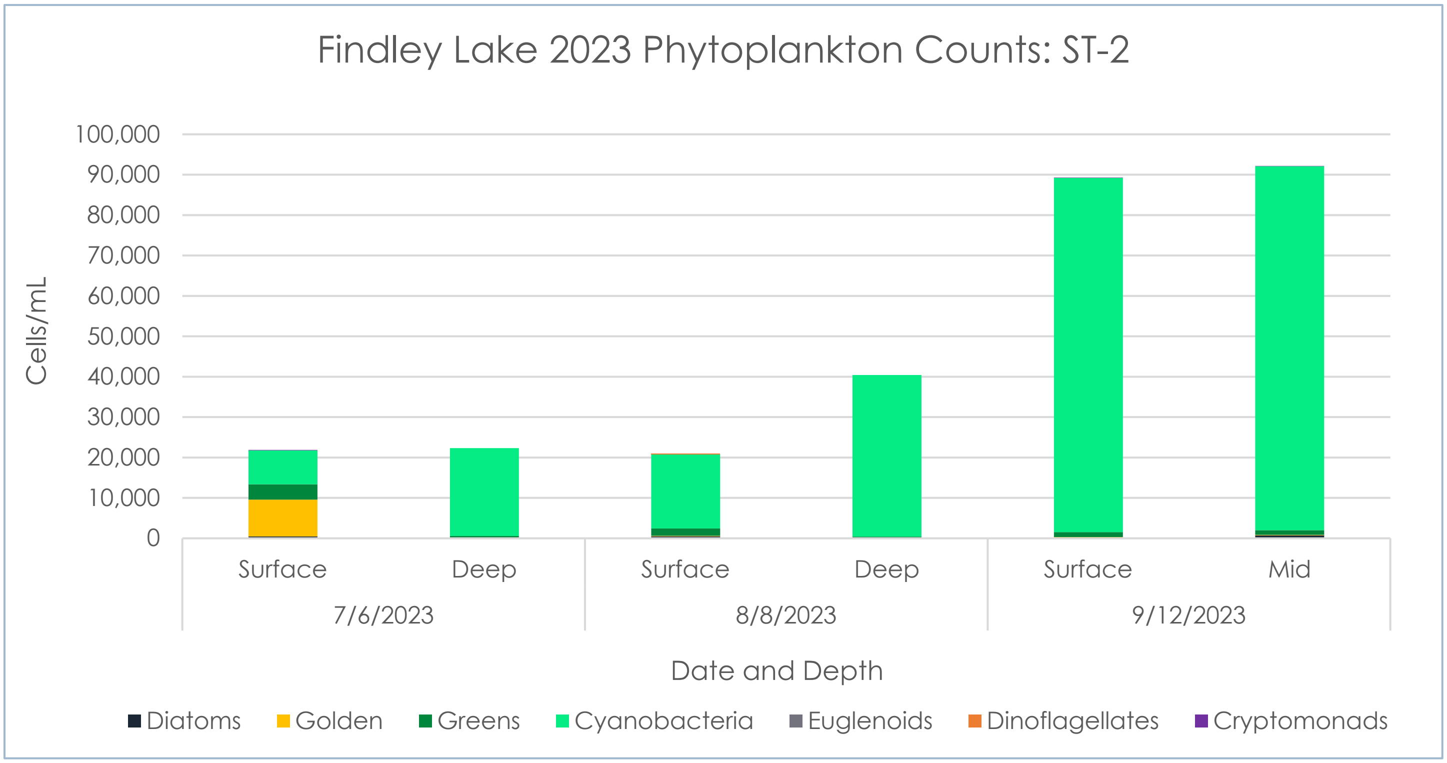


Figure 2.10: Surface and mid-depth phytoplankton densities at ST-2 throughout the 2023 season

The phytoplankton tows collected at ST-1 and ST-3 were typically more diverse than the grab samples, with greater representation by the diatoms and dinoflagellates. The dinoflagellate genus *Ceratium* was particularly abundant in July and August. However, cyanobacteria still dominated the plankton communities in the tow samples throughout the season.

Overall, Findley Lake had a cyanobacteria-dominated plankton community at all three stations from July through September in 2023. The three dominant cyanobacteria genera, *Planktothrix, Dolichospermum,* and *Aphanizomenon* all possess gas vacuoles and have the ability to regulate their position in the water column. Additionally, *Dolichospermum* and *Aphanizomenon* possess heterocysts and akinetes, making them hardy organisms with great potential to produce nuisance blooms. Given the fact that the photic zone extended down into the hypolimnion in July and August, even species without gas vacuoles were likely able to assimilate phosphorus in the nutrient-rich hypolimnion and photosynthesize at depth.

ZOOPLANKTON

Zooplankters are the micro-animals that inhabit the water column of an aquatic ecosystem. The zooplankton of freshwater ecosystems is represented primarily by four major groups: the protozoa, the rotifers, and two (2) subclasses of Crustacea, the cladocerans and the copepods. The cladocerans are a particularly important taxon within an aquatic ecosystem, and factor importantly in lake management. Cladocerans are typically characterized as large, highly herbivorous zooplankters capable of keeping algal densities naturally in check through grazing pressure. Many species of copepods are herbivorous and can also help maintain algal densities.

Aside from algae, many copepods also feed on other small aquatic animals and debris. Rotifers display a diversity of feeding habits. A portion of omnivorous rotifers feed on any organic material including bacteria and algae, while predaceous rotifers feed primarily on algae and other rotifer species. Protozoa feed either through ingestion or photosynthesis.

Figures 2.11 and 2.12 below present zooplankton community proportions and densities at the surface and mid-depth at the deep, mid-lake station (ST-2) across the 2023 growing season.

The smaller rotifers dominated the surface zooplankton community during most of the growing season, representing at least 69% of the community in five of the six samples; rotifers accounted for 53% of the community in the deep sample in September (Figure 2.11). Copepod community composition was more variable, ranging between 8% of the deep sample in July up to 16% of the sample in July (surface), August (deep), and September (deep). Cladoceran community composition was also variable, ranging between 1% of the surface sample in July up to 31% of the deep sample in September. Of more importance than relative community composition is total zooplankton abundance which is discussed below.

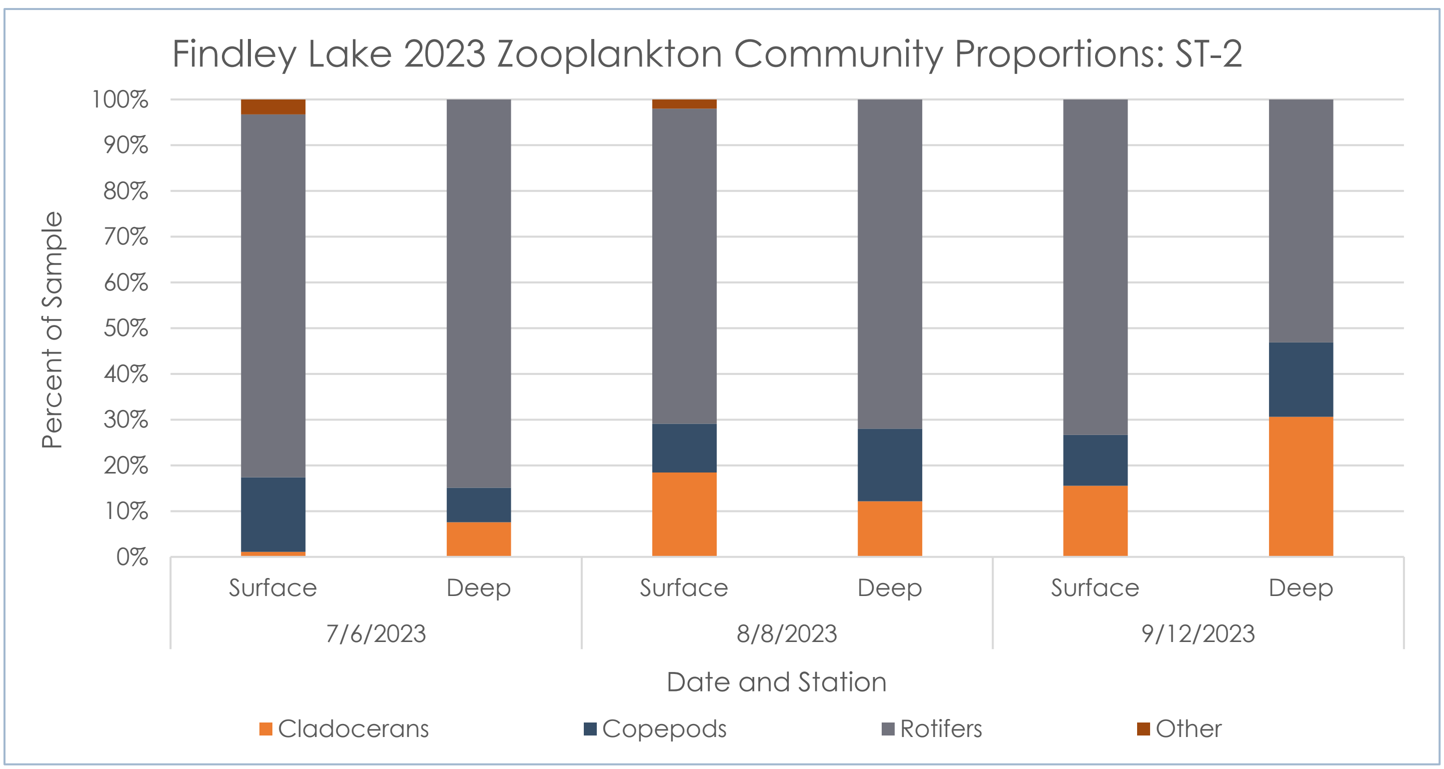


Figure 2.11: Surface and mid-depth zooplankton community composition at ST-2 throughout the 2023 season

Surface and deep total zooplankton abundance was variable throughout the season but was significantly higher deeper in the water column during two of the sampling events (Figure 2.12). This is not uncommon during the summer when water temperatures are cooler at depth. Zooplankton are aerobic organisms that require oxygen, so the deep samples were always collected at a depth with sufficient DO concentrations. It's a positive sign that the zooplankton community was robust, with good representation from the herbivorous copepods and Cladocerans in the deep sample during the final sampling event in September. However, the zooplankton community was dominated by the smaller rotifers for the entire season. Improving the phytoplankton community, with less cyanobacteria and more green algae may benefit the zooplankton community.

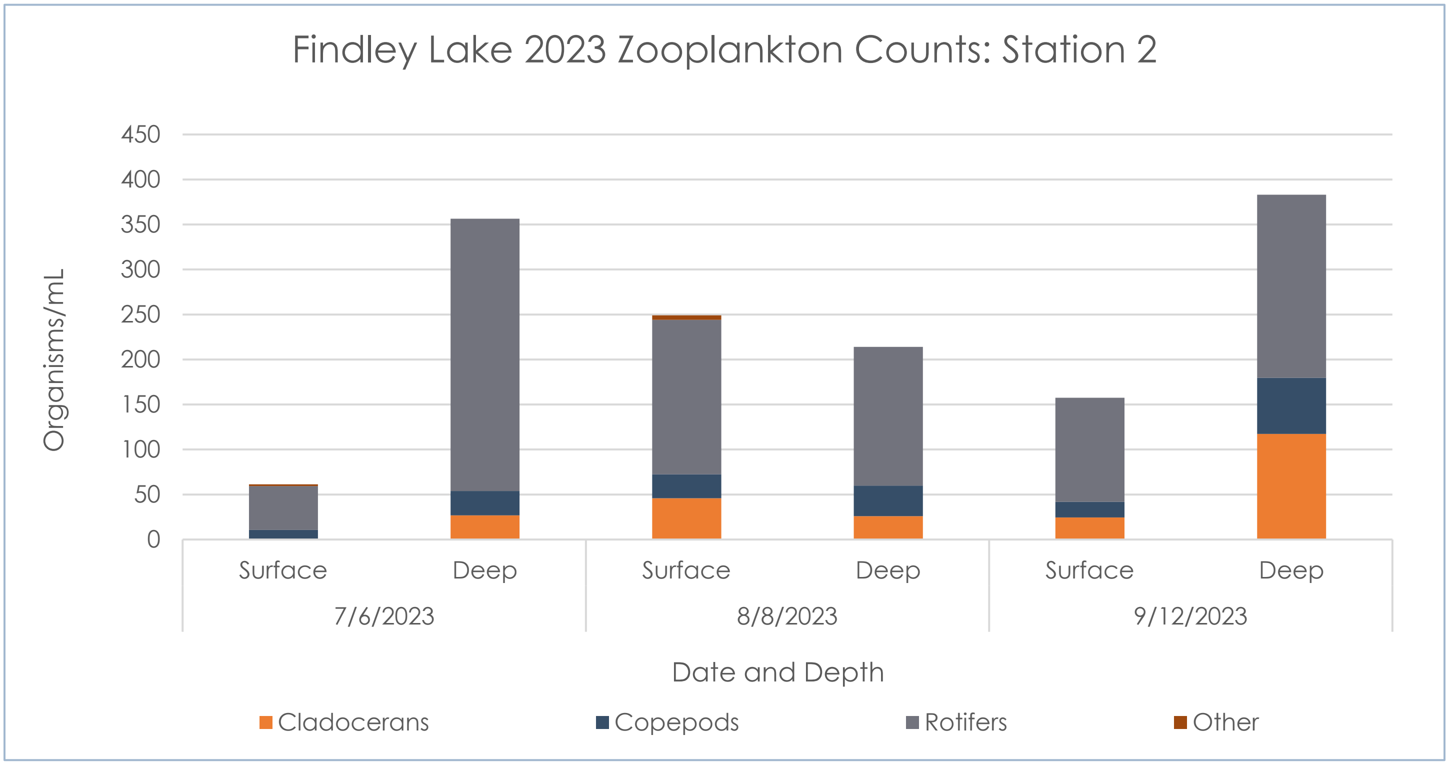


Figure 2.12: Surface and mid-depth zooplankton abundance at ST-2 throughout the 2023 season

3.0 INTERNAL PHOSPHORUS LOADING ANALYSIS

3.1 PRIMER ON INTERNAL PHOSPHORUS LOADING

3.1.1 THERMAL STRATIFICATION AND DISSOLVED OXYGEN

The physical properties of water are such that water reaches its greatest density at 4 °C. As water warms its density decreases. During the summer, due to the sun's heating of a lake's surface, the shallower waters (referred to as the epilimnion) become warmer than the deeper waters (referred to as the hypolimnion). A temperature gradient as low as 1°C/m between two depth intervals can result in a density difference great enough to inhibit the vertical mixing of the water column. When this occurs, the lake becomes thermally stratified. Thermal stratification can potentially form in any lake but is more prevalent in lakes deeper than six feet. The depth or boundary layer that inhibits vertical mixing is referred to as the thermocline or metalimnion. At times, this boundary can be very sharp, while in other circumstances it may cover several meters.

Once the thermocline becomes established, vertical mixing of the water column is inhibited resulting in the deeper waters of the lake becoming segregated from the surface waters. The thermocline can develop at any water depth, deep or shallow, and often migrates vertically over the course of a season. The depth at which it forms will be dictated by a number of factors including:

- Time of year, solar intensity, and air temperature
- Water color and clarity
- Lake depth
- Wind and wave action
- Flushing rate (hydraulic retention)
- Lake fetch (the uninterrupted distance that wind blow across a lake's surface)
- Magnitude and strength of the lake's seiche (an internal wave most commonly produced along the
- thermocline)
- Other factors that affect light penetration and water column stability

The maintenance of dissolved oxygen in lake water is largely a function of the consistent vertical mixing of the water column and the continued and repeated exposure of water to the atmosphere. Although some re-oxygenation may occur as a result of the photosynthetic activity of benthic algae, phytoplankton, and aquatic plants, or the turbulence created at the mouth of a tributary, the majority of re-oxygenation occurs due to the exposure of lake water to the atmosphere. Once stratified, the waters below the thermocline are no longer able to freely mix to the surface, and over time these thermally segregated layers become depleted of oxygen and go anoxic due to community respiration. The rate at which this occurs is variable from lake to lake depending in part on respiration rates, the volume of the segregated layer, the organic composition of the sediments, water temperatures, and other factors.

When the density differences between the epilimnion and the hypolimnion are great enough, thermal stratification will persist for long-periods of time leading to the majority of the lake water below the thermocline becoming devoid of oxygen. Some hypolimnetic oxygen consumption is due to community respiration by fish and other aerobic organisms. However, the majority of hypolimnetic oxygen consumption is the result of the bacterial decomposition of the organic material that settles and accumulates at the bottom of the lake, referred to as sediment oxygen demand (SOD). As a result of these processes, a large volume of a lake can become oxygen depleted during periods of stratification. This not only results in a large portion of the lake being unable to support organism's dependent on oxygen like fish and zooplankton, but it also alters the chemistry of the lake's sediments.

3.1.2 THERMAL STRATIFICATION AND INTERNAL PHOSPHORUS RECYCLING

Under oxic conditions (presence of oxygen) the majority of the phosphorus present in lake sediments is covalently bound to ferric iron (Fe^{3+}), forming ferric phosphate and ferric hydroxyl phosphate complexes. These complexes effectively lock a large portion of potentially biologically available phosphorus in the sediment. However, the ferric hydroxyl phosphate complexes are redox sensitive, and the covalent bond is relatively weak. When water overlying the sediments becomes anoxic the ferric iron gains an electron, becoming soluble ferrous iron (Fe^{2+}). When this occurs, the complexed phosphate is released from the sediment into the water column. The released phosphorus then becomes potentially available for algal assimilation under any of the following circumstances:

- The anoxic boundary extends into the photic zone of the epilimnion where phytoplankton (including cyanobacteria) are actively photosynthesizing,
- The lake destratifies or partially mixes resulting in the upwelling of a portion of the phosphorus rich water into the photic zone of the epilimnion, and/or
- Certain species of cyanobacteria may sink down into the phosphorus rich hypolimnion, assimilate the available phosphorus, and then rise back into the photic zone through the use of gas vacuoles where they are able to photosynthesize using the assimilated phosphorus.

Elevated internal phosphorus loads that go unmanaged can also lead to a feedback cycle of increasing productivity. Essentially, if the internally released phosphorus leads to increased productivity in the epilimnion, usually reflected in cyanobacteria densities and chlorophyll-a concentrations, this in turn can lead to more acute anoxia in the hypolimnion through an increase in the biological oxygen demand (BOD). More severe anoxia then increases the total release of sediment bound phosphorus, starting the cycle anew. Since the hypolimnion loses oxygen through the respiration associated with bacterial decomposition of organic matter while it is thermally separated from the surface waters, the increased productivity in the epilimnion that results from internally released phosphorus will result in more organic matter to be decomposed in the hypolimnion upon senescence of that load.

3.2 INTERNAL PHOSPHORUS LOADING METHODOLOGY

3.2.1 KEY METRICS

A few key parameters were required to conduct the internal phosphorus load analysis, including:

- Temperature profiles and the extent of thermal stratification,
- Dissolved oxygen profiles and hypolimnetic anoxia,
- Total phosphorus concentrations,
- Hypsographic data of the Findley Lake basin (area and volume associated with depth contours from the deepest point in the lake to the surface).

The temperature, dissolved oxygen, and total phosphorus data required for this analysis were collected as part of the 2023 water quality monitoring program and are outlined in Section 2.0 of this report. The bathymetric map utilized for this analysis was produced by the Cadmus Group, Inc and is included in the TMDL Report (NYSDEC, 2008). Princeton Hydro's GIS team digitized the existing bathymetric map and computed the necessary hypsographic data required for the internal phosphorus loading analysis (Appendix V). The analysis produced the area of sediment and the associated water volume from the surface to the deepest point of the lake at 0.5-meter intervals.

3.2.2 FINDLEY LAKE INTERNAL LOAD MODEL

The anoxic internal load was calculated on an event basis across the 2023 season. Only stations ST-2 and ST-3 were utilized in this analysis because both stations were anoxic in the hypolimnion during all three sampling events; ST-1 was shallow and sufficiently oxygenated. For each event, the anoxic internal load was calculated by multiplying the average measured deep TP concentration from ST-2 and ST-3 by the volume of water that corresponds to the average anoxic depth interval at ST-2 and ST-3 using the hypsographic data generated from the bathymetric map.

The highest event-based internal phosphorus load calculated was then used as the internal phosphorus load for Findley Lake in 2023. The seasonal event maximum statistic is likely the best representative of the actual internal load of the lake because it integrates the accumulation of phosphorus over the course of the entire season.

After calculating the total anoxic zone phosphorus load on an event basis, net anoxic sediment TP loading rates between events were also calculated. Static anoxic sediment TP loading rates were calculated by dividing the event based total anoxic zone phosphorus load by the area of sediment subject to internal phosphorus loading. The net anoxic zone sediment TP loading rates between events were then calculated by dividing the static loading rates by the number of days between sampling events.

3.2.3 RESULTS

The annual internal phosphorus load at Findley Lake is estimated to be 130 kg/yr (287 lbs/yr). Because it would be difficult to differentiate between the source of phosphorus concentrations in the oxic zone of the lake, whether from the release of phosphorus from the oxic sediment, other autochthonous sources such as macrophytes, or externally produced, the growing season anoxic zone phosphorus load will represent the annual internal phosphorus load. Table 3.1 below presents the internal phosphorus loading metrics on an event basis.

Table 3.1: Findley Lake Internal Phosphorus Load

Parameter	7/6/2023	8/8/2023	9/12/2023
Average Anoxic Depth (m)	6	6	5
Average Anoxic Area (m²)	247,667	247,667	290,256
Average Anoxic Volume (m³)	295,132	295,132	563,834
Average Deep TP (mg/L)	0.13	0.16	0.23
Anoxic TP Load (kg)	*36.9*	*47.2*	*129.7*

As mentioned in the methodology section, the maximum event-based internal phosphorus load was used to represent the internal phosphorus load because it integrates the accumulation of phosphorus over the course of the entire season. Using the maximum event-based internal phosphorus load is also particularly useful here because no data was collected prior to 6 July, but the lake was likely stratified and anoxic to a lesser extent for at least the previous month and potentially even longer. However, in a dimictic waterbody like Findley Lake, the internal phosphorus load almost always increases as the season progresses because the phosphorus accumulates in the hypolimnion. Thus, the maximum event-based internal phosphorus load occurred during the final monitoring event on 12 September. The internal load would likely have continued to increase throughout September as the lake remained stratified. Thus, while the estimate from early September is a good indication of the late season internal phosphorus load, it likely continues to grow until the lake mixes.

In addition to the total anoxic zone internal phosphorus load, areal loading rates were also calculated. Please note that no net anoxic zone loading rate was calculated for the first sampling event of the year because there was no preceding sampling event. The area used for the August and September events are provided in Table

3.1. The daily areal TP loading rates for August and September are 1.3 mg TP/m^2/d and 8.1 mg TP/m^2/d, respectively. The average daily loading TP rate from 6 July – 12 September, which represents the peak of the growing season, is 4.7 mg TP/m^2/d. For reference, 6.0 mg TP/m^2/d is a common internal phosphorus loading coefficient used for lakes in the northeast based on values reported in a 1985 paper (Nürnberg, 1985). The seasonal average daily loading rate in Findley Lake would have likely been higher than 4.7 mg TP/m^2/d if sampling was conducted from the onset of thermal stratification, as we would have been able to account for the initial increase in the internal phosphorus load. When sampling commenced on 6 July, hypolimnetic TP concentrations were already high. Nonetheless, the daily TP loading rates still agree fairly well with the literature values.

3.2.4 DISCUSSION

The 2008 TMDL reported a total phosphorus load of 436 kg/yr (929 lbs/yr) for Findley Lake, with a targeted load of 99 kg/yr (218 lbs/yr). However, the TMDL did not account for an internal phosphorus load, but it did acknowledge the need for additional monitoring to determine if phosphorus release from the sediments plays a significant role in the phosphorus loading of Findley Lake. The data collected over the course of the 2023 season and the subsequent analysis indicates that the internal phosphorus load in Findley Lake is sizeable.

Adding the estimated 2023 internal phosphorus load of 130 kg/yr (287 lbs/yr) to the total load of 436 kg/yr (929 lbs/yr), the updated total phosphorus load for Findley Lake is 566 kg/yr (1,238 lbs/yr); please note that this does not account for any watershed or other management measures that may have been implemented since the development of the TMDL. Assuming a total phosphorus load of 566 kg/yr (1,238 lbs/yr), the internal phosphorus load accounts for 23% of this load. Reducing the internal phosphorus load through in-lake management has the potential to significantly reduce the total phosphorus load in Findley Lake. While it's still important to continuously address the external phosphorus load, these efforts can sometimes take decades to have any measurable impact on in-lake water quality conditions.

The 2008 TMDL states that internal rates estimated from measured phosphorus accumulation in the hypolimnion during the stratified period should not be incorporated into the full-lake total phosphorus model unless there is evidence the accumulated phosphorus is transported to the mixed layer during the growing season. While this point makes sense in theory, discrete phosphorus samples at the surface and at depth are not typically sampled frequently enough to account for this mixing into the upper layer. Additionally, there are multiple ways that the phosphorus released from the bottom sediments during periods of anoxia can become available for phytoplankton growth other than direct mixing into the epilimnion:

- The anoxic boundary extends into the photic zone of the epilimnion where phytoplankton (including cyanobacteria) are actively photosynthesizing,
- The photic zone extends down into the hypolimnion if water clarity is high, allowing for algal assimilation and photosynthesis directly in the hypolimnion,
- Certain species of cyanobacteria may sink down into the phosphorus rich hypolimnion, assimilate the available phosphorus, and then rise back into the photic zone through the use of gas vacuoles where they are able to photosynthesize using the assimilated phosphorus.

The 2023 water quality data indicates that the photic zone likely extended down into the hypolimnion at times throughout the summer, allowing for algal assimilation and photosynthesis directly in the hypolimnion. The photic zone is the upper layer in a waterbody with enough sunlight, or photosynthetically available radiation (PAR), to permit photosynthesis; doubling the Secchi depth is often used as a proxy measurement for estimating the depth of the photic zone in a lake. Water clarity at ST-2 was 4.3 meters in July and August, resulting in a photic zone that extended down as far as approximately 8.6 meters. Thus, even though surface phosphorus concentrations remained relatively low throughout the season, chlorophyll *a* concentrations and algal densities increased significantly as the season progressed and the internal phosphorus load increased.

Additionally, allowing the internal phosphorus load to continue unmanaged can lead to late season algae blooms as the surface waters cool and the thermocline is weakened. This can lead to pulses of phosphorus-rich water from the hypolimnion to the epilimnion. If there is a particularly cool cold-snap in late summer or early fall, the lake can also overturn rapidly, allowing for a significant amount of phosphorus to be mixed with the surface water. Conditions in 2023 got progressively worse into September as the internal load increased, indicating that the internally released phosphorus was becoming available for algal growth somehow. A review of historical images on Google Earth reveals multiple instances of intense, lake-wide cyanobacteria blooms in September and October; October 2011 and November 2014 are two examples. In both instances, cyanobacteria can be seen flowing downstream of the outlet, posing a risk to upstream waterbodies.

These data all support the claim that the internal phosphorus load is contributing to increased algal densities in the surface waters, and managing this internal load should improve water quality in Findley Lake.

4.0 PROPOSED FINDLEY LAKE AERATION SYSTEM

The following section discusses various aeration systems and recommends a strategy and system design suitable for Findley Lake.

4.1 WHY AERATE FINDLEY LAKE?

Due to the thermal properties of water, lakes with a maximum depth greater than 6 to 8 feet can develop thermal stratification of the water column. During these periods of thermal stratification, the differences in water density between the layers prevents the full vertical mixing of the water column. This can lead to the loss of oxygen (anoxia) below the thermocline, and sometimes extending up into the thermocline depending on the oxygen demand. Once the water overlying the sediments becomes anoxic, the lake's sediment chemistry is quickly altered, potentially resulting in the rapid release of sediment bound phosphorus into the water column.

Water quality data collected by Princeton Hydro during the summer months of 2021 and 2023 shows that the water column thermally stratifies in the deeper areas of the lake. During the 2023 season, ST-2 and ST-3, with respective maximum depths of approximately 10.5 meters and 7.8 meters, were both thermally stratified with anoxia in the hypolimnion during three consecutive sampling events from July through September. These data, along with the bathymetric data, indicate that Findley Lake is a dimictic lake that stably stratifies during the summer months and undergoes periods of mixing in the spring and fall. Thus, although the necessary data to compute the internal phosphorus load was only available from the 2023 season, the lake likely undergoes a similar process during each growing season.

In addition to the internal phosphorus load accounting for approximately 23% of the total phosphorus load identified in the 2008 TMDL, biological data indicates that the internal load is likely contributing to impaired water quality. In 2023, chlorophyll *a* concentrations and algal densities increased significantly as the season progressed and the internal phosphorus load increased. Historical data collected by the Citizens Statewide Lake Assessment Program (CSLAP) also indicate elevated chlorophyll *a* concentrations and cyanobacteria densities late in the season. The trend of late-season algal blooms further supports the claim that the internal phosphorus load is a significant contributing factor because the internal phosphorus load is low early in the season but progressively increases as anoxia persists.

Mitigating internal nutrient loading typically occurs in lake management via one of two means: aerating the deep portions of the lake to maintain the iron-phosphorus bond during the summer or chemically treating the lake sediments with an aluminum sulfate (alum) or other compound that creates a stronger bond with phosphorus than iron, thereby maintaining sequestration of P in the sediments under anoxia. However, the use of alum for internal load control are currently not permissible in New York; thus, aeration is recommended to control the internal phosphorus load in Findley Lake. Nationwide, aeration is the one of the most implemented and widely employed lake restoration strategies to address deep water anoxia and control the internal phosphorus loading caused by thermal stratification (Alhamarna and Tandyrak 2021).

4.2 REVIEW OF AERATION STRATEGIES

There are three main aeration strategies used for internal phosphorus load control: full air-lift (destratification), partial air-lift (hypolimnetic aeration and Layer-Air), and direct oxygen injection systems. However, there are a multitude of technologies available for each of those strategies. Several of the major classifications will be described and discussed, as well as system benefits and disadvantages specific to Findley Lake.

4.2.1 FULL AIR-LIFT (DESTRATIFICATION)

Destratification (complete water column mixing) aeration systems use compressed air to vertically circulate the entire water column which prevents thermal stratification from occurring or from persisting. This results in a water column characterized by relatively uniform surface to bottom water temperatures and densities. As a result, the entire water column can easily circulate from surface to bottom. Lake water reoxygenation occurs due to the constant vertical mixing of the water column and the exposure of the water to the atmosphere. Although compressed air facilitates water column mixing, it is the exposure of the water to the atmosphere rather any direct oxygen transfer associated with the compressed air that is responsible for the vast majority of reoxygenation; however, advances in diffuser technology and the production of increasingly smaller air bubbles may directly transfer some limited amount of oxygen to the column. The primary goal is to limit the formation of a stable hypolimnion and circulate oxygenated water to the lake bed in order to prevent anoxia and the leaching of phosphorus from the sediments. A secondary benefit of these types of systems is that they disrupt the formation of stable mid-column habitat which is often crucial to the growth of various nuisance algae, and particularly cyanobacteria; some species have the ability to regulate their position in the water column under relatively stable (stratified) conditions.

Destratification systems create a vertical convection current that results in the bottom waters being circulated to the surface of the lake, replicating the natural mixing of a lake during periods of turnover or when the water column is of uniform water temperature and density. This is accomplished by the strategic placement of air diffusers throughout the lake, but especially within the lake’s deeper reaches. The air compressors and the negatively buoyant air lines account for the majority of the cost associated with destratification aeration systems. The diffusers are relatively inexpensive (approximately $700 per diffuser unit, although this can vary widely depending on design, especially when incorporating multi-head diffusers). The compressor or more likely multiple compressors must be housed in suitably-sized compressor buildings. To mitigate the noise and heat resulting from the operation of the compressors, the compressor buildings must be both heat and sound insulated and vented.

Destratification systems are operated continuously, typically starting in early- to late-spring (before thermal stratification occurs) and throughout the entire summer until the early fall and the natural breakdown of stratification due to lake cooling. Operational costs are a function of the size of the required compressor. The compressors for a destratification system servicing a relatively large lake typically require 3-Phase, 220-volt or 440-volt power sources. The annual maintenance for these systems primarily involves inspection and servicing of the compressor. Most modern lines are very robust, often offered with lifetime warranties, as are the diffusers, which utilize self-scrubbing technologies, and it is not unreasonable to expect at least 20 years of service from those components. Periodic inspection, most efficiently conducted by a dive crew, is recommended.

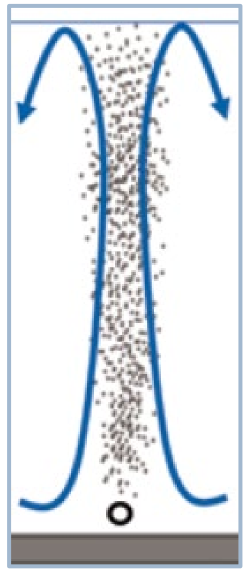


Figure 4.1: Schematic diagram of a destratification system. Source: Moore, et al., 2015

While these systems work extremely well in many settings, there are drawbacks to their use in Findley Lake for management, operational, and practical reasons. In its natural state, Findley Lake is a dimictic lake. This means that it undergoes two mixing cycles per year; once in the spring as water temperatures are increasing and again in the fall as temperatures are cooling. In between these periods, the lake is stratified throughout the winter and again throughout the summer. In winter, depending on temperature, the lake likely exhibits inverse stratification in which cooler waters overlie warmer water; the maximum density of freshwater is achieved at 4.00 °C and will therefore be found at depth when the lake is frozen. Typical stratification occurs during the summer months in which the epilimnion is warm and the hypolimnion cooler. The loss of oxygen in the hypolimnion occurs during this time because this bottom layer cannot mix with upper water layers whereby dissolved oxygen concentrations would be replenished with atmospheric sources. Destratification would therefore eliminate this period of summer stratification and would result in a significant change to the current regime.

In its current state, the internal load is sequestered in the hypolimnion through most of the year, although there are a few ways in which this phosphorus can become available for algal assimilation: vertical cyanobacteria migration in the water column; the vertical migration of the thermocline; if the anoxic boundary extends into the photic zone of the epilimnion; or during fall turnover which can result in the release of phosphorus to the epilimnion. More importantly though, it could have a negative impact on the current fishery. Although Findley Lake does not support a coldwater fishery, it does support a coolwater fishery, including muskellunge (*Esox masquinongy*), northern pike (*Esox lucius*), and walleye (*Sander vitreus*). While these fish can withstand warmer temperatures for short periods of time during the summer, they generally prefer cooler water. While increased DO concentrations, especially at depth, would be of benefit, the impact to the thermal structure could be detrimental. Any temperature refuge in the lower epilimnion / upper thermocline would be eliminated and the water column would be of nearly uniform temperature, expected to align closely with the current surface temperature regime of the lake. This could change and disrupt the current fishery, an important recreational resource of the lake and valuable to many lake users.

Given these limitations, and the fact that there are superior options that would not eliminate but would likely enhance coolwater fish habitat in the lake, a destratification system is not recommended as the primary option for Findley Lake. However, if cost is a significant limiting factor, a destratification system would likely be the lowest cost option, although it would still be a significant investment. It's also important to recognize the limitations relative to increased water temperatures and reduced fish habitat during the summer months.

4.2.2 PARTIAL AIR-LIFT

There are essentially two types of partial air-lift systems: hypolimnetic aeration and Layer-Air. Conventional partial air-lift hypolimnetic systems, as well as depth specific Layer-Air systems, make use of a "tube within a tube" design.

HYPOLIMNETIC

An alternative to the use of destratification is the use of a hypolimnetic aeration system. Like destratification systems, they use compressed air to lift deep oxygen-poor water higher in the water column, sometimes to the surface, but with hypolimnetic systems the deep anoxic water is returned to the bottom of the lake following re-oxygenation. This return is driven by temperature-dependent density differences between the waters. Even though a major transfer of DO results between the warm and cold water, because of the limited duration of time needed to mix the cold, oxygen-poor bottom water with the warm, oxygen-rich surface water, only a nominal increase in water temperature is experienced. Thus, the lake remains thermally stratified.

Hypolimnetic systems may be operated to maintain either relatively high (>4.0 mg/L) or minimal (1.0 mg/L to 2.0 mg/L) DO concentrations at the lake bottom or targeted aeration zone. With the main goal of internal phosphorus loading, the targeted DO concentration may only utilize the lower DO bound as sufficient to prevent internal phosphorus leaching. Conversely, if the goal is to create or maintain coldwater fish habitat as well as control internal phosphorus loading, the targeted DO concentration may be significantly higher. The hypolimnetic unit may be equipped with a hatch, air tube, or vent that allows any hydrogen sulfide present in the anoxic bottom waters to be released into the atmosphere. These vents can cause the characteristic rotten egg smell associated with hydrogen sulfide which may be off-putting to lake users; however, the hydrogen sulfide does not pose a danger to lake users at this concentration, and the smell is usually limited to the immediate vicinity of the vent.

LAYER-AIR

An adaption of or alternative to standard hypolimnetic aeration is depth specific aeration. These systems also use a "tube within a tube" design approach similar to conventional hypolimnetic systems (Moore, et al., 2015). The difference is that water is drawn into the unit at a specified depth; usually the upper stratum of the hypolimnion or from the metalimnion. Once again, compressed air is used to lift oxygen-poor water higher in the water column. The anoxic or hypoxic water is then mixed with the more highly oxygenated surface water and then returned to the stratum from which it was drawn. Typically, multiple mixing units are positioned within one or more strata. The designated stratum often provides the water temperature needed to provide critical holdover summer habitat for coldwater fish.

Although Layer-Air systems are designed and operated to preserve thermal stratification, they usually are not designed to eliminate bottom water anoxia. Thus, the epilimnetic and metalimnetic strata will be well-oxygenated, but the hypolimnion strata may remain anoxic. Because deep water anoxia is not abated, hypolimnetic internal phosphorus loading may still occur. By creating a thermally separated, oxygen-rich mid-water depth zone, however, it is possible to maintain separation of the phosphorus rich-hypolimnetic water from the photic zone of the epilimnion where photosynthesis occurs. These systems were originally designed with the assumption that phosphorus liberated from the anoxic lake bottom would remain mostly contained at the bottom of the lake and would not become available for biological uptake. While this is mostly true, as has been mentioned previously, there are multiple ways in which this phosphorus can still become available for algal assimilation, and particularly cyanobacteria:

- The vertical migration of cyanobacteria into the phosphorus-rich hypolimnion through the use of gas vacuoles. Some species can manipulate their position in the water column, allowing them to migrate downwards to assimilate the phosphorus, and then back up to the photic zone to photosynthesize,
- The photic zone extends down into the hypolimnion if water clarity is high, allowing for algal assimilation and photosynthesis directly in the hypolimnion, which was observed in Findley Lake in 2023,
- The upward migration of the thermocline into the photic zone where cyanobacteria and other phytoplankton are most active. The vertical position of the thermocline is dynamic during summer stratification and a warming period can cause the formation of a shallow epilimnion, resulting in the expansion of the hypolimnion and phosphorus rich water, and/or
- The temporary disruption of the stable stratification pattern from a storm can result in the upwelling of the phosphorus rich water into the photic one.

Climatic conditions throughout the region have changed since these systems were originally designed over 30 years ago, resulting in longer periods of thermal stratification, more severe anoxia, and increased internal phosphorus loads. These conditions and increased temperatures also favor cyanobacteria as they can utilize available phosphorus in the water column very efficiently. Thus, while effective when originally designed, this type of system is likely not the best technology for the current conditions.

ADDITIONAL CONSIDERATIONS

For Layer Air and hypolimnetic systems operated in a manner that does not completely prevent anoxia and the resulting internal phosphorus loading, it is necessary to manipulate the operation of the system immediately in advance of the lake's natural turnover to prevent the late season upwelling of phosphorus rich water to avoid an autumnal algae or cyanobacteria bloom. In such cases, the lake's thermal and DO profile will need to be closely monitored. As the water column begins to naturally cool and surface to bottom water temperatures become increasingly uniform, mixing and reoxygenation of the deeper portions of the lake is intensified, resulting in enough deepwater DO to create the oxic conditions necessary for the liberated inorganic phosphorus to re-bind with available dissolved iron. Once bound again to iron, the sedimentary recycled phosphorus can no longer be bioassimilated by algae or cyanobacteria. These operational considerations as well as the generally shallow anoxic boundary that was observed in 2023 would both suggest that these systems are not well suited to use at the lake.

The power needs, operation, and maintenance of conventional hypolimnetic and Layer Air systems are very similar. The compressors tend to be relatively large (at least 20 HP) and usually require a 3-Phase, 220-volt or 440-volt power source. The compressors for either type of system must be housed in a large footprint (at least 12' x 12'), properly insulated, and vented compressor building. To decrease the length and cost of the air line runs, the building should be located close to the shore and as close to the two deep pockets in the lake as possible. The majority of the material costs associated with hypolimnetic and Layer Air systems are related to the length, number, composition, and size of the air lines as well as the size and number of compressors. Additionally, the system's cost will be a function of the type and number of mixing units, all supporting system elements (filters, expansion tank, flow meters, etc.), and the construction of the compressor building. The compressors and supporting system elements must be serviced at least annually by manufacturer certified service providers and professional divers may be needed to periodically inspect and service the mixing units and the airlines. Utility costs are a function of the number and size of the compressors but can be expected to be significant ($20,000-$40,000 annually) given that hypolimnetic and Layer Air systems must be operated continuously from once the lake is thermally stratified in early- to late-spring until early fall after the lake turns over.

While partial air-lift systems offer a significant advantage over destratification systems in that thermal stratification is preserved, lessening the impact to coolwater fishery habitat, there are limitations that must be taken into account. One significant difference is the size of the in-lake apparatus. They can be very large, extending from the lake bed to at least the thermocline and potentially to the surface and are usually at least several feet in diameter and sometimes significantly larger. The units often use a large buoyancy chamber at the top of the water column which helps to maintain the unit in a vertical attitude and makes the unit telescopic so that it can collapse in place. The life-span is not particularly long. In addition, those that have the chamber require winterization, and they are typically flooded and moved subsurface to avoid ice damage. This of course introduces another navigation hazard to the lake.

These systems are also logistically more complicated than destratification systems and would include in-the-water operations. The operation of the unit itself can be more complicated, especially if the telescopic devices are used which must be floated to the surface in the spring and sunk in the fall. Monitoring DO concentrations on a consistent basis is critical and the system must be adjusted accordingly to maintain the desired DO concentration and preserve stratification. This is much more complicated than destratification, yet even for destratification systems it may be important to adjust the system as necessary to maintain the proper vertical mixing and DO while limiting resuspension of sediments and entrainment of phosphorus and particulates. Achieving this balance would be even more difficult for the depth specific aeration, especially if used to improve fisheries habitat. The unit must be operated to prevent destratification, while maintaining the proper DO concentration, and then during periods of metalimnetic erosion and prior to fall turnover must be adjusted to precipitate phosphorus prior to mixing.

Given these limitations, a traditional hypolimnetic or Layer-Air system are not recommended for Findley Lake.

4.2.3 DIRECT INJECTION PURE OXYGEN SYSTEMS

Pure oxygen systems (also referred to as direct oxygen or DOX systems) are typically used in relatively deep lakes and run-of-river reservoir systems. As with hypolimnetic systems, stratification is maintained but anoxia is overcome; some of these systems can also be designed to disrupt stratification, acting as a destratification system but with increased oxygenation efficiency. Thus, direct oxygen systems are well suited for managing internal phosphorus loading in a variety of lakes, but especially in deeper lakes where stratification must be maintained to support a fish habitat. Unlike hypolimnetic systems, direct oxygen systems do not rely on an air lift approach to circulate and oxygenate the hypolimnion or rely on atmospheric oxygen to reoxygenate the lake. Rather, oxygen is directly introduced to the lake water. The overall goal with all of these system designs is to increase oxygen concentrations directly over the sediment where oxic conditions are required to preclude the internal release of phosphorus from the sediment.

There are two types of direct injection oxygen aeration systems: line diffuser aeration systems and super saturation oxygenation (SSO). SSO systems can be further classified in to three designs: Speece cone, side stream supersaturation (SSS), and Oxygen Saturation Technology (OST). Although the design and operation of line aeration and SSO differ, the underlying approach is similar in that it involves the direct mixing of oxygen gas with lake water.

One of the major benefits of the various direct oxygen systems is that they can be designed to meet the SOD and BOD specific to Findley Lake. SOD refers to the rate at which dissolved oxygen is removed from the water column due to the chemical and biological oxygen consuming processes occurring within the sediment. While it’s true that some oxygen is depleted from the hypolimnion due to community respiration, primarily by fish and other aerobic organisms, the majority of the oxygen consumption is the result of bacterial decomposition in the sediment. At a minimum, the amount and rate of oxygen delivered into the hypolimnion must be enough to exceed the lake’s computed biological and SOD. This will vary seasonally, with peak demands occurring in the latter half of the summer. When the goal is to sustain coldwater fish habitat, or enhance coolwater fish habitat, more oxygen may be supplied and higher hypolimnetic DO concentrations maintained. Thus, oxygen injection systems offer a distinct advantage over the other types of lake aeration.

SPEECE CONE OXYGENATION

Speece cones utilize a water pump to transfer the oxygen-poor hypolimnetic water into a large, cone-shaped chamber. The water is then mixed with oxygen gas before being released back into the hypolimnion. These large mixing chambers can be placed directly in the lake or on shore. Mixing chambers that are placed in the lake require underwater power cables that deliver power from a source on shore. Speece cones are large structures that require the use of a large water pump. The pump extracts water from the hypolimnion, pumps it into the Speece cone, mixes the water with the injected oxygen, and then pumps the re-oxygenated water back into the hypolimnion. Oxygen is supplied either by an onsite oxygen generator or oxygen stored in tanks. The oxygen-poor water and oxygen gas are mixed at the top of the conical shaped structure. The shape of the Speece cone maximizes the contact and mixing of the oxygen-poor water with the introduced oxygen gas. The pumping, reoxygenation, and mixing process does not increase the temperature of the hypolimnetic water or result in enough turbulence to cause the lake to thermally destratify. Figure 4.2 provides a diagram of a typical Speece cone system with a submerged mixing chamber.

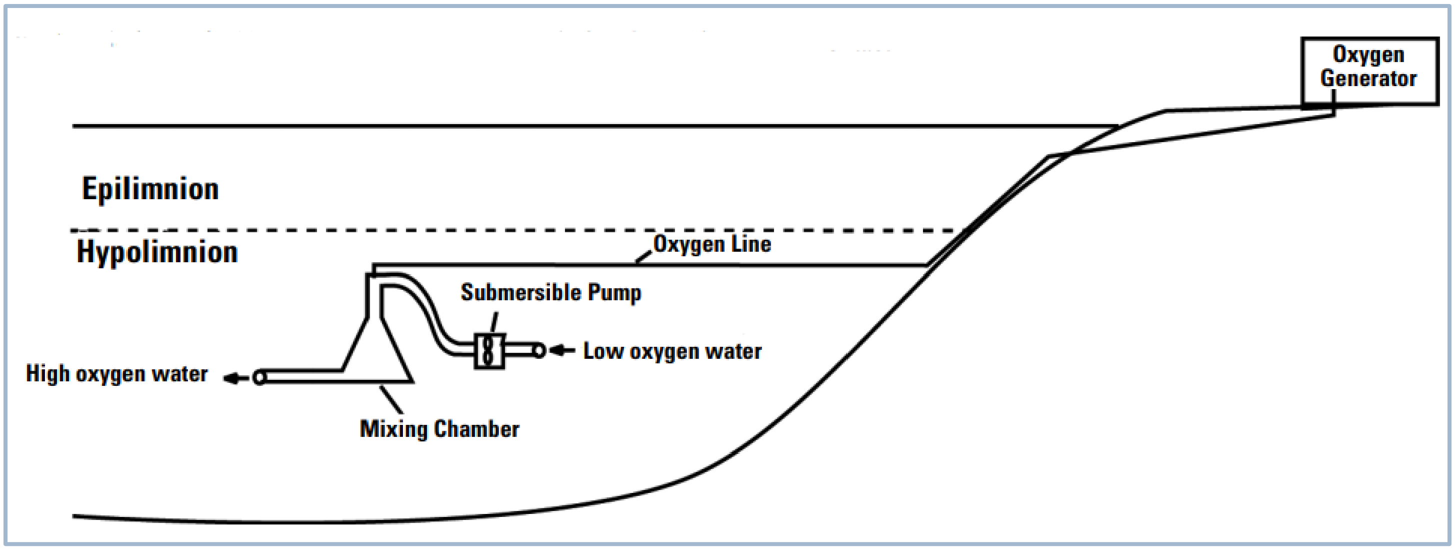


Figure 4.2: Diagram of a Speece cone system (not to scale). Source: Moore, et al., 2015

SIDE STREAM SUPERSATURATION

SSS systems were developed after Speece cone systems and offer the same benefit of maintaining oxic conditions in the hypolimnion while preserving thermal stratification. This design has become popular in recent years. SSS functions in a similar manner to the Speece cone in that it utilizes a water pump to transfer the oxygen-poor hypolimnetic water through a mixing chamber. Instead of the large mixing chamber that's used in the Speece cone design, SSS utilizes smaller chambers located on shore to mix oxygen with anoxic water. While these systems require longer lines and bigger pumps to transfer the water to the mixing chamber on shore, the design prevents the need to run power into the lake. As with a Speece cone, the oxygenated water is released back into the hypolimnion under low pressure at a specified depth. This low pressure is key to preventing the disruption of thermal stratification and any resuspension of sediment at the bottom of the lake. Oxygen is supplied either by an onsite oxygen generator or oxygen stored in tanks. These systems have typically been used in lakes with a maximum depth of approximately 10.0 m. Figure 4.3 provides a diagram of a typical SSS system.

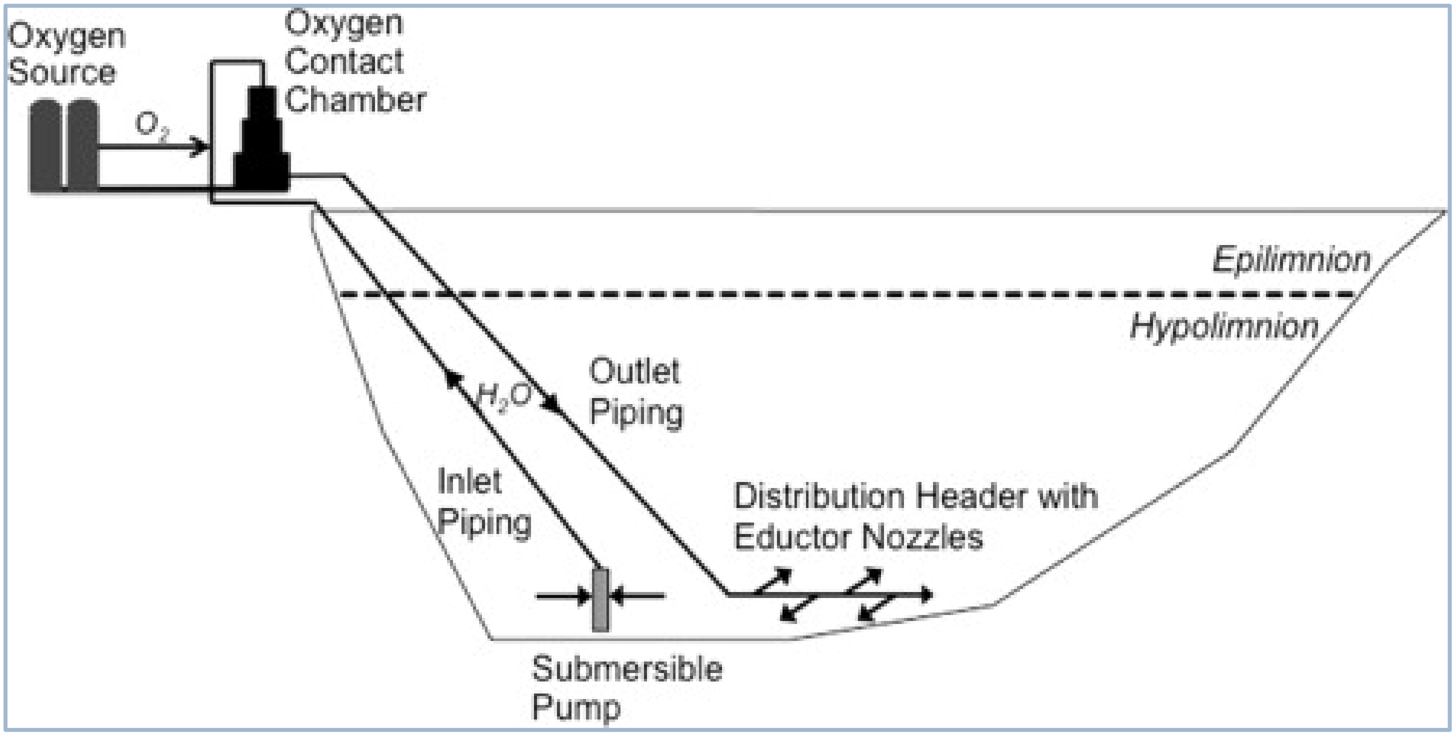


Figure 4.3: Diagram of a side stream supersaturation system (not to scale). Source: Gerling, et al., 2014

OXYGEN SATURATION TECHNOLOGY

OST is a relatively new type of oxygenation system that essentially combines the features of Speece cone and SSS systems. Similar to the aforementioned technologies, OST utilizes a water pump to transfer the oxygen-poor hypolimnetic water through a mixing chamber. The mixing chambers are located in the lake, similar to the Speece cone design; however, the mixing chambers are scaled down in size, similar to the SSS mixing chambers. This removes the need to pump the oxygen-poor water from the hypolimnion to the shore, introduce oxygen, then pump the oxygenated water back to the hypolimnion. Instead, oxygen is supplied either by an onsite oxygen generator or oxygen stored in tanks, pumped to the in-lake mixing chamber, and is introduced back into the hypolimnion under low pressure at a specified depth; typically, this is directly above the sediments where oxygen demand is greatest. OST is designed to dissolve all of the oxygen generated from the shoreline compressor into the water, preventing the release of bubbles and preserving thermal stratification.

OST systems are designed with oxygen sensors as part of the in-lake infrastructure, resulting in a highly efficient oxygenation system. The systems are designed with a target DO concentration in the hypolimnion and are programmed to turn on and off based on real-time DO concentrations. All in-lake components are built with extremely durable materials that will not be damaged if an anchor falls on it; however, it would still be recommended to mark the location of in-lake structures with buoys. Figure 4.4 below provides a diagram of an OST system.

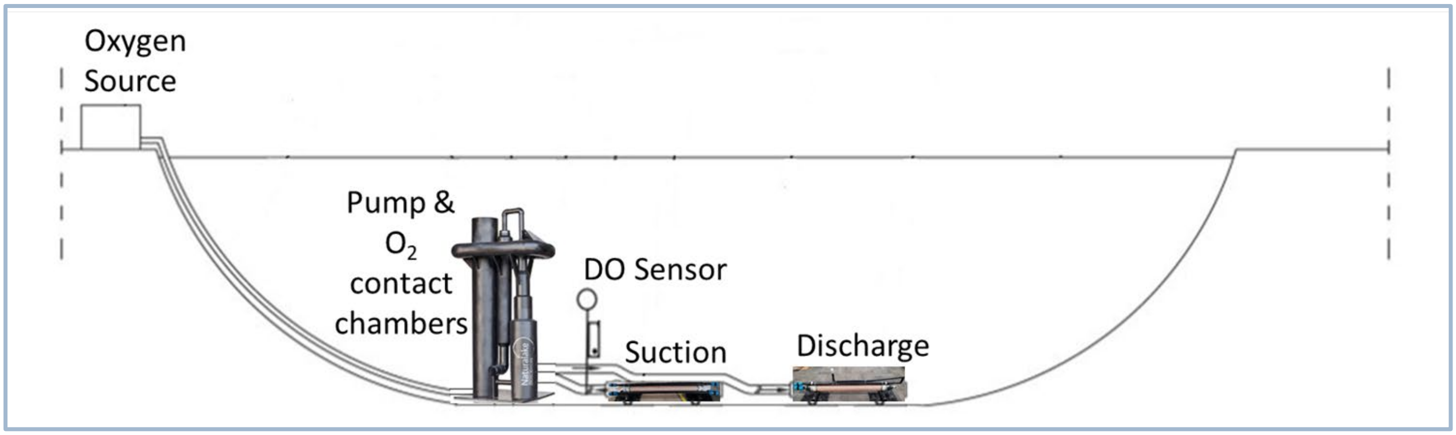


Figure 4.4: Diagram of an Oxygen Saturation Technology system (not to scale). Source: Paul Gantzer

LINE DIFFUSER OXYGENATION

Line diffuser direct oxygen systems use fine-pore oxygen diffusion lines to introduce oxygen directly into the water. This approach does not rely on any pumps to draw in hypolimnetic water. Rather, oxygen gas is released under low pressure into the lake via porous air lines anchored along the bottom but suspended above the sediments. As with SSO systems, oxygen may be supplied from large land-based oxygen gas storage tanks or by means of a land-based onsite oxygen generator. The rate at which the oxygen gas bubbles are released from the porous air lines is not enough to create the turbulence needed to thermally destratify the lake. Thus, anoxia is prevented and internal phosphorus loading is controlled, but the lake remains in a thermally stratified state.

One of the features that makes these systems particularly advantageous is the single line, two-pipe design (Moore, et al., 2015). Under this design, one of the pipes supplies the oxygen while the other is used for buoyancy. The porous air lines run the full length of the pipes and are suspended above the sediments. There are multiple benefits with this design: increased maneuverability during the initial installation or if the location of the system needed to be adjusted, economic advantages, and simplicity of periodic maintenance and inspection. The buoyancy pipe is used to float the entire diffuser and anchor assembly to the surface for inspection and maintenance. Essentially, when the buoyancy pipe is filled with air, the entire assembly will float. To sink the assembly back down to the bottom, the process is reversed and the buoyancy pipe is simply filled with water. With most other hypolimnetic aeration systems, divers are required for periodic inspection and maintenance of the submerged components which can be a costly expense. Figure 4.5 provides a diagram of the single line, two-pipe design.

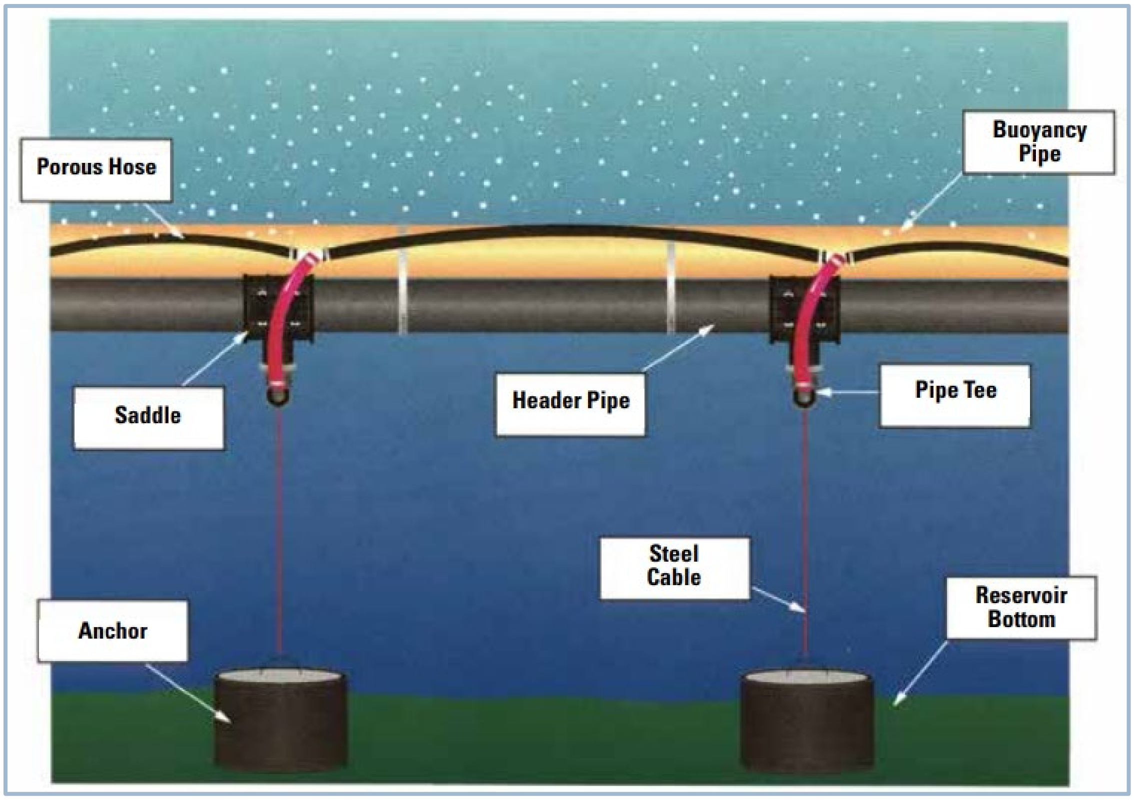


Figure 4.5: Diagram of in-lake line diffuser components. Source: Moore, et al., 2015 (Graphics – TVA)

ADDITIONAL CONSIDERATIONS

PERIOD OF OPERATION

SSO and line diffuser aeration systems are operated continuously from late spring/early summer through late summer until the fall turnover. The system is typically started at the onset of thermal stratification, prior to the depletion of hypolimnetic oxygen, and is shut down after the fall turnover when the lake is thermally mixed and there is no longer the potential for deep water anoxia. There is some utility to turning these systems on beginning in the early spring, prior to establishment of thermal stratification. The main goal of starting the system earlier would be to pump as much oxygen as possible into the deeper water so that there is a large reserve of DO as the hypolimnion is established. However, this decision would be highly dependent on the actual oxygen demand of the lake and the utility cost to run the system for an extended period of time.

OXYGEN SUPPLY

The on-site oxygen generation option requires additional equipment located in a secure building on shore. It has a greater initial capital cost due to the compressor equipment used to create the air supply and the pressure swing adsorption (PSA) oxygen generation equipment. The PSA unit is a molecular sieve that strips nitrogen from the compressed air to produce "pure oxygen."

For Findley Lake, on-site generation would be the more feasible of the two options for oxygen supply based on a number of factors, including the required footprint on shore to house the liquid oxygen storage tanks and code restrictions related to the storage tanks. Public perception associated with large liquid oxygen tanks and truck traffic associated with periodic refilling of the tanks would also need to be taken into consideration. Thus, even with the additional cost associated with on-site oxygen generation, this would be the recommended option for oxygen supply at Findley Lake.

POWER REQUIREMENTS AND STAGING

The power requirements for the compressor, PSA, and potential water pumps (SSO only) should be met using a 3-Phase 460 - 480-volt power source. The amount of land and the size of the building needed for direct oxygen systems will vary depending on whether the system uses oxygen storage tanks or an oxygen generator. For an oxygen tank system, a secure, fence-enclosed concrete pad needs to be constructed along with a structure large enough to house all the supporting metering and gauging equipment. In total, this may require as much as 0.25 acres of land. Conversely, if the system's oxygen supply is met using an oxygen generator, the building needed to house the system will be much smaller (12' x 12'), similar to that associated with a hypolimnetic or destratification system. It is still recommended to fence off the perimeter of the building even if oxygen is generated on site rather than delivered.

The building should be located near the shoreline and as close to the deep-water area of the lake as possible. This will decrease costs associated with the oxygen supply air lines. Inspection and maintenance of direct oxygen systems focus on the routine inspection (at least bi-weekly) of the oxygen reserves in the storage tanks or the operation of the oxygen generator. Annually, all in-lake components of the system, in particular the oxygen supply lines, should be evaluated. These systems can be designed with buoyancy pipes that are used to float and sink all of the submerged components, reducing maintenance and inspection costs related to divers. Operational costs are highly variable and dependent on the lake's oxygen demand and hypolimnetic DO goals. For systems supplied by land-based oxygen storage tanks, the cost of tanker truck oxygen deliveries must be taken into consideration.

SUMMARY

Line diffuser systems are likely not suitable for Findley Lake due to the relatively shallow maximum depth, which poses the risk of disrupting the normal thermal stratification pattern; this would most likely be minor but could cause the lake to mix at an earlier date at the end of the growing season. Speece cone systems seem poorly suited for use at Findley Lake due to the large footprint of the mixing chamber; again, the relatively shallow maximum depth of the two deep pockets could result in the structures extending close to the surface. Thus, SSS and OST systems seem better suited for the size of Findley Lake. The chief design concern with either of these systems is oxygen demand. The systems must be designed to supply and distribute sufficient oxygen to counteract the hypolimnetic oxygen demand, which includes both SOD and BOD. Another advantage to the use of a direct oxygen system is that latent oxygen demand can be suppressed after some time, although the effect is slow to be realized; a recent paper reported that oxygen demand had decreased by 75% over the course of several decades in the studied system (Horne, et al., 2019).

A direct oxygen system is recommended for Findley Lake due to the efficient nature of the systems and the fact that they can restore coldwater fish habitat, in addition to reducing the internal phosphorus load, by sufficiently oxygenating the hypolimnion.

It is difficult to estimate the cost of one of these systems at this stage because costs are usually proportional to design oxygen supply needs, but capital costs of $1,100,000 to $1,500,000 are likely based on similar recent cost estimates; this includes permitting, architectural and engineering design, installation labor, construction of shoreline building, and all in-lake components. Annual operational costs, including electric, equipment inspection, and maintenance are anticipated to start around $20,000 - $30,000. The bulk of this cost will be related to the generation of oxygen, as well as labor costs associated with regular system inspection and operation, which is a more technical nature than some of the other systems and will require carefully monitoring *in-situ* hypolimnetic DO concentrations and adjusting the system accordingly as demands change over the growing season. Additional information on cost estimates is provided in the proceeding sections.

4.3 RECOMMENDED AERATION APPROACH FOR FINDLEY LAKE

A number of aeration systems were reviewed, including destratification, partial air-lift (Layer-Air and hypolimnetic), and direct oxygen (SSO, line diffuser), for potential installation and operation at Findley Lake. A destratification system is not the primary recommendation because it would alter the thermal regime of the lake, increase water temperatures throughout the water column, and potentially reduce fish refuge during the summer months. Partial air-lift systems are also not recommended due to the large size of the in-lake structures and the fact that they are much more logistically complicated, requiring frequent monitoring and adjustments throughout the growing season. A direct oxygen system is therefore recommended as the best option to restore oxygen to the hypolimnion and preclude the internal release of phosphorus while maintaining the natural thermal structure of the lake.

Both SSS and OST systems appear to be applicable for meeting the oxygen requirements in Findley Lake. Based on the relatively shallow maximum depth of Findley Lake compared with other dimictic systems, an OST system seems best suited. OST would likely have lower operational costs because the oxygen is mixed with the anoxic lake water directly in the hypolimnion rather than in the shoreline compressor building as it would with a SSS system; this eliminates the need to pump the water to and from the compressor buildings. An OST system will likely be the most cost-effective and efficient system for Findley Lake for a number of reasons:

1. The built in DO sensors and automation of the system allow for the maintenance of a specific DO range while only generating enough oxygen to meet the demand.
2. The relatively small size of the in-lake infrastructure will not impede recreation.
3. The positioning of the pumps and oxygen mixing chamber in the hypolimnion reduces operational costs by eliminating the need to pump the oxygen-poor water from the hypolimnion to the shoreline, then back into the hypolimnion.
4. The oxygenated water is discharged into the hypolimnion, directly over the sediments, without any bubbles, effectively preserving thermal stratification.
5. The potential to address the legacy SOD, which could reduce the hypolimnetic oxygen demand over time, resulting in reduced operational costs.

However, before moving forward with the design of an OST system, or any oxygenation system for that manner, it is recommended that an additional SOD analysis be conducted to calculate the exact oxygen demand in Findley Lake. It would also be practical to utilize updated bathymetric data in determining the specific direct oxygen system design. The SOD analysis will be conducted by an engineer who is directly involved in designing oxygenation systems.

While we currently have a general sense of the oxygen demand in the hypolimnion through a review of the 2023 in-lake data, we currently do not have any data that quantifies the SOD. The SOD largely dictates the amount of oxygen that will need to be delivered to the lake via the direct oxygen system to provide sufficient oxygenation throughout the duration of the growing season. Additionally, the only official bathymetric maps available for the lake are an old NYSDEC fishing map and the bathymetric map provided in the TMDL, which is cited from a 2002 report, but it is not known when the survey was conducted. Thus, there has not been a bathymetric survey of Findley Lake conducted in over 20 years, and potentially much longer. The following tasks are recommended in order to move forward with an accurate design and cost estimate for a system specific to Findley Lake.

SEDIMENT OXYGEN DEMAND ANALYSIS

The scientific collection of data pertaining to the SOD of Findley Lake should be conducted. Specifically, this involves the *in-situ* measurement of SOD utilizing isolation champers following United States Environmental Protection Agency (USEPA) approved methodology. Relative to the size of Findley Lake, it is recommended that the SOD is measured in triplicate with a fourth deployment to include estimation of water column oxygen demand (WOD). Again, while we currently have a general idea of the WOD, the SOD data will allow for the most cost-efficient design of an OST system. The SOD analysis and associated reporting can be conducted for approximately $30,000.

BATHYMETRIC ASSESSMENT

A bathymetric survey is the mapping of water depth and the amount of accumulated unconsolidated sediment (top of sediment to bottom of sediment) in a waterbody. The data from this assessment can be modeled to produce topographic contours of water depth and sediment thickness, and statistics such as mean depth and volume of water and sediment. Based on the available bathymetric maps in previous reports or available online, it is assumed that a professional bathymetric survey has not been conducted in at least 20 years, and possibly much longer. It is important to get an accurate assessment of the depth contours throughout the entire lake. This will not only help with determining the best location in the lake to place the submerged components of the OST system, but it will help quantify the volume of the anoxic zone, which, in turn, will help to design an efficient system. Thus, an updated bathymetric assessment in Findley Lake should be conducted prior to system design. A bathymetric assessment, along with all data analysis, reporting, and figure, can be conducted for approximately $25,000.

If the SOD analysis and bathymetric assessment can be coordinated together, the overall price can be reduced.

4.3.1 ANTICIPATED BENEFITS OF AN OXYGEN SATURATION TECHNOLOGY SYSTEM

Oxygenation has become the most effective aeration method throughout the country in recent years to address hypolimnetic anoxia and internal phosphorus loading. There are a number of oxygenation technologies available, but OST is recommended for Findley Lake. In addition to the efficiency of these systems in oxygenating the hypolimnion without disrupting stratification, the annual operating costs are typically lower than destratification systems due to the use of smaller compressors, potentially shorter period of operation, and higher oxygen transfer efficiencies (OTE) and reoxygenation capabilities.

The OST system would be designed specific to the thermal properties present in Findley Lake so that thermal stratification is preserved. There is less risk of disrupting thermal stratification with an OST system, which makes this technology a prime candidate for Findley Lake.

The system would also be designed to meet the oxygen demand specific to Findley Lake. As previously mentioned, the majority of the oxygen consumption in a lake is the result of bacterial decomposition. Over time, detritus and other organic matter accumulates at the bottom of the lake in response to eutrophication. This process increases the rate of respiration in the lake, as bacteria present in the lake are continuously decomposing this organic matter; a process which utilizes oxygen as the terminal electron acceptor in aerobic organisms. As the limited concentration of oxygen present in the hypolimnion is consumed during summer stratification, bacteria continue to decompose the organic matter anaerobically; a process that further contributes to the eutrophication of the system due to the accumulation of anaerobic respiration byproducts. Thus, it’s imperative that the SOD in Findley Lake is addressed to counteract these processes.

The benefit of an OST system is the ability to address the SOD due to the high OTE. The ability for the oxygen to penetrate into the anoxic sediments also allows for the potential control of the legacy SOD, which has built up over time (Moore, et al., 2015.). Addressing the legacy SOD takes years of system operation but can result in a positive feedback loop in the lake that ultimately leads to a decrease in the internal phosphorus load, less primary productivity, less oxygen demand in the hypolimnion, and all of these associated metrics. As this legacy SOD is addressed over time, it's possible that the OST system could be operated at a reduced capacity while still providing sufficient oxygenation and internal phosphorus load control.

4.3.2 LOCATION OF THE LAND-BASED COMPONENTS OF THE OST SYSTEM

The physical location of the land-based components of the OST system can greatly affect the system's design, capital cost, and operational cost. The criteria used to evaluate the feasibility of a given location for the sitting of the land-based elements of the system minimize capital, installation, and annual operating costs. They also maximize oxygen supply efficiency and reduce long-term maintenance of the in-lake components. Additional criteria include availability of suitable power, access, aesthetic concerns, and proximity to private residences, and, most importantly, likelihood of availability. Criteria include:

- Proximity to the OST mixing chambers that would be located in the two deep pockets of the lake, including the deeper mid-lake pocket (ST-2) and the deep pocket located at the northern end of the lake (ST-3). These are the two areas of the lake that consistently thermally stratify over the growing season. However, based on the availably bathymetric maps, these two deep pockets appear to be separated by a much shallower area, and thus would need to be oxygenated separately. This does make things more logistically complicated and expensive because the two deep pockets are located approximately 3,700 feet apart and would require either two separate land-based components in proximity to each basin, or one land-based component with very long runs of wire and piping to reach the further deep pocket. Line lengths can significantly impact the system's capital equipment and long-term operational and maintenance costs. Keeping the length of lines as short as possible also helps decrease the system's possible interference with navigation, angling, and other lake uses.
- The site should be located on publicly owned land, or private land where the owner is willing to provide a long-term easement, lease, or option agreement.
- The site should be preferably close to the lake's shoreline and not encumbered by any NYSDEC regulated lands (wetlands, wetland transitional areas, riparian areas, threatened and endangered species habitat, etc.).
- To facilitate construction and installation activities, the site should also be as encumbered as possible by any steep slopes and require minimal clearing of upland vegetation and/or land grading to create a flat, level base for the pump house.
- The site needs to be either presently serviced by or close to an existing 3-phase, 460 - 480-volt power source.
- The site needs to be large enough to erect a suitably sized (12'x12' – 16'x16) structure to house the system's land-based elements; referred to as the "compressor building".
- To minimize noise, aesthetic and site use conflicts, the compressor building should be adequately distanced from homes and high public-use areas.
- The compressor building should be easily accessible to facilitate the periodic inspection and seasonal servicing of the land-based elements of the system.
- The site should have enough existing landscaping or be capable of being further landscaped to additionally mitigate any aesthetic and/or noise impacts, if located in a residential area.

Princeton Hydro reviewed aerial images of Findley Lake and the surrounding shoreline and associated properties to evaluate potential sites where the compressor building could be located. The majority of the shoreline appears to be surrounded by private residences, especially in proximity to the two deep pockets where the in-lake equipment would be located. However, two potential locations were determined to best meet the noted criteria:

1. Findley Lake Waterway Access at the north end of the lake (Figures 4.8 and 4.10),
2. The DEC cartop/kayak boat launch along the southwest shoreline (Figure 4.8)

Based on these two locations, the most cost-effective scenario would be to locate a compressor building at both of these locations; the northern location would generate oxygen for the northern deep pocket and the southwest location would generate oxygen for the mid-lake pocket. Although this may seem like a more expensive option because it would require the construction of two separate compressor buildings, it would place a compressor building in relative proximity to each of the two deep pockets that needs to be oxygenated. In turn, this would significantly reduce the total length of wire and piping, and thus reduce capital and operational costs. Under this scenario and based on our current estimate of oxygen demand in each deep pocket, this would require an 8' x 8' compressor building at the north end of the lake (Findley Lake Waterway Access) and a 12' x 10' compressor building at the southwest location (DEC boat launch) (Figures 4.6 and 4.7). Both sites would require at least a few additional feet of buffer around the outside of the building for access, fencing, landscaping, gravel entryways, or whatever is preferred.

If one of the two aforementioned shoreline locations is not a feasible option, one larger (12' x 12') compressor building could be used to generate the oxygen for both sites (Figure 4.9). Of the two locations, the northern location would likely be the most feasible because it's located on a larger, more open plot of land. Although feasible, this would increase the cost of electrical and piping by an estimated 60 – 70% because the compressor building would be located approximately 4,700 feet from the mid-lake deep pocket.

Please note that if any alternative shoreline locations can be secured closer to the mid-lake deep pocket, capital and operational costs will be reduced, potentially significantly.

General specifications and cost estimates for both of these scenarios are provided below.

4.3.3 PRELIMINARY DESIGN

Figure 4.4 on page 40 shows a diagram of the in-lake components of the OST system; please note that this diagram is not built to scale, and the in-lake components will not extend that close to the surface. The dimensions of the in-lake components specific to each basin in Findley Lake are provided below. Based on current bathymetric data that shows two separate deep pockets, both design options include two OST systems to effectively oxygenate Findley Lake and reduce the internal phosphorus load; one OST system in each basin. Details for the OST designs were provided by Gantzer Water Resources, LLC.

ESTIMATE OF HYPOLIMNETIC OXYGEN DEMAND

As mentioned above, it is strongly recommended that an SOD analysis is conducted to quantify the precise hypolimnetic oxygen demand. Without knowing the SOD, and with only one summer's worth of monthly full water column *in-situ* profiles, the oxygen demand can only be estimated. However, based on similar projects throughout New York and New Jersey in recent years, a relatively accurate oxygen demand can be deduced. The oxygen demand is one of the main components required to design any oxygenation system, as this will dictate the size of the compressors and oxygen generators, as well as the daily power requirements.

It is estimated that the hypolimnetic oxygen demand in Findley Lake is in the range of 300 kg/d. This can be further broken down by basin, with an estimated oxygen demand in the range of 50 kg/d in the north basin and 250 kg/d in the deeper mid-lake basin. Thus, if two separate compressor buildings can be accommodated in proximity to each basin, the mid-lake basin will require larger components, including the compressor and oxygen generator.

DESIGN OPTION 1: TWO COMPRESSOR BUILDINGS

The primary recommendation for the Findley Lake OST system would include separate compressor buildings for the two deep pockets in the lake. This would include an OST unit that generates 150 GPM situated in the smaller, northern deep pocket (ST-3) and a second OST unit that generates 300 GPM situated in the deeper, mid-lake pocket (ST-2). The smaller unit in the north would require a compressor building approximately 8' x 8' that would house an AriSeP Model AS-B PSA oxygen generator rated at 55 Standard Cubic Feet Per Hour (SCGH), a 60-gallon oxygen receiver, and a 5 HP air compressor (Figure 4.6). Of the two compressor building locations outlined above, this one would be situated at the Findley Lake Waterway Access. The in-lake component for the northern basin would be one 4' x 4' x 7' OST chamber with approximately 100' of combined suction and discharge piping along the lake bottom.

The larger unit in the deeper mid-lake basin would require a compressor building approximately 12' x 10' that would house an AriSeP Model AS-G PSA oxygen generator rated at 320 SCGH, a 120-gallon oxygen receiver, and a 20 HP air compressor (Figure 4.7). This building would be situated at the DEC cartop/kayak boat launch. The in-lake component for the mid-lake basin would be two 5' x 5' x 8' OST mixing chambers with approximately 200' of combined duction and discharge piping each. The size of the electrical wire needed to run power from the compressor buildings to the OST mixing chambers under this scenario is 6 AWG.

None of the in-lake structures would extend higher than ~8-10' from the bottom of the lake in the deepest sections of the lake; thus, the structures will not impede navigation or recreation. The in-lake OST units would be built with DO sensors that measures DO in real time and communicates with the oxygen generators on shore, resulting in a fully automated system.

An aerial view of this proposed system, including shoreline compressor building locations, wire and oxygen lines, and the position of the OST mixing chambers and suction and discharge line are provided in Figure 4.8.

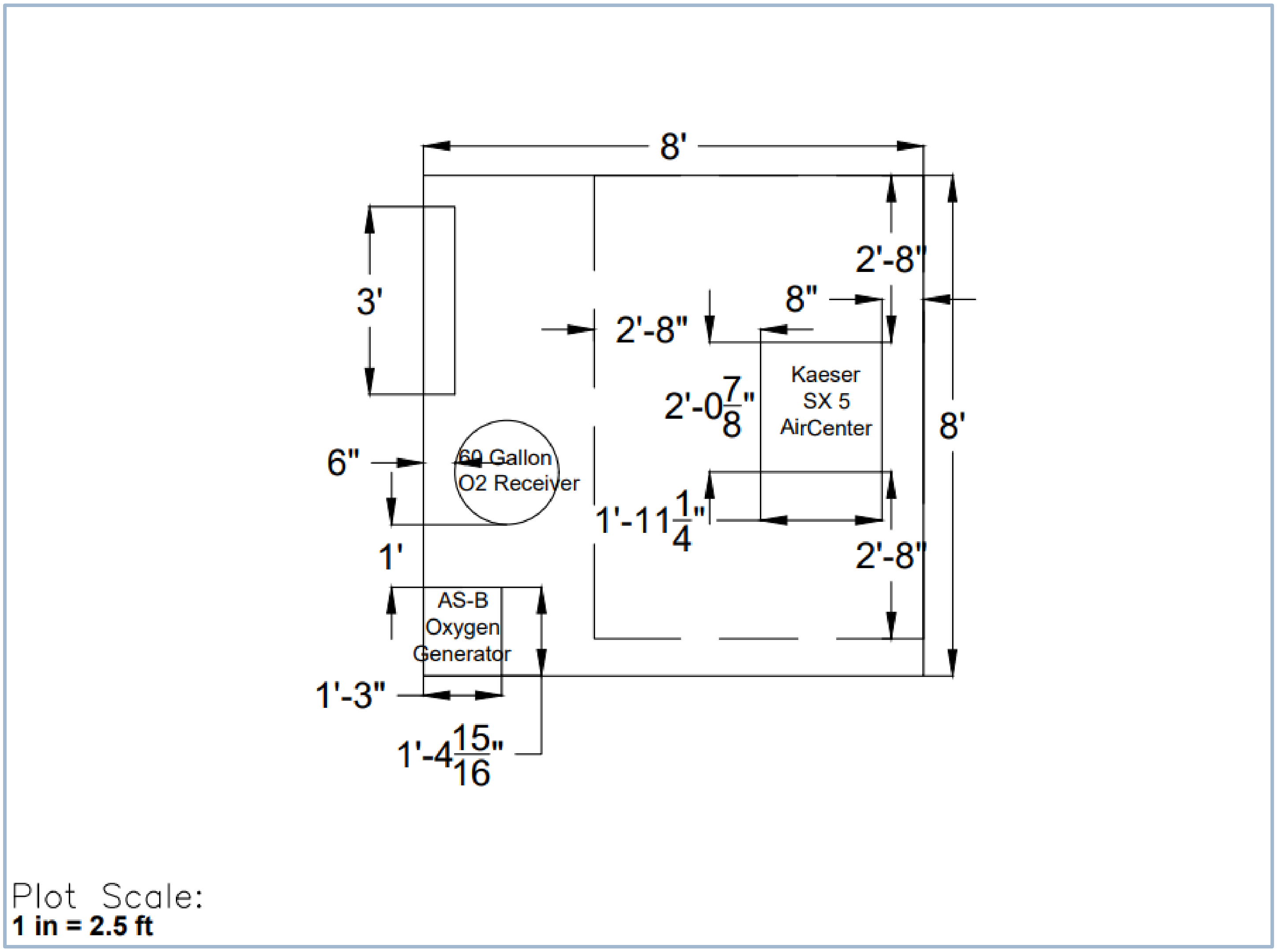


Figure 4.6: Schematic of the 8' x 8' compressor building for the north basin. Source: Paul Gantzer

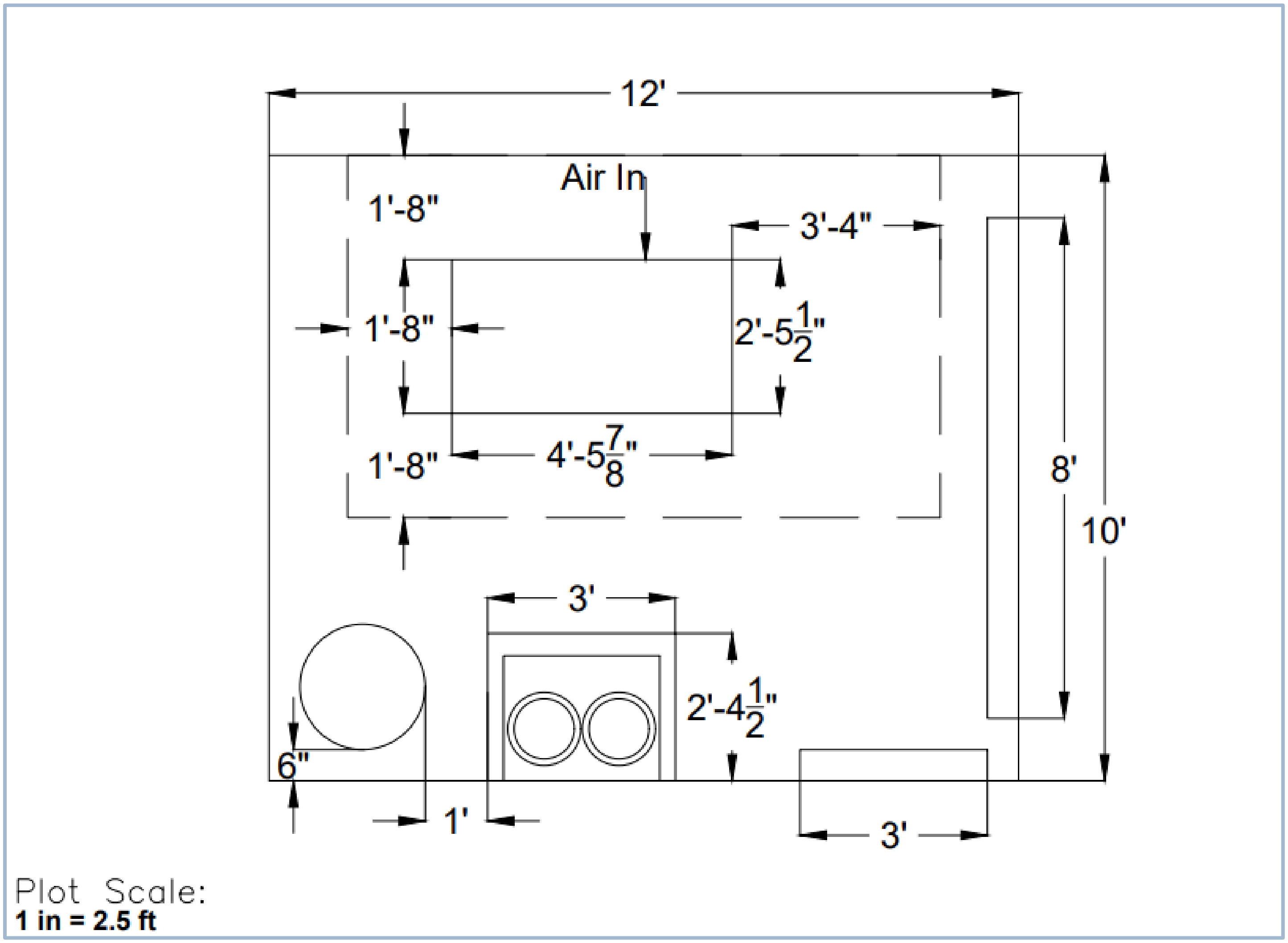
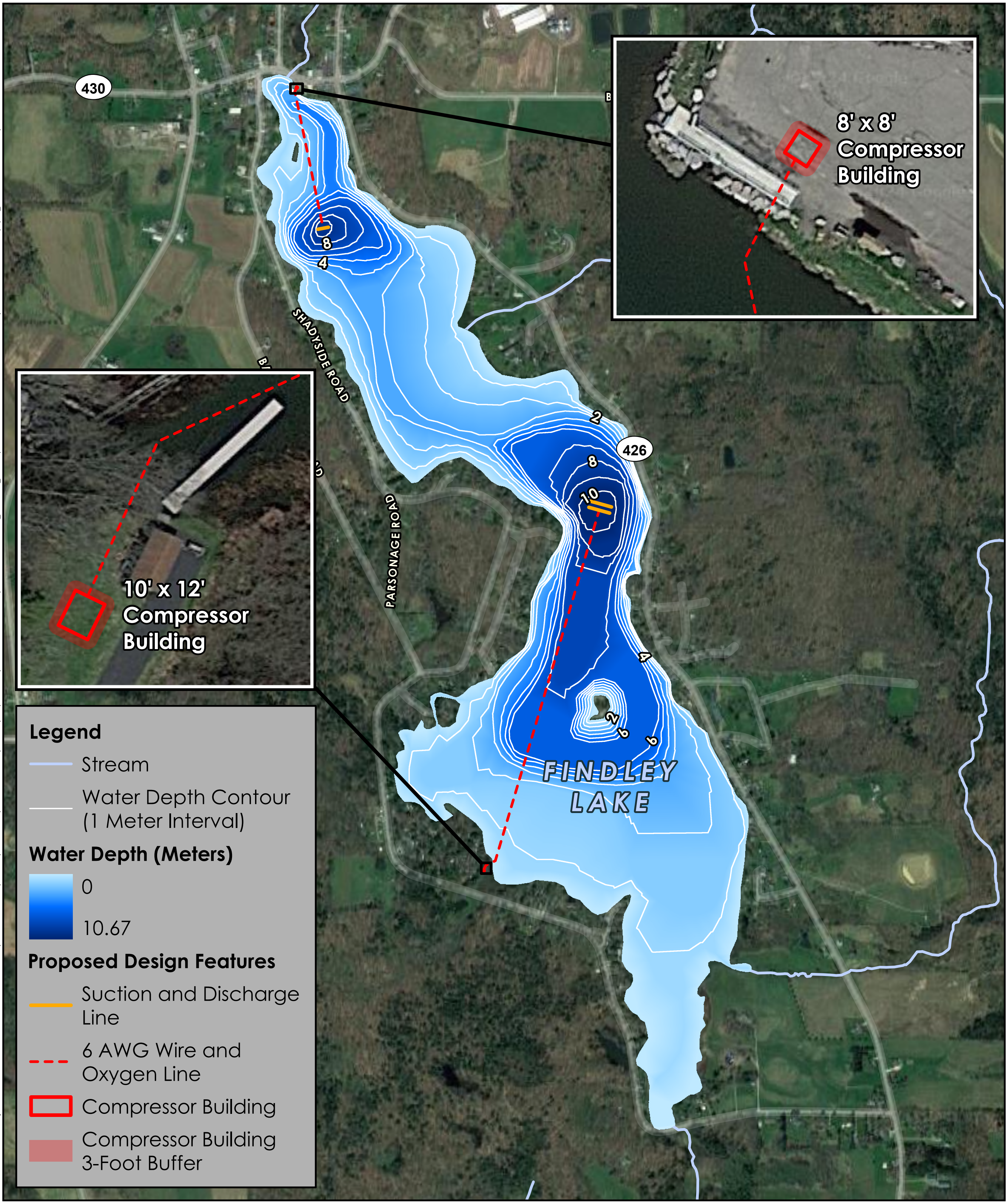


Figure 4.7: Schematic of the 12' x 10' compressor building for the mid-lake basin. Source: Paul Gantzer



File: P:\2142\Projects\2142001\GIS\APRX\Findley Lake Bathymetry\Findley Lake Bathymetry.aprx, Layout: Two Compressor Buildings Design, Exported: 2/8/2024, Drawn by tsrinivasan, Copyright Princeton Hydro, LLC.

NOTES:
1. Streams obtained from the United States Geological Survey's (USGS) National Hydrography Dataset (NHD).
2. Water depth data approximated using bathymetry figure provided in 2008 report entitled "TMDL for Phosphorus in Findley Lake", prepared by The Cadmus Group.
3. Proposed design features are approximate.
4. Aerial imagery provided by Google Earth, obtained through ArcGIS Online.

0 600 1,200 Feet

Spatial Reference: NAD 1983 2011 StatePlane New York West FIPS 3103 Ft US

FIGURE 4.8
TWO COMPRESSOR BUILDINGS DESIGN

FINDLEY LAKE
TOWN OF MINA
CHAUTAUQUA COUNTY, NEW YORK

PRINCETON HYDRO
SCIENCE DESIGN ENGINEERING
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DESIGN OPTION 2: ONE COMPRESSOR BUILDING

A secondary option for the Findley Lake OST system would include one compressor building, most likely located at the Findley Lake Waterway Access lot at the northern end of the lake. The in-lake OST chambers would be the same as the primary design option described above; one unit that generates 150 GMP situated in the smaller, northern deep pocket (ST-3) and a second OST unit that generates 300 GPM situated in the deeper, mid-lake pocket (ST-2). All of the land-based components would be housed in a 12' x 12' compressor building (Figure 4.9). Again, the compressor building components would be the same as the primary design option but they would be located in one larger building. This includes an AriSeP Model AS-B PSA oxygen generator, rated at 55 Standard Cubic Feet Per Hour (SCGH), a 60-gallon oxygen receiver, and a 5 HP air compressor for the smaller unit in the north and an AriSeP Model AS-G PSA oxygen generator, rated at 320 SCGH, a 120-gallon oxygen receiver, and a 20 HP air compressor for the larger unit in the mid-lake basin.

The primary difference between the two designs, in addition to the size and number of compressor buildings, is the size of the electrical wire, and the length of both electrical wire and piping that would need to run from the compressor building to the mid-lake unit. This scenario would require 2 AWG wire, which is significantly more expensive than the 6 AWG required for the primary recommendation, and the length of wire required would also be much longer.

The in-lake components of the OST system would remain the same. For the northern basin it would be one 4' x 4' x 7' OST chamber with approximately 100' of combined suction and discharge piping. For the mid-lake basin it would be two 5' x 5' x 8' OST mixing chambers with approximately 200' of combined duction and discharge piping each.

An aerial view of this proposed system, including the shoreline compressor building location, wire and oxygen lines, and the position of the OST mixing chambers and suction and discharge line are provided in Appendix 4.10.

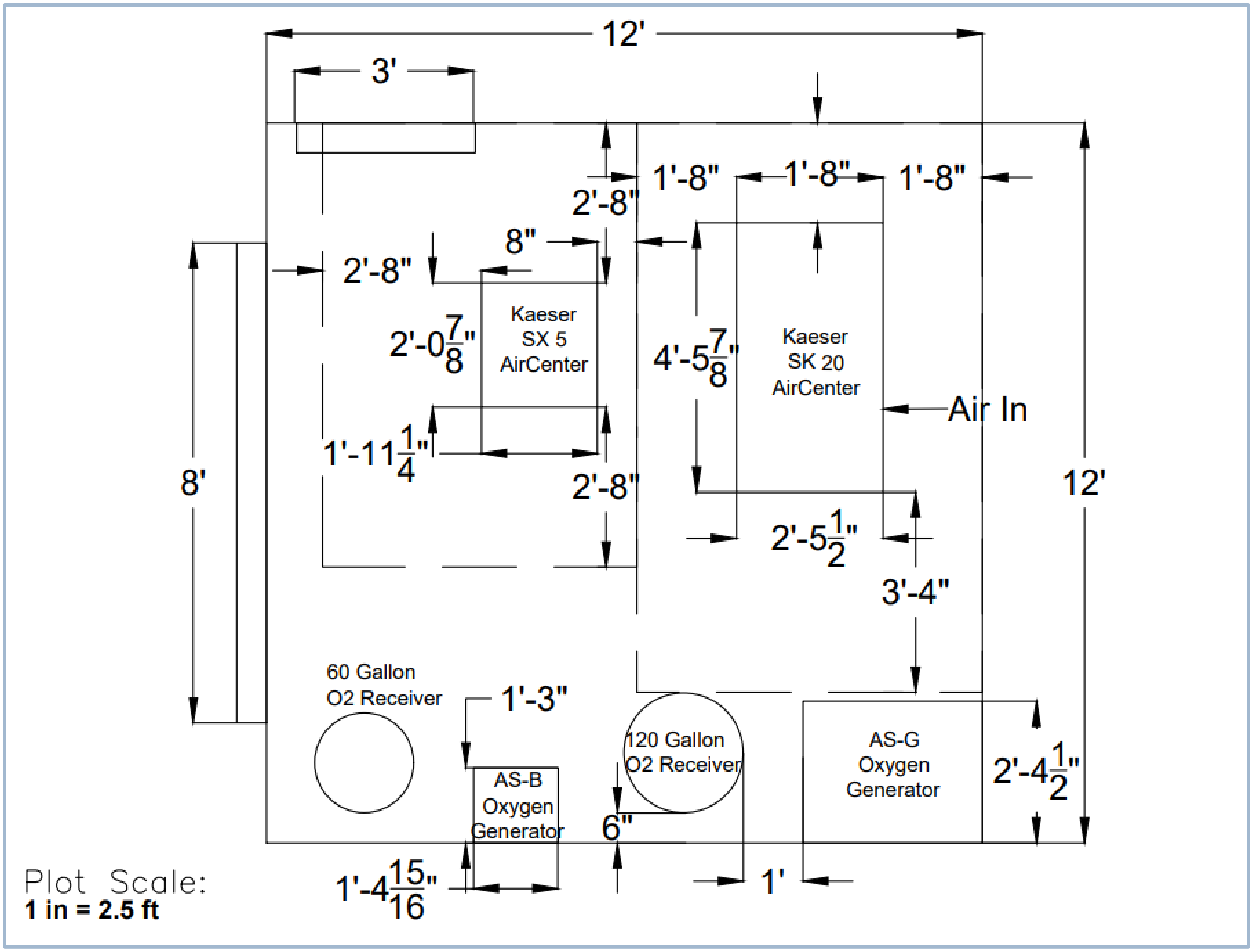
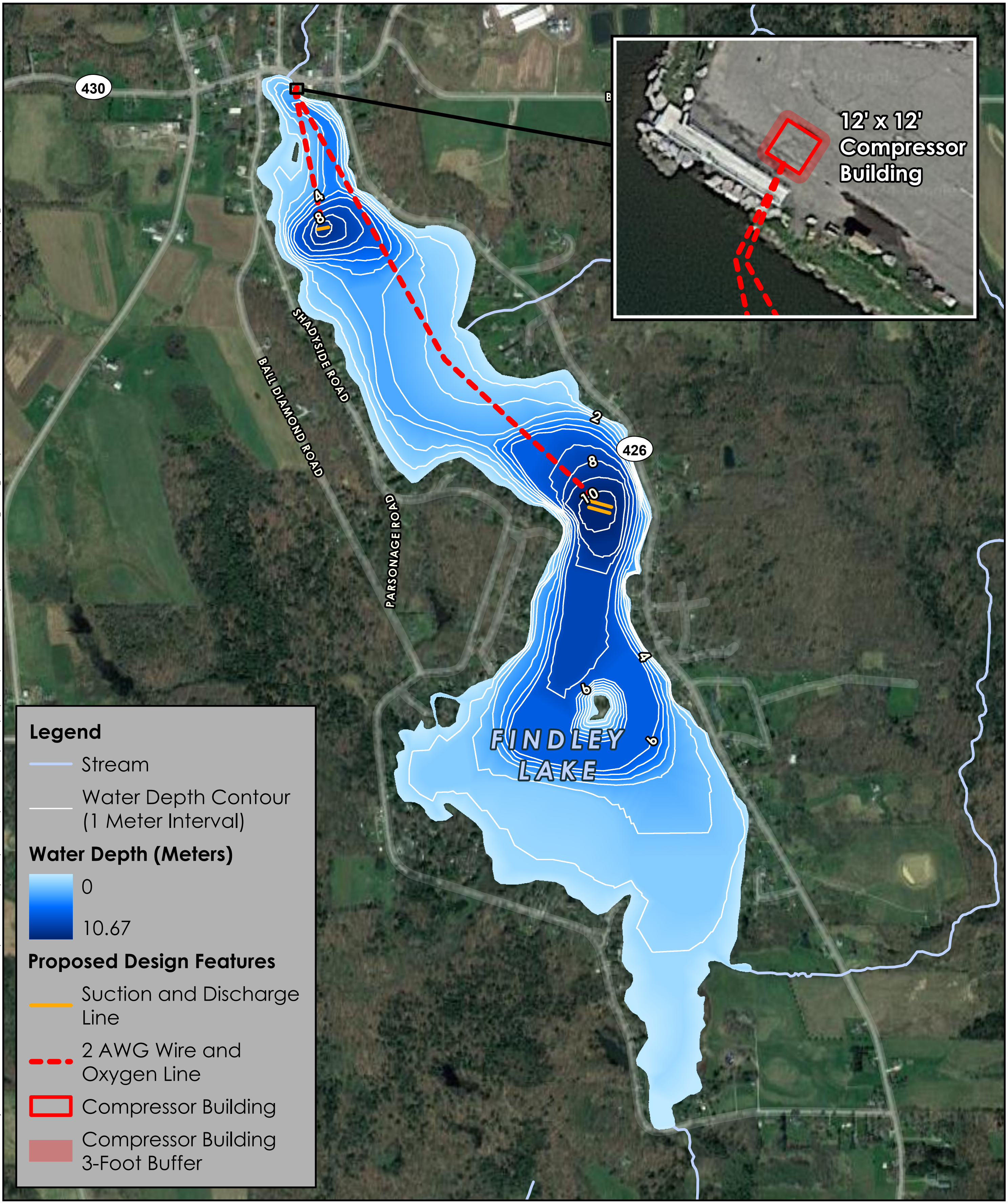


Figure 4.9: Schematic of the 12' x 12' compressor building for both basins. Source: Paul Gantzer



NOTES:
1. Streams obtained from the United States Geological Survey's (USGS) National Hydrography Dataset (NHD).
2. Water depth data approximated using bathymetry figure provided in 2008 report entitled "TMDL for Phosphorus in Findley Lake", prepared by The Cadmus Group.
3. Proposed design features are approximate.
4. Aerial imagery provided by Google Earth, obtained through ArcGIS Online.

0 600 1,200 Feet

Spatial Reference: NAD 1983 2011 StatePlane New York West FIPS 3103 Ft US

FIGURE 4.10
ONE COMPRESSOR BUILDING DESIGN

FINDLEY LAKE
TOWN OF MINA
CHAUTAUQUA COUNTY, NEW YORK

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4.3.4 COST ESTIMATES

Costs for both design options will be broken down by the cost of the OST systems, including all in-lake and compressor building infrastructure, and the cost for all other components and labor. Without having updated bathymetric data or results from the SOD analysis, it is not feasible to provide itemized costs for specific components. Rather, an opinion of costs based on the current level of design and knowledge with similar systems in the region will be provided. Below are lists of what is included with each component of the price estimates:

OST System:
- Oxygen generators
- Oxygen receivers
- Air compressors
- In-lake OST components (contact chambers, pumps, DO sensors)
- Electrical wiring (from compressor building(s) to in-lake components)
- Oxygen discharge lines (from compressor building(s) to in-lake components)

Other Costs:
- Compressor building (including concrete slab, construction, insulation, sound deadening, cooling, etc.)
- Installation of 3-phase power
- Preparation of NYSDEC permit materials, SEQR materials, and permit fees
- Architectural and engineering: final specifications and bidding documents
- Installation including general contractor and installation oversight

DESIGN OPTION 1: TWO COMPRESSOR BUILDINGS

Opinions of cost for the OST system components is in the range of $800,000 - $1,000,000 while all other costs are estimated between $350,000 - $450,000. Thus, it is estimated that the capital cost for the system would be in the range of $1,150,000 - $1,450,000.

DESIGN OPTION 2: ONE COMPRESSOR BUILDING

Opinions of cost for the OST system components is in the range of $1,100,000 - $1,300,000 while all other costs are estimated between $350,000 - $450,000. Thus, it is estimated that the capital cost for the system would be in the range of $1,450,000 - $1,750,000.

Please note that neither of these estimates include the SOD analysis or updated bathymetric survey, which can be completed for approximately $30,000 and $25,000, respectively; it's possible to reduce costs if both are scheduled at the same time.

ANNUAL OPERATION AND MAINTENANCE COSTS

Without knowing the precise oxygen demand of each basin, or the exact locations of the compressor buildings, it is difficult to estimate accurate annual operational costs. A range will be provided below based on current estimates, assuming five months of full operation per year (May – September) and will include the following:

- **Utilities –** As per the equipment manufacturers' specifications, to power the compressor(s), pumps, and PSA effectively and efficiently, the lake's OST system requires a 3-phase, 460 - 480-volt power source.

- **System Maintenance –** Annual maintenance of the system will consist of the seasonal inspection and maintenance and end of year winterization of the land-based elements. Typically, this is done through a service contract with the equipment supplier or a local firm that specializes in compressor, air handler, and water pump maintenance. At the beginning of the season there may be the need to inspect and clear the intake and discharge pipes of the OST system, and other routine maintenance of the underwater elements of the system. For this servicing, the lines could and other OST components can be raised to the surface of the lake using the attached buoyancy lines. This negates the use and the cost of hiring professional divers for the routine inspection, maintenance, and servicing of the system.

Annual operation and maintenance costs are anticipated to be in the range of $20,000 - $40,000, depending on the final design.

Please note that all of the cost estimates, including capital and annual operation and maintenance, are based under the assumption that the two deep pockets are not connected by a similarly deep channel, but are essentially separate deep basins. All available bathymetric data points to this, but this can't be confirmed without updated, highly accurate bathymetric data.

4.3.5 ALTERNATIVE RECOMMENDATION

If cost is a significant limiting factor, a destratification (full air-lift / full water column mixing) system would likely have a lower capital cost, although it would still be a significant investment. It's also important to recognize the limitations relative to increased water temperatures and reduced fish habitat during the summer months. If the main goal is strictly to reduce the internal phosphorus load, a destratification system would be a less efficient alternative.

The design of a destratification system would be slightly less involved than the OST system; an SOD study would not be required but an updated bathymetric assessment would still be recommended. The diffuser heads would be positioned throughout the two deep pockets, but instead of one in-lake structure in each of the deep pockets, diffusers would be placed throughout the entire area of the lake that is subject to thermal stratification. Based on available water quality data and bathymetric data, this would likely include at least all areas of the lake that are ≥ 4.0 meters, or an approximate area of 87 acres. This would likely require at least 30 diffusers to be dispersed throughout the lake. All diffusers would be connected via weighted airline tubing to shoreline compressor buildings similar in size to the compressor buildings required for the OST system. Because it appears that available shoreline locations in proximity to the deepest section (mid-lake) of the lake is limited, a destratification system would require long runs of airline which would increase capital and operational costs.

An opinion of cost for all capital costs, including design, permitting, materials, shoreline compressor building(s), and installation is in the range of $600,000 - $900,000. While the capital cost of the materials for a destratification system would be significantly cheaper than an OST system, installation costs would likely be much higher due to the amount of airline that would need to be run to all of the diffusers. Permitting, design, and construction of the compressor building(s) would be similar to the OST system. Annual operation and maintenance costs would likely be at least as much as the OST system, and potentially even higher due to the larger compressors required to power all of the diffusers.

5.0 SYSTEM MAINTENANCE PLAN

5.1 ANNUAL OPERATING PLAN

On an annual basis it is imperative that the system be ready to go into operation by 1 May. We don't currently have *in-situ* data for that early in the season, but based on other lakes in the region, this is likely in advance of the lake's historic pattern of thermal stratification and deep-water anoxia. However, completing a system inspection by the end of April should provide ample opportunity to ensure the system is ready to be put into full operation in May or June.

The following is a basic operating schedule including inspection of the system's land-based and in-lake elements. Please note that the annual inspection, maintenance, and servicing schedule is generic and will need to be modified to some extent based on the local availability of trained/certified technicians or the equipment manufacturers' specification. The following schedule is specific to an OST system but can be applied to a destratification system with minor modifications.

- No later than March conduct all required servicing of the land-based elements of the system by a certified maintenance specialist and conduct each element in accordance with the manufacturer's maintenance and servicing requirements.
- No later than March inspect the compressor building(s) for any damage and complete necessary repairs. Ensure heat and noise mitigation components of the building are functioning properly.
- The system's design will include buoyancy lines that enables each line to be independently floated to the surface for inspection and cleaning. This limits the need for diver-based maintenance of the system. This allows inspection and cleaning to be conducted simultaneously without the added cost and safety to perform the work underwater. The pre-operational inspection/maintenance of the in-lake elements of the system should be scheduled for early-April.
- No later than mid-May, turn the system fully on and operate accordingly through mid-October. It may be advantageous to further decrease the lake's legacy SOD to continue to partially operate the system later into the fall but this will come down to annual cost of operation. Please note that the startup and shut down dates may need to be adjusted slightly as these are based on what is common for other regional lakes. Additional early and late season water quality monitoring to determine the full length of thermal stratification and hypolimnetic anoxia would be beneficial.
- Throughout the operating period, especially during the first few years of operation, collect periodic water column temperature and dissolved oxygen data (surface to bottom at one-meter increments) at both deep pockets. Both OST systems would be designed with in-lake DO sensors for system automation based on pre-determined target DO concentrations; however, the DO sensors would be in the immediate vicinity of the OST systems, and it would be beneficial to record DO concentrations at a further distance.
- At system shutdown (following lake turnover and surface cooling) in mid-October or earlier, winterize the land-based elements of the system. System winterization should follow all guidelines from the specific manufacturers.

While a general maintenance plan is provided above, it is recommended that a detailed lifetime maintenance plan be prepared after installation, consistent with manufacturers' user manuals and specifications and installers' recommendations. Warranties should be included in any bid specifications for equipment procurement.

6.0 REGULATORY REVIEW AND APPROVALS

The proposed installation of the aeration system in Findley Lake will be subject to regulatory review and approval under multiple jurisdictions, from federal to local. Depending on the final specifications for the project, other agency reviews may be triggered.

6.1 PERMITS AND AGREEMENTS

US Army Corps of Engineers (USACE): Permitting under the Clean Water Act
US Army Corps of Engineers is responsible for a permit program under Section 404 of the Clean Water Act regulating discharge of dredged or fill material into waters of the United States, including wetlands. For the proposed aeration project, trenches would likely be dredged to bury the oxygen lines and electrical wire in the shallow, nearshore environment to minimize damage to and from boats. As long as the aeration system compressor building/equipment is not located in a wetland (triggering additional review), this project would likely fall under USACE's Nationwide Permit Program, a series of general permits for project types having minor effect on waters or wetlands. Nationwide Permit 58 for "Utility Line Activities for Water and Other Substances" would likely apply to the aeration project.

NYS Office of General Services (OGS): Use of Lands Under Water
Findley Lake is a public lake. Though most of the perimeter shoreline property is in private ownership, the lakebed (or lands under water) is held in trust for the people of New York State under jurisdiction of the OGS. Among its functions, OGS Bureau of Land Management reviews applications for activities affecting lands under water pursuant to Public Lands Law. This Bureau also reviews matters affecting navigation pursuant to NYS Navigation Law. Application to OGS Bureau of Land Management will be made to determine whether a license, permit, or easement is required for installation and operation of the aeration system.

NYS ORHP: Floating Object Permit during In-Lake Inspection
An annual floating object permit may be required for inspection of the underwater components, particularly if system intake and discharge lines are floated to the lake surface using the buoyancy lines. A temporary floating object permit may require prior approval from the County's Office of the Sheriff and be subject to review by the Marine Services Bureau of NYS Parks, Recreation and Historic Preservation. The ORHP should be contacted for further details if the project moves forward.

Local Site Plan and Zoning Review
Development of proposed land-based facilities will require approval by the Planning Board of the municipality where the affected parcel is located. Professionally stamped engineering drawings (or plot) are required with an application to the Planning Board. The municipal Planning Board will also review any proposal for subdivision, special use permit, or use variance required to develop and operate the land-based facilities.

The site development application will be referred to Chautauqua County Planning Board for comment and recommendation if the proposed action is located within 500 feet of a municipal boundary, county or state highway, recreation area, an agricultural district (as defined under Article 25-AA of NYS Agriculture & Markets Law), or under other certain circumstances.

Prior to construction, a building permit must be secured from the local municipality. New construction must be inspected for compliance with applicable building and energy codes prior to issuance of a Certificate of Compliance by the municipality.

Stormwater Management
Construction projects disturbing one (1) acre or more are subject to Federal Clean Water Act stormwater rules, and coverage under the State Pollutant Discharge Elimination System (SPDES) General Permit for Stormwater Discharges from Construction Activity must be obtained. Under the requirements of this permit, a stormwater pollution prevention plan (SWPP) would be required, and the construction project would be subject to inspection by a qualified entity to ensure compliance with pollution prevention measures. The land-based facilities for the OST system should not disturb an acre of land. Nonetheless, the land-based facilities plan should incorporate stormwater best management practices (BMPs). Chautauqua County Soil and Water Conservation District can be consulted to provide advice on appropriate measures.

Utility Connection
To bring three-phase electric power to the aeration system compressor building(s), application must be made to National Grid. An easement granted by the property owner for National Grid facilities installed on private property may be required.

Property Agreement
If the compressor building(s) is to be installed on private property, a legal agreement (e.g., subdivision and transfer, long term lease, etc.) between the landowner(s) and the project prime will need to be negotiated. Charitable options beneficial to the parties can also be explored.

6.2 NYSDEC AND STATE ENVIRONMENTAL QUALITY REVIEW ACT (SEQR)

The New York State Environmental Quality Review Act (SEQR) is Article 8 of the Environmental Conservation Law. It requires all state and local government agencies to consider environmental impacts alongside social and economic factors when deliberating on actions they have discretion to approve, undertake or fund. SEQR lays out a process to improve decision-making by ensuring 1) agency coordination and communication, 2) determination of a proposed action's "significance" in terms of potential to result in adverse environmental impacts, 3) documentation of potential impacts and options for mitigation for significant actions via completion of an Environmental Impact Statement (EIS), and 4) opportunity for public comment on project documents. Given SEQR's comprehensive and multi-step review process, it is given detailed attention below.

NYSDEC Pre-Application Meeting
The SEQR process is integral to local approval processes outlined above. Local Planning Boards consider SEQR findings in review of development applications. Applications for NYSDEC permits require submission of an Environmental Assessment Form or EAF, which initiates the SEQR process. Therefore, before initiating any work on local approvals, it is highly recommended that a Pre-Application Permit meeting be scheduled with NYSDEC Region 9 personnel, with staff represented from relevant disciplines, e.g., Permitting, Fisheries, and Wetlands. Through a pre-application meeting, local municipalities, Chautauqua County, and the representatives of Findley Lake will be in a better position to determine the types of NYSDEC permits that will need to be obtained for this project and, of equal importance, how to implement the project to minimize impacts.

Detailed land use and land cover mapping of the proposed compressor building sites should be conducted in advance of the pre-application meeting and the resulting information available as a series of graphics to present to NYSDEC staff. For cost savings purposes, until so instructed by the NYSDEC, Princeton Hydro suggests waiting to conduct any formal wetland and riparian delineation of the proposed compressor building sites. To protect the oxygen lines, these lines will likely need to be trenched between the compressor building(s) and the lake. As a result, there will be some disturbance of the lake's shoreline. The remainder of the in-lake elements of the system will be anchored to bottom. NYSDEC has permitted other aeration systems using similarly placed and anchored lines, thus there is some precedent for such an action. It will also be important to have a NYSDEC Fishery representative participate in any pre-application meeting.

Multi-Step State Environmental Quality Review (SEQR) Process

As mentioned above, the installation of the Findley Lake aeration system will trigger the SEQR process. Much of the information that follows was obtained from the 2020 (4th Edition) SEQR Handbook published by the NYSDEC Division of Environmental Permitting and DEC webpage https://www.dec.ny.gov/permits/32521.html. However, it also reflects Princeton Hydro's SEQR and environmental permitting history of projects with NYSDEC.

Determine the Project Sponsor and Classify the Action

The first step in the process will be to identify the Project Sponsor who will submit the application for review under SEQR. The next step will be to classify the action, based on definitions described in 6 NYCCR Part 617 (Official Compilation of Codes, Rules and Regulations of the State of New York):

- Type II – a list of actions, described in Section 617.5, that have been determined not to have significant adverse environmental impacts; or
- Type I – a list of actions, described in Section 617.4, that experience has shown are more likely to have significant adverse environmental impact; or
- Unlisted – all actions that are not Type I or Type II. The majority of actions that come under SEQR review fall under this classification.

Type II actions are categorical exclusions from SEQR, and no further environmental review is required. Both Type I and Unlisted Actions require further review under SEQR through preparation of the Environmental Assessment Form (EAF).

Lead Agency, EAF, and Coordinated Review

It will be necessary to identify the Lead Agency that will coordinate the review process of the EAF. The pre-application meeting with NYSDEC will be used as the means to identify the appropriate Lead Agency.

For all projects subject to SEQR (Type I and Unlisted), it is mandatory that an EAF be prepared and submitted to the Lead Agency by the Project Sponsor. An EAF workbook is available through NYSDEC (https://www.dec.ny.gov/permits/90125.html). The workbook provides guidance on the content and preparation of the EAF. Preparation of the full, 3-part EAF entails investigation and discussion of a wide array of potential ecological and socio-economic impacts from the project. Where applicable, it should also identify how such impacts can be averted, minimized and/or mitigated. A more succinct form, the short EAF, may be used for some Unlisted Actions.

Declaration of Significance

Following coordinated review, with participation by multiple "involved agencies" with jurisdiction or interest in the project, the Lead Agency will determine whether the project results in significant adverse environmental impact and issue a declaration. If it is determined there will be no significant adverse impacts, the Lead Agency will issue a Negative Declaration and the SEQR process ends. If Ontario County is the Lead Agency, the County Board of Supervisors would act to accept the Negative Declaration following a public hearing. Conversely, if the Lead Agency determines the project could have a significant adverse environmental impact, a Positive Declaration is issued and the SEQR process continues with the preparation of a detailed Environmental Impact Statement (EIS). For Unlisted Actions, a Conditioned Negative Declaration may be issued in certain circumstances.

Draft EIS

Preparation of a Draft EIS first requires a scoping process, usually by the Lead Agency, to focus the issues to be investigated and to provide for public participation. The Draft EIS is reviewed by the Lead Agency. When revisions are complete and the Lead Agency determines the Draft EIS is adequate, a Notice of Completion of the Draft

EIS is published. The revised Draft EIS is then made available for 30-day public review and comment. The Lead Agency will decide whether to hold a public hearing on the Draft EIS, which is not mandatory under SEQR. If a hearing is to be held, notice of such shall be as prescribed in 6 NYCCR Part 617, Section 617.12. If a public hearing is required under applicable local or state law, it is not necessary to hold a separate SEQR hearing.

Final EIS and Findings

After addressing and incorporating public comments received, a Final EIS will be prepared and submitted to the Lead Agency. When the Lead Agency is satisfied that the Final EIS is adequate, a Notice of Completion of the Final EIS is published and the Final EIS is made publicly available. A SEQR Findings Statement must be prepared by each involved agency before the Lead Agency renders its Findings, either Positive (the project or action is approvable) or Negative (the project or action is not approvable with an explanation of reasons for denial).

Overall, the SEQR process is likely to take approximately six months to complete following the submittal of the EAF to the Lead Agency with a Positive Declaration. Given the complexity of the SEQR process and the level of detail associated with adequate preparation of the EIS, the cost to prepare documentation and complete the SEQR process could exceed $50,000. Add to this preparation costs of any local, county or NYSDEC or OGS applications for the construction of the compressor building(s) or installation of the in-lake elements of the aeration system, and it is possible that the total permitting costs for the project could be close to $80,000. The cost estimate for the OST system in Section 4.3 includes this estimate for permitting and SEQR review.

6.3 IMPACT ASSESSMENT UNDER SEQR

The OST System recommended in this report is designed to optimize benefits to water quality and minimize risks and adverse impacts to the Findley Lake ecosystem and greater community. Potential impacts to be further evaluated under SEQR are included in Table 6.1.

Table 6.1 - Potential impacts for review under SEQR

Potential Impact	**Comment**
Fish and Wildlife Habitat	Maintenance of DO at lake bottom will enhance coolwater fish habitat; slow rate of withdrawal and discharge will minimize artificial water movement that could impact fish and wildlife in the treatment zone.
Zooplankton and Phytoplankton Food Chain Dynamics	Screens on intake and discharge manifolds will limit trapping of organisms. Some plankton will be entrained in the system in the deep waters, but impact on primary food sources is not expected to be significant.
Aquatic Macrophytes	Increasing water clarity could extend the growth of macrophytes into deeper water and the macrophyte growing season.
Wetlands	No known impacts currently.
Endangered or Threatened Species	Requires investigation.
Sedimentation/Sediment Resuspension	The system is designed with low flow rates to minimize sediment disturbance and resuspension at the intake and discharge manifolds. The system should not increase sedimentation to the lake bottom and may, through increased decomposition with the addition of oxygen, eventually cause a net decrease in the organic muck layer in the deep-water zone.
Thermal Profile	Unlike the aeration destratification system that circulates water from bottom to top, the OST system will not disrupt the natural thermal profile.
Shoreline Disturbance/Modification	Installation of the wiring and oxygen lines could disturb approximately 20 linear feet of shoreline. Boat docking, swimming, and other uses will be impacted in this area. Compressor building(s) in the range of 8'x8' – 12'x12' will be constructed on slab. Potential for erosion during construction can be minimized through erosion and sediment control practices.
Aesthetics	
Compressor Building(s)	Design features and vegetative screening can be used to minimize visual impacts.
Noise	System componentry is designed to minimize noise impacts from pumps and compressors. Sound insulation in the building can further minimize noise disturbances.
In-Lake Disturbances	The system is designed to operate in the deep water with no observable impact at the water surface, e.g., bubbling or currents.
Access and Traffic	Impacts can be minimized by locating compressor building(s) where access already exists or requires minimal disturbance. Traffic to compressor building(s), except during construction and installation, should be minimal and not cause unreasonable adverse impacts to adjoining properties or increase burden on public roads.
Navigation, Recreation, and Angling	Navigation will be temporarily impacted during installation and annual inspection. Impacts can be minimized by scheduling installation and annual maintenance around the peak lake usage season. Information can be posted at public access points and on websites to inform lake users about the location of the OST system equipment to reduce potential snagging of fishing lines or damage to/from boats propellers where the oxygen lines extend from shore.
Fiscal	Grants can be applied for to reduce the local fiscal impact. In-kind effort from local agencies and private donations may help further reduce the cost to local governments. New annual operating and maintenance budgets must be established.

7.0 REFERENCES

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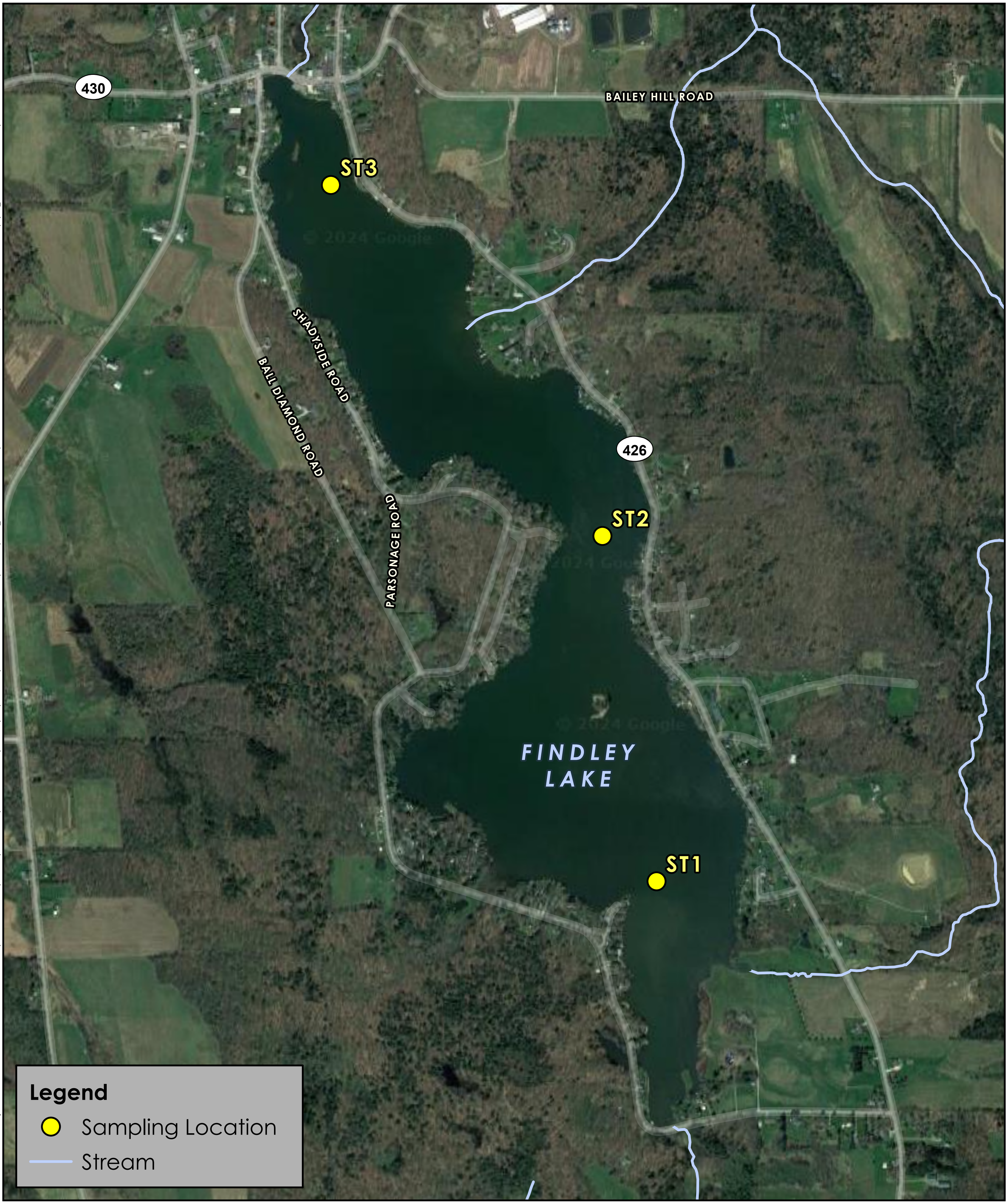
APPENDIX I: MAPS



File: P:\2142\Projects\2142001\GIS\APRX\Findley Lake Bathymetry\Findley Lake Bathymetry.aprx, Layout: Water Quality Sampling Locations, Exported: 2/8/2024, Drawn by tsrinivasan, Copyright Princeton Hydro, LLC.

NOTES:
1. Sampling locations are approximate.
2. Streams obtained from the United States Geological Survey's (USGS) National Hydrography Dataset (NHD).
3. Aerial imagery provided by Google Earth, obtained through ArcGIS Online.

0 600 1,200 Feet

Spatial Reference: NAD 1983 2011 StatePlane New York West FIPS 3103 Ft US

WATER QUALITY SAMPLING LOCATIONS

FINDLEY LAKE
TOWN OF MINA
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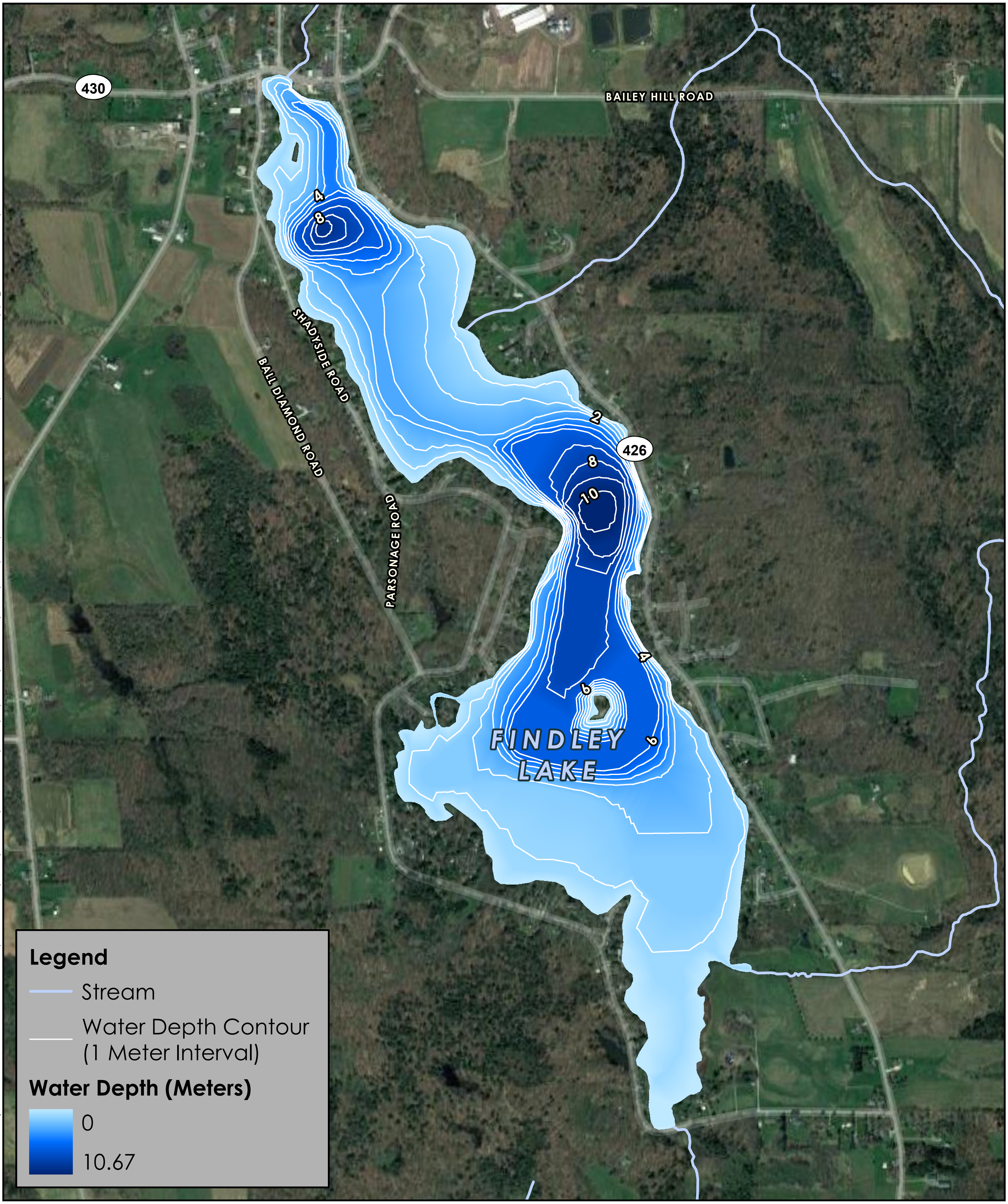

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3. Aerial imagery provided by Google Earth, obtained through ArcGIS Online.

0 600 1,200 Feet

Spatial Reference: NAD 1983 2011 StatePlane New York West FIPS 3103 Ft US

BATHYMETRY MAP

FINDLEY LAKE
TOWN OF MINA
CHAUTAUQUA COUNTY, NEW YORK

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APPENDIX II: IN-SITU DATA

In-Situ Monitoring for Findley Lake 7/6/23											
Station	DEPTH (meters)			Temperature	Conductivity	Dissolved Oxygen	Dissolved Oxygen	pH	Phycocyanin	Chlorophyll *a*
	Total	Secchi	Sample	(^{0}C)	µS/cm	(mg/L)	(%)	S.U.	RFU	RFU
ST-3	7.80	3.80	Surface	24.59	189.8	9.46	119.7	8.96	2.998	0.011
			1.0	25.03	191.5	9.33	118.8	8.91	2.951	0.025
			2.0	25.08	189.7	9.27	118.3	8.91	2.958	0.014
			3.0	25.13	187.4	9.23	117.9	8.94	2.921	0.018
			4.0	21.19	191.3	3.71	44.4	7.59	2.827	0.042
			5.0	19.68	187.0	0.59	6.7	7.28	2.534	0.033
			6.0	16.23	194.6	0.40	4.0	7.27	1.822	0.092
			7.0	13.78	200.2	0.00	0.0	6.98	1.783	1.144
			7.5	13.75	223.3	0.00	0.0	6.95	1.716	0.016
ST-2	10.50	4.30	Surface	25.07	185.8	8.75	111.5	8.65	0.709	0.014
			1.0	25.12	187.1	8.74	111.4	8.67	0.572	0.016
			2.0	25.07	187.4	8.69	110.5	8.63	0.529	0.013
			3.0	24.94	187.6	8.65	110.0	8.63	0.600	0.014
			4.0	22.75	189.8	8.39	103.3	8.63	0.548	0.015
			5.0	19.55	197.5	7.39	85.8	8.22	0.648	0.008
			6.0	16.26	204.7	4.37	46.6	7.68	0.739	0.016
			7.0	13.12	208.8	2.38	23.9	7.26	1.898	0.013
			8.0	11.91	213.9	0.00	0.0	7.20	0.625	0.001
			9.0	10.68	212.9	0.00	0.0	7.07	0.625	0.021
			10.0	9.02	250.1	0.00	0.0	7.01	3.651	0.034
ST-1	1.70	1.60	Surface	25.86	161.4	13.09	169.5	9.69	2.155	0.009
			1.0	25.71	174.2	11.20	143.3	9.20	3.188	0.017
			2.0	25.44	177.7	7.44	98.4	9.07	1.811	0.928

In-Situ Monitoring for Findley Lake 8/8/23											
Station	DEPTH (meters)			Temperature	Conductivity	Dissolved Oxygen	Dissolved Oxygen	pH	Phycocyanin	Chlorophyll *a*
	Total	Secchi	Sample	(^{0}C)	µS/cm	(mg/L)	(%)	S.U.	RFU	RFU
ST-3	7.80	1.90	Surface	23.97	198.3	8.55	107.5	8.85	2.132	0.024
			1.0	23.84	198.8	8.55	107.1	8.90	2.121	0.025
			2.0	23.94	198.6	8.47	106.3	8.89	1.830	0.027
			3.0	23.92	198.3	8.45	106.3	8.93	1.799	0.023
			4.0	23.92	198.2	8.47	106.3	8.91	2.063	0.022
			5.0	21.64	218.3	3.59	42.3	7.94	2.057	0.023
			6.0	19.23	220.3	0.62	5.7	7.31	5.195	0.028
			7.0	13.56	241.7	0.00	0.0	7.18	2.947	0.026
			7.5	13.11	245.2	0.00	0.0	7.14	0.681	0.025
ST-2	10.50	4.30	Surface	24.21	196.3	8.77	110.8	8.88	1.856	0.034
			1.0	24.17	196.5	8.69	109.5	8.85	1.986	0.180
			2.0	24.11	196.7	8.38	108.0	8.84	1.868	0.063
			3.0	24.06	196.8	8.52	107.3	8.83	1.694	0.102
			4.0	23.99	197.0	8.38	105.3	8.79	1.650	0.189
			5.0	23.35	201.0	3.29	36.9	8.03	1.067	0.024
			6.0	23.93	196.9	1.64	18.8	8.83	5.677	0.192
			7.0	23.42	200.9	0.46	3.8	8.47	2.706	0.045
			8.0	19.94	209.5	0.07	0.6	7.78	1.868	0.086
			9.0	16.63	208.5	0.04	0.2	7.54	1.756	0.456
			10.0	9.86	284.9	0.02	0.1	7.40	1.679	0.160
ST-1	1.70	1.60	Surface	23.44	200.8	7.39	91.8	8.23	3.256	0.541
			1.0	23.45	200.6	7.37	91.7	8.22	3.606	0.461
			2.0	23.45	200.7	6.95	86.2	8.16	3.033	0.988

In-Situ Monitoring for Findley Lake 9/12/23											
Station	DEPTH (meters)			Temperature	Conductivity	Dissolved Oxygen	Dissolved Oxygen	pH	Phycocyanin	Chlorophyll *a*
	Total	Secchi	Sample	(^{0}C)	µS/cm	(mg/L)	(%)	S.U.	RFU	RFU
ST-3	7.80	1.10	Surface	22.29	212.3	5.71	69.1	7.74	4.764	0.396
			1.0	22.43	21.2	5.53	67.0	7.81	4.485	0.448
			2.0	22.42	212.8	5.54	67.0	7.85	4.284	0.376
			3.0	22.41	212.4	5.38	65.2	7.81	4.002	0.295
			4.0	21.33	212.4	4.87	0.5	7.74	3.941	0.029
			5.0	20.09	210.4	0.05	0.0	7.45	0.574	0.027
			6.0	17.57	237.5	0.00	0.0	7.52	0.675	0.033
			7.0	13.71	254.2	0.00	0.0	7.44	0.558	0.031
			7.5	12.28	259.2	0.00	0.0	7.29	0.568	0.024
ST-2	10.50	1.10	Surface	22.65	205.1	7.28	88.6	8.26	5.044	0.060
			1.0	22.79	204.5	7.24	88.3	8.24	5.050	0.091
			2.0	22.75	264.3	7.38	89.7	8.27	4.953	0.217
			3.0	22.76	204.3	7.25	88.3	8.25	4.513	0.051
			4.0	22.67	195.5	6.93	83.9	8.15	2.746	0.050
			5.0	21.35	205.6	0.17	1.9	7.46	0.624	0.025
			6.0	20.88	237.1	0.00	0.0	7.36	0.744	0.026
			7.0	17.45	262.6	0.00	0.0	7.41	0.625	0.025
			8.0	14.18	276.8	0.00	0.0	7.40	0.668	0.026
			9.0	12.40	285.4	0.00	0.0	7.19	0.712	0.027
			10.0	11.97	286.6	0.00	0.0	7.07	0.679	0.819
ST-1	1.80	1.00	Surface	22.85	199.9	8.05	98.1	8.37	4.134	0.197
			1.0	22.94	200.9	7.99	97.7	8.37	4.048	0.080
			2.0	22.94	201.6	7.95	97.0	8.35	3.939	0.392

APPENDIX III: DISCRETE DATA

Findley Lake Discrete Data - July 6, 2023									
Station	Depth	Chl a (µg/L)	NH3 (mg/L)	NO3 (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	TDP (mg/L)	TSS (mg/L)
ST-1	Surface					ND < 0.003	0.02		ND < 2
ST-1	Deep					ND < 0.003	0.02		5
ST-2	Surface	1.4	0.02	ND < 0.03	0.11	ND < 0.003	0.01	0.01	2
ST-2	Deep					ND < 0.003	0.19		9
ST-3	Surface					ND < 0.003	0.02		ND < 2
ST-3	Deep					ND < 0.003	0.06		17

Findley Lake Discrete Data - August 8, 2023									
Station	Depth	Chl a (µg/L)	NH3 (mg/L)	NO3 (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	TDP (mg/L)	TSS (mg/L)
ST-1	Surface					0.003	0.05		17
ST-1	Deep					0.003	0.07		17
ST-2	Surface	15	0.02	ND < 0.03	ND < 0.08	ND < 0.003	0.02	0.01	2
ST-2	Deep		0.24	0.05	0.29	ND < 0.003	0.22	0.01	21
ST-3	Surface					ND < 0.003	0.03		6
ST-3	Deep					0.006	0.10		20

Findley Lake Discrete Data - September 12, 2023									
Station	Depth	Chl a (µg/L)	NH3 (mg/L)	NO3 (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	TDP (mg/L)	TSS (mg/L)
ST-1	Surface					0.002	0.03		11
ST-1	Deep					0.002	0.03		2
ST-2	Surface	34	0.03	ND < 0.07	0.53	0.001	0.03	ND < 0.02	8
ST-2	Deep		0.63	0.11	0.71	0.003	0.39	0.03	24
ST-3	Surface					0.002	0.04		10
ST-3	Deep					0.003	0.07		12

APPENDIX IV: PLANKTON DATA

Phytoplankton Community Composition Analysis

Sampling Location: Findley Lake | **Sampling Date:** 2023.07.06 | **Examination Date:** 2024.01.23

Site A: Station 2 Surface | **Site B:** Station 2 Mid-Depth | **Site C:** Station 1 Tow | **Site D:** Station 3 Tow

Phytoplankton

Diatoms	A (cells/mL)	B (cells/mL)	C	D	Chlorophytes	A (cells/mL)	B (cells/mL)	C	D	Cyanophytes	A (cells/mL)	B (cells/mL)	C	D
Asterionella	473.4		P	P	*Actinastrum*					*Anabaenopsis*				P
Aulacoseira					*Ankistrodesmus*					*Aphanizomenon*			P	P
Cocconeis					*Chlamydocapsa*					*Aphanocapsa*	355.0	982.7		
Cyclotella					*Chlamydomonas*	118.3	65.5			*Chroococcus*				
Cymatopleura					*Chlorella*				P	*Coelosphaerium*				P
Denticula					*Chlorogonium*					*Cylindrospermopsis*				
Eunotia			C		*Coccomonas*					*Dactylococcopsis*				
Fragilaria			C	R	*Crucigenia*			R		*Dolichospermum*	7692.6		C	C
Frustulia			R		*Didymocystis*	946.8	131.0			*Gloeocapsa*				
Gyrosigma					*Franceia*					*Lyngbya*				R
Melosira					*Gloeococcus*	591.7				*Merismopedia*				
Navicula					*Gloeocystis*			P		*Microcystis*			C	P
Nitzschia					*Golenkinia*					*Nostoc*				
Pseudonitzschia					*Gonium*					*Planktothrix*	355.0	20243.7		
Surirella					*Kirchneriella*	118.3				*Raphidopsis*		262.1		
Synedra					*Lagerheimia*					*Synechococcus*		262.1		
Tabellaria					*Mougeotia*			P		Woronichinia				
					Nannochloris	236.7	196.5			**Euglenoids**	**A (cells/mL)**	**B (cells/mL)**	**C**	**D**
					Oocystis					*Euglena*				
					Pandorina					*Lepocinclis*				P
					Pediastrum			C	P	*Phacus*				
Chrysophytes	**A (cells/mL)**	**B (cells/mL)**	**C**	**D**	*Scenedesmus*					*Trachelomonas*				
Dinobryon		196.5			*Scourfeldia*					**Dinoflagellates**	**A (cells/mL)**	**B (cells/mL)**	**C**	**D**
Chromulina	118.3				*Selenastrum*					*Ceratium*			A	C
Mallomonas					*Sphaerocystis*	1775.2				*Gloeodinium*				
Synura	8994.4				*Spinoclosterium*					*Tetradinium*				
					Spirogya									
					Staurastrum			P	P	**Cryptophytes**	**A (cells/mL)**	**B (cells/mL)**	**C**	**D**
					Teilingia					*Chroomonas*				
					Tetraselmis					*Cryptomonas*				
					Treubaria					*Rhodamonas*	118.3			
					Volvox									
					Zygnema									

Zooplankton

Cladocera	A (org/mL)	B (org/mL)	C	D	Copepoda	A (org/mL)	B (org/mL)	C	D	Rotifera	A (org/mL)	B (org/mL)	C	D
Bosmina			P	P	*Diaptomus*	1			R	*Conochilus*			P	
Ceriodaphnia			P	C	*Microcyclops*	1	5	P	P	*Kellicottia*		106	P	
Chydorus		2	R		Nauplii	8	22	C		*Keratella*	33	90	P	P
Daphnia	1	22	C	C						*Monostyla*				
Diaphanosoma		3								*Polyartha*	15	101	C	C
Other Arthropods	**A (org/mL)**	**B (org/mL)**	**C**	**D**						*Trichocerca*		5		R
Ostracoda	2													

Sites:	A	B	C	D
Cyanobacteria Abundance (cells/mL)	8,403	21,751		
Total Phytoplankton Abundance	21,894	22,340		
Phytoplankton Genera Richness	13	8	13	13
Total Zooplankton Abundance (org/mL	61	356		
Zooplankton Genera Richness	7	9	10	8

Comments:

Princeton Hydro, LLC

35 Clark Street, Trenton, NJ 08611; Phone (908) 237-5660

Phytoplankton Community Composition Analysis

Sampling Location: Findley Lake | Sampling Date: 2023.08.08 | Examination Date: 2024.01.23

Site A: Station 2 Surface | Site B: Station 2 Mid-Depth | Site C: Station 1 Tow | Site D: Station 3 Tow

Phytoplankton

Diatoms	A (cells/mL)	B (cells/mL)	C	D
Asterionella	283.0			R
Aulacoseira				
Cocconeis				R
Cyclotella				
Cymbella	31.4			
Denticula				
Eunotia			C	P
Fragilaria	157.2		P	P
Frustulia				R
Gyrosigma				
Melosira				
Navicula				
Nitzschia	31.4			
Pseudonitzschia				
Surirella				R
Synedra				
Tabellaria				

Chrysophytes	A	B	C	D
Dinobryon	125.8			
Chromulina				
Mallomonas				
Synura				

Chlorophytes	A (cells/mL)	B (cells/mL)	C	D
Chlorophytes	A	B		
Actinastrum	62.9			
Ankistrodesmus				
Brachiomonas	31.4			
Chlamydomonas	31.4			
Chlorella		293.1	P	P
Chlorogonium				
Cosmariuma				R
Coelastrum				
Didymocystis	628.9			
Franceia				
Gloeococcus	880.5	146.5		
Gloeomonas				
Golenkinia				
Gonium				
Kirchneriella	31.4			
Lagerheimia				
Microspora				
Nannochloris	157.2			
Oocystis			R	R
Pandorina				
Pediastrum			C	C
Scenedesmus				
Scourfeldia				
Selenastrum				
Sphaerocystis				
Spinoclosterium				
Spirogya				
Staurastrum			R	
Teilingia				
Tetraselmis				
Treubaria				
Volvox				
Zygnema				

Cyanophytes	A (cells/mL)	B (cells/mL)	C	D
Anabaenopsis			P	P
Aphanizomenon	2138.4	1025.7	C	A
Aphanocapsa	4496.9	146.5		
Chroococcus				
Coelosphaerium			A	C
Cylindrospermopsis				
Dactylococcopsis				
Dolichospermum	11666.7		A	A
Gloeocapsa				
Lyngbya				R
Merismopedia				R
Microcystis			C	C
Nostoc				
Planktothrix		37363.9	C	
Raphidopsis		1465.3		
Synechococcus				
Woronichinia			P	

Euglenoids	A	B	C	D
Euglena	31.4			R
Phacus				
Trachelomonas	31.4		P	P

Dinoflagellates	A	B	C	D
Ceratium	220.1		A	A
Gloeodinium				
Tetradinium				

Cryptophytes	A	B	C	D
Chroomonas				
Cryptomonas				
Rhodamonas				

Zooplankton

Cladocera	A (org/mL)	B (org/mL)	C	D
Bosmina	5	2		C
Ceriodaphnia			P	C
Chydorus	2	2	P	C
Daphnia	10	4	P	
Diaphanosoma	29	18	A	A

Other Arthropods	A (org/mL)	B (org/mL)	C	D
Ostracoda	5			

Copepoda	A (org/mL)	B (org/mL)	C	D
Diaptomus	7	2	P	
Microcyclops	5	10	P	C
Nauplii	2		P	C
Orthocyclops	12	22		

Rotifera	A (org/mL)	B (org/mL)	C	D
Ascomorpha	48	68		
Asplanchna		2	P	P
Conochilus		4	P	P
Gastropus			P	
Kellicottia		4		
Keratella	80	56	P	P
Polyartha	36	6	P	P
Pompholyx		8		
Trichocerca	7	6		

Sites:	A	B	C	D
Cyanobacteria Abundance (cells/mL)	18,302	40,001		
Total Phytoplankton Abundance	21,037	40,441		
Phytoplankton Genera Richness	18	6	15	20
Total Zooplankton Abundance (org/mL)	249	214		
Zooplankton Genera Richness	13	15	12	10

Comments:

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Phytoplankton Community Composition Analysis

Sampling Location: Findley Lake | **Sampling Date: 2023.09.12** | **Examination Date: 2024.01.23**

Site A: Station 2 Surface | **Site B: Station 2 Mid-Depth** | **Site C: Station 1 Tow** | **Site D: Station 3 Tow**

Phytoplankton (cells/mL)

Diatoms	**A (cells/mL)**	**B (cells/mL)**	**C**	**D**
Asterionella	149.7		P	
Aulacoseira				
Cocconeis				
Cyclotella				
Cymbella				
Denticula				
Diploneis				
Fragilaria		134.1	P	
Frustulia				
Gyrosigma				
Melosira		603.3		P
Navicula				
Nitzschia				
Pseudonitzschia				
Surirella				
Synedra				
Tabellaria				

Chrysophytes	**A (cells/mL)**	**B (cells/mL)**	**C**	**D**
Dinobryon	112.3	134.1		
Chromulina				
Mallomonas	37.4			
Synura				

Chlorophytes	**A (cells/mL)**	**B (cells/mL)**	**C**	**D**
Actinastrum	112.3	134.1		
Ankistrodesmus				
Brachiomonas				
Chlamydomonas	37.4			
Chlorella	37.4	134.1		
Chlorogonium				
Coccomonas				
Coelastrum				
Didymocystis	524.1	737.4		
Franceia				
Gloeococcus	149.7			
Gloeotila			R	
Golenkinia				
Gonium				
Kirchneriella		67.0		
Lagerheimia				
Microspora				
Nannochloris				
Oocystis	299.5	67.0		
Pandorina				
Pediastrum			C	P
Scenedesmus				
Scourfeldia				
Selenastrum	37.4			
Sphaerocystis				
Spinoclosterium				
Spirogya				
Staurastrum			R	
Teilingia				
Tetraselmis				
Treubaria	37.4			
Volvox				
Zygnema				

Cyanophytes	**A (cells/mL)**	**B (cells/mL)**	**C**	**D**
Anabaenopsis	299.5	603.3	P	
Aphanizomenon	44212.3	54367.2	A	
Aphanocapsa	25980.8	25004.9	P	A
Coelosphaerium			C	C
Cylindrospermopsis				
Dactylococcopsis				
Dolichospermum	15124.3	9653.4	A	A
Gloeocapsa				
Lyngbya	2059		C	P
Merismopedia			P	
Microcystis			A	A
Nostoc				
Planktothrix		469.3		
Raphidopsis				
Synechococcus				
Woronichinia				C

Euglenoids	**A (cells/mL)**	**B (cells/mL)**	**C**	**D**
Euglena	37.4			
Phacus				
Trachelomonas				P

Dinoflagellates	**A (cells/mL)**	**B (cells/mL)**	**C**	**D**
Ceratium			C	P
Gloeodinium				
Tetradinium				

Cryptophytes	**A (cells/mL)**	**B (cells/mL)**	**C**	**D**
Chroomonas	37.4	67.0		
Cryptomonas	37.4			
Rhodamonas				

Zooplankton

Cladocera	**A (org/mL)**	**B (org/mL)**	**C**	**D**
Bosmina	23	79	P	P
Chydorus		2	R	P
Daphnia	2	33	P	R
Diaphanosoma		4	P	R

Other Arthropods	**A (org/mL)**	**B (org/mL)**	**C**	**D**
Chaborus		4		

Copepoda	**A (org/mL)**	**B (org/mL)**	**C**	**D**
Diaptomus		4	P	P
Microcyclops	5	28	P	P
Nauplii	12	31	P	P

Rotifera	**A (org/mL)**	**B (org/mL)**	**C**	**D**
Ascomorpha	35	35	R	
Asplanchna				
Conochilus				
Kellicottia	5	20	P	R
Keratella	56	127	P	P
Polyartha	12	13	P	
Pompholyx	2	4		
Trichocerca	5	6		P

Sites:	**A**	**B**	**C**	**D**
Cyanobacteria Abundance (cells/mL)	87,676	90,098		
Total Phytoplankton Abundance	89,323	92,176		
Phytoplankton Genera Richness	19	14	14	10
Total Zooplankton Abundance (org/mL)	158	387		
Zooplankton Genera Richness	10	14	11	10

Comments:

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APPENDIX V: BATHYMETRIC DATA

DEPTH (m)	AREA (m^2)	VOLUME (m^3)
-10.5	4,223	599
-10.0	9,262	3,890
-9.5	16,215	10,179
-9.0	28,237	20,927
-8.5	36,994	37,126
-8.0	48,345	58,353
-7.5	92,418	89,426
-7.0	116,556	141,438
-6.5	146,283	206,916
-6.0	247,667	295,132
-5.5	268,572	424,160
-5.0	290,256	563,834
-4.5	319,773	715,009
-4.0	351,730	882,835
-3.5	384,850	1,066,931
-3.0	449,584	1,269,222
-2.5	542,320	1,516,697
-2.0	647,018	1,813,532
-1.5	814,336	2,166,904
-1.0	980,747	2,615,063
-0.5	1,118,918	3,143,561
0.0	1,249,922	3,732,639