Northeast Aquatic Research

Highland Lake 2020 Water Quality Report & Long-Term Data Assessment

Prepared for the Town of Winchester and the Highland Lake Watershed Association

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Introduction

Highland Lake is a 445-acre lake in Winchester, Connecticut. The lake has three main basins and a maximum depth of approximately 60 feet in the middle basin. The lake has two primary inlets – Taylor Brook and Sucker Brook. The Sucker Brook inlet is controlled by an Army Corps of Engineers flood control dam located at the mouth to the lake. The lake outlet flows through a spillway that can be opened or closed to control the water level.

Northeast Aquatic Research (NEAR) has been involved with water quality monitoring at Highland Lake since 2008. In the early 2000s, water clarity and total phosphorus data were collected by volunteer monitors. Historical data has not been fully analyzed and reported upon until now. This report examines Highland Lake water quality data collected between 2000 and 2020, with the aim of establishing current water quality condition and providing recommendations for future management.

Over the past thirteen years, water quality monitoring has occurred approximately once per month over the summer season at three separate stations in the lake. In this report, the three bays are referred to as North Bay, Center Bay, and South Bay monitoring stations (**Figure 1**). Stations are positioned at the deepest location in each bay. Center Bay is the deepest of the three stations, with a maximum depth of 15-18 meters (~50-60 ft) depending on the water level and GPS position accuracy. The depth of North Bay deepest water ranges from ~6.5-8.5 meters, (~21-28 ft), while the South Bay deep spot ranges from ~13-14 meters (~43-46 ft). In addition to water level change, the station depth changes slightly if the boat is positioned slightly off of the geo-positioning coordinates.

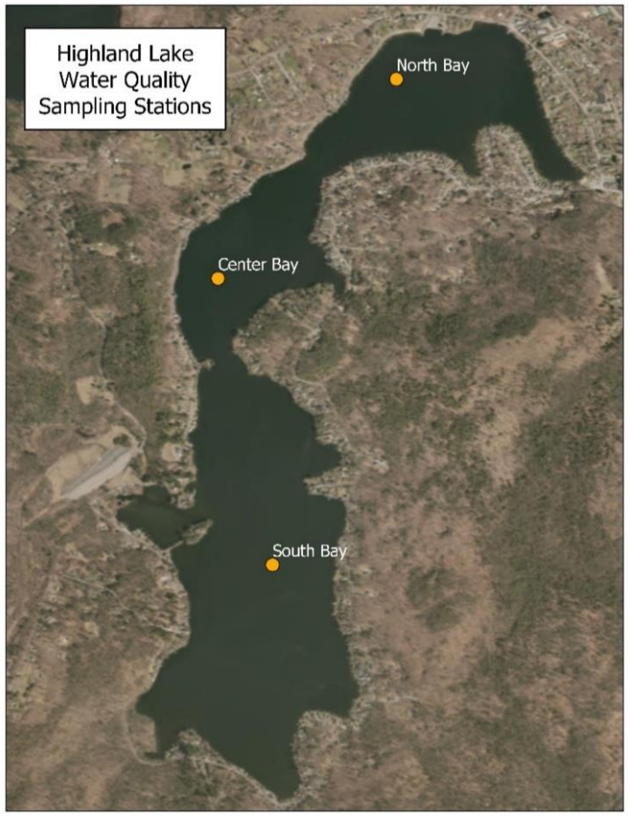


Figure 1. Highland Lake water quality sampling stations.

Dissolved oxygen, temperature, and occasionally conductivity and salinity profiles have been collected at the three monitoring stations since mid-2008. NEAR staff have performed the water quality monitoring in April and November in most years, while volunteer monitors performed the monitoring in the summer months.

In 2020, NEAR staff conducted the water quality monitoring in April and May. Volunteers conducted the monitoring from June through September. Monitoring could not be conducted in October and November 2020 because an early lake drawdown was coupled with low water levels caused by moderate to severe drought conditions. The 2020 drought conditions began in July and continued through November.

Lake Assessment

The Highland Lake data is assessed using the CT DEEP categorization of lakes, which is primarily based on the concentration of nutrients in surface waters during summer (**Table 1**). This categorization is general and does not apply to all lakes in Connecticut or across the country. It is a simplification of water quality assessment and categorization that is used as part of the CT Department of Energy and Environmental Protection (DEEP)'s reporting of lake conditions to the U.S. Environmental Protection Agency.

Trophic categories are a simplified and widely used method of lake classification, related to the degree of plant and algae growth in a lake. Plants and algae increase in abundance as nutrient concentrations increase. Water quality condition in a lake can be tracked using total phosphorus, total nitrogen, water clarity, dissolved oxygen, and the phytoplankton community.

Lake water that is very clear, with no weeds or algae, results from very low phosphorus and nitrogen conditions. These clear-water and low-nutrient lakes are classified as oligotrophic. Lakes with excessive amounts of weeds and very green water resulting from high nutrient concentrations are eutrophic. Humans generally increase the rate at which a lake receives nutrients from the surrounding watershed, which in turn accelerates the process of a lake becoming less oligotrophic and more eutrophic over time. The further a lake deteriorates towards eutrophic conditions, the more difficult it becomes to re-establish clear-water oligotrophic conditions.

Table 1. Connecticut lake trophic categories and ranges of indicator parameters.

Category	Total phosphorus (ppb)	Total Nitrogen (ppb)	Secchi Depth (m)	Chlorophyll *a* (ppb)
Oligotrophic	0 -- 10	2 -- 200	6 +	0 -- 2
Oligo-mesotrophic	10 -- 15	200 -- 300	4 -- 6	2 -- 5
Mesotrophic	15 -- 25	300 -- 500	3 -- 4	5 -- 10
Meso-eutrophic	25 -- 30	500 -- 600	2 -- 3	10 -- 15
Eutrophic	30 -- 50	600 -- 1000	1 -- 2	15 -- 30
Highly Eutrophic	50 +	1000 +	0 -- 1	30 +

**Source = CT DEP 1982*   ***Chlorophyll-a not included in testing*

****(color represents the visual appearance of the lake water in each category)*

Highland Lake data is compared against the trophic categories to assess and rank the trophic state of the lake. This report analyzes these and other parameters to determine Highland Lake's current condition, and the change in lake condition over time. The report concludes with actionable recommendations for water quality improvement.

In-lake Water Quality Goals

Long term in-lake water quality goals for Highland Lake are detailed below, consistent with the trophic category ranges provided in **Table 1**. These goals are not remediation based. Rather, the goal values have been established with the aim of maintaining the current lake condition and preventing worsening water quality.

In the event that a formal watershed management plan is created for the Highland Lake watershed, these goals may need to be revised to align with the DEEP's TMDL (Total Maximum Daily Load) plans for waterbodies.

Nutrients

Phosphorus – Phosphorus is one of the primary nutrients limiting algae and cyanobacteria growth in freshwaters. To ensure adequate water quality, TP concentrations in Highland in any one month should remain close that that month's long-term average and the total long-term average (**Table 2**). The long-term lake-wide average TP concentration in the surface waters is 11ppb.

Table 2. Monthly long-term average total phosphorus concentrations (ppb).

Month	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Overall
TP (ppb)	10.8	9.1	10.7	10.2	9.0	12.9	10.5	14.9	11.0

Nitrogen – Nitrogen concentrations are also linked to algae and cyanobacteria growth. Monitoring data suggest the upper tolerable level for total nitrogen in the surface waters is 250ppb.

Symptomatic Water Quality Parameters

Water Clarity – The Secchi disk depth is a measure of plankton density, as well as mineral or organic turbidity. The long-term goal for water clarity is >4 meters for at least two months during the summer. The lake should experience even better clarity in years when there is low precipitation, resulting in reduced watershed loading

Cyanobacteria – Increasing cell numbers causes diminished water clarity and increased likelihood of cyano-toxins. The goal for cyanobacteria numbers is <20,000 cells/mL in open water, as counted using *Standard Methods for Phytoplankton Analysis*. These cell concentrations are consistent with Connecticut Public Health guidelines.

The long-term monitoring program should be improved to include data collection to determine whether cyanobacteria blooms in Highland Lake are becoming more common and more serious.

Dissolved Oxygen – Dissolved oxygen loss in bottom waters is common in Highland Lake and is accelerated by anthropogenic nutrient input. While oxygen loss during summer months in the deep-waters of lakes is very common and a natural process, low oxygen is also indirectly related to bottom-water nutrient concentrations. Additionally, a lack of oxygen in the bottom waters can be a problem for fisheries management so the volume of anoxic water should be considered in any future management practices.

Dissolved oxygen below 1 mg/L (ppm) should not occur above 2 meters from the bottom at North Bay, 7 meters above the bottom at Center Bay, and 6 meters above the bottom at South Bay.

Monitoring Components Overview

Water quality monitoring was conducted by a combination of NEAR staff and HLWA volunteers from an anchored boat at each monitoring station, North Bay, Center Bay, and South Bay. Historically, NEAR monitoring visits tended to be in April and November, and volunteer monitoring usually took place between the May through October time period. During each visit, the following data was collected: Secchi disk depth, water temperature, dissolved oxygen, percent oxygen saturation, and frequently conductivity profiles. Water samples were collected for nutrient analysis, and phytoplankton and zooplankton samples were collected during monitoring visits conducted by NEAR staff. Volunteers were trained for plankton sampling in 2021 and will be retrained in subsequent years to ensure adequate data collection procedures.

Lake Profiles

Temperature, dissolved oxygen, percent oxygen saturation, and conductivity were measured at each station using a Hach LDO101 probe and a Hach HQ40D portable meter. Values were recorded at one-meter depth increments from the surface to the lake bottom to achieve a full water column profile. Mixing resistance (RTRM) values were calculated between each one-meter increment.

Lake Samples

Water samples are collected from the following depths at each station using a horizontal Van-Dorn water sampler: North Bay – 1, 4, and 7 meters; Center Bay – 1, 7, and 16 meters; South Bay – 1, 7, and 13 meters. The depth at which the bottom water sample was collected varied slightly on some dates, based on water level and location of the boat. All samples were analyzed for concentrations of total phosphorus. Select samples were also analyzed for concentrations of total nitrogen, nitrate nitrogen, and ammonia.

Secchi Disk Depth

During each monitoring event, water clarity was measured at the three stations using a Secchi disk and a view scope. Secchi disk transparency values attempt to quantify how turbidity and plankton assemblages diminish transparency in the water column over the growing season.

Plankton

Water samples for phytoplankton identification and enumeration were collected from each station during the April and November visits using a 3-meter vertical composite sampler. Monthly phytoplankton sample collection began in 2021, when volunteers were trained to collect the samples. Samples were preserved with iodine solution until microscopic examination at 100x. Organisms were identified to genera level and counted for quantitative values of cells/milliliter. Phytoplankton samples that required higher magnification for proper cell identification were temporarily placed under 400-1000x magnification. Phytoplankton samples were used in lieu of filtered chlorophyll-a.

Zooplankton samples were collected from whole lake vertical tows from bottom to top using a net with 80 µm mesh size. Samples were preserved with iodine until microscopic examination at 50x. Organisms were identified to genera with counts of organisms/milliliter.

Water Clarity

Water clarity, as determined by the Secchi disk depth, is the simplest parameter used to assess the water quality of lakes. Clarity is dependent on the extent of light penetration, which is affected by phytoplankton, suspended sediments, and microscopic organic matter in the water column. Clearer waterbodies have greater Secchi transparency values. Lakes and ponds experience fluctuations in water clarity throughout the season, typically driven by increases or decreases in nutrients that stimulate phytoplankton growth.

Highland Lake water clarity data collection began in 2005, though monitoring in the early years was sporadic and inconsistent. Consistent monthly monitoring from April through November began in 2009. The use of a view scope, which generally makes Secchi readings slightly better and more consistently reliable, may have been added to the monitoring program circa 2010, which would make early Secchi clarity readings technically incomparable to readings taken with a view scope. Use of a view scope would also increase the range of Secchi values across a season. Unfortunately, this analysis cannot adequately confirm when a view scope was added to the monitoring program, so this analysis focused on seasonal patterns of water clarity, instead of simply looking for significant change over years.

The water clarity in the lake follows a similar pattern each year (**Figure 2**). Generally, clarity is poor in the early spring, likely related to watershed nutrient loading. Clarity then typically improves somewhat by June, when thermal stratification causes spring phytoplankton and other suspended material to drop out of the water column. Sometimes a 'clear-water' phase is also related to a combined increase in predatory zooplankton populations, but there is very little corresponding plankton data to suggest a relationship[1]. An explanation of stratification within lakes is included in the '*Temperature*' section of this report on **page 11**. Clarity remains fairly constant, typically between 4 meters and 5 meters, during summer until the fall. Clarity tends to decline again after fall overturn. Between 2005 and 2020, water clarity across the three stations in Highland Lake has ranged in depth from a low of approximately 1.8 meters to a high of 6.3 meters.

Water clarity in April and May 2019 was the poorest on record, between 1.9 and 2.0 meters at all three stations. Clarity was notably improved in 2020 over 2019, specifically showing much improved spring and summer clarities. 2020 Secchi disk measurements were also better (deeper) than the long-term median in most months at all three stations (**Figure 3**). In July, August and September 2020, the water clarity was

[1] Wetzel, Robert G. *Limnology*. Elsevier Science, 2001.

much better than average at all three stations; the Secchi depth at Center Bay and South Bay hovered around 6 meters. The August South Bay Secchi disk depth of 6.3 meters was the first recorded clarity greater than 6 meters. The late summer and fall of 2020 was very dry, reaching moderate to extreme drought conditions. The lack of precipitation and associated watershed loading may have been a cause of the improved clarity, particularly since South Bay receives inputs from the three largest watershed inlets.

There is not a statistically significant difference in mean Secchi disk depths between the three stations within each year, despite certain months having very clear differences from one station to another on specific sampling dates. The Secchi disk depth typically remains within a 20-centimeter range between the three stations on most dates.

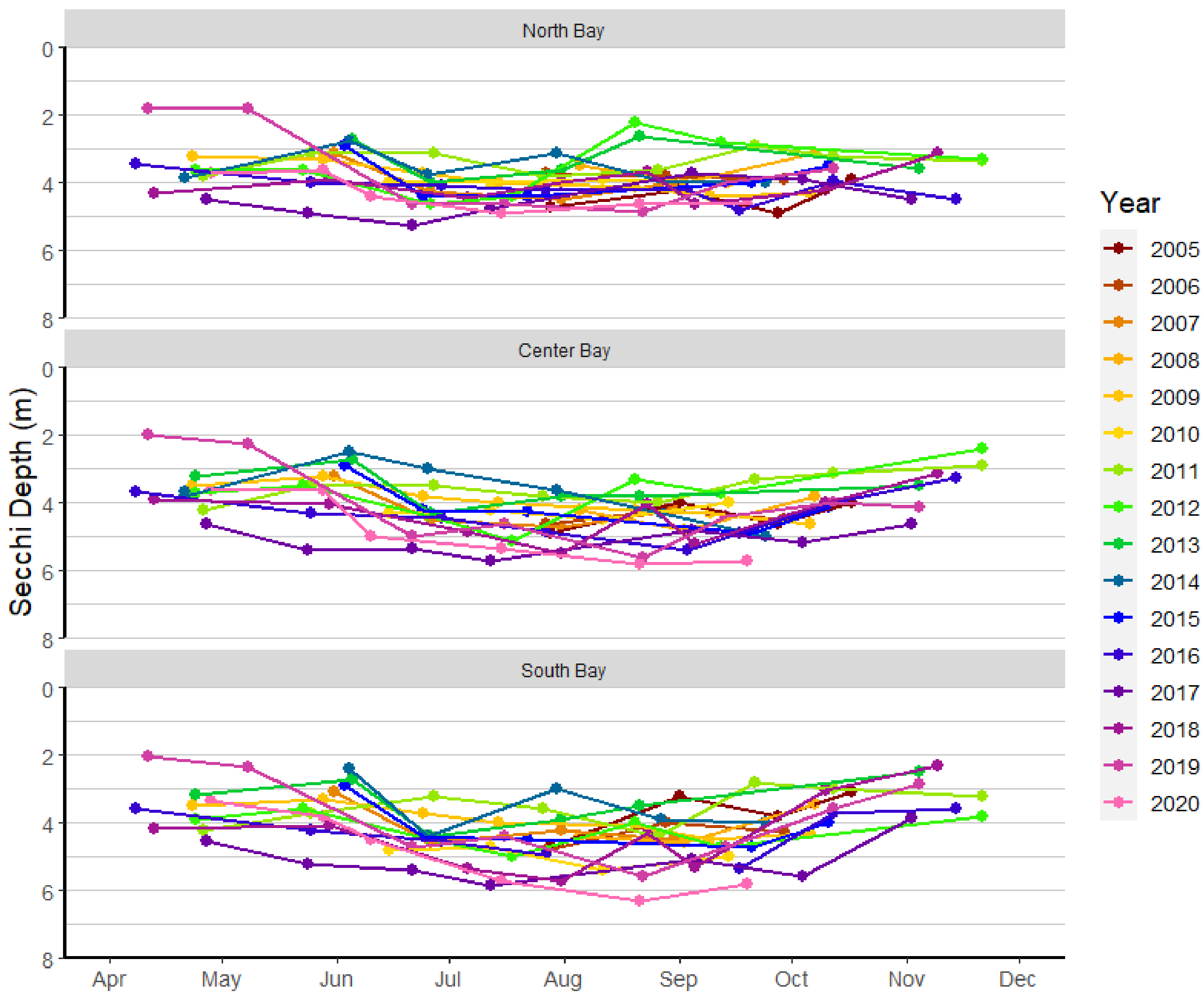


Figure 2. Seasonal Secchi disk depth measurements, 2005-2020.

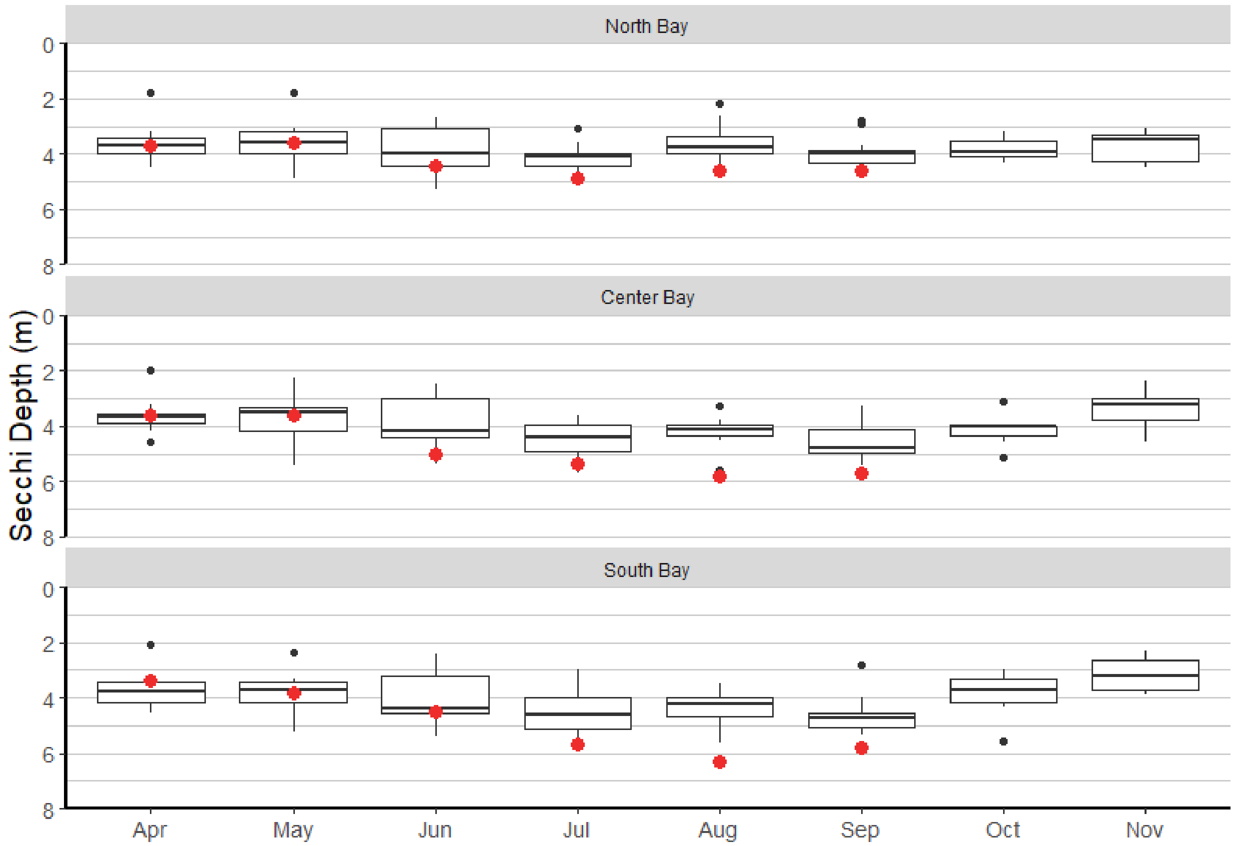


Figure 3. Long-term monthly Secchi disk depth boxplots, 2009-2019. Red dots indicate 2020 Secchi values.

Temperature

Water temperature in lakes and ponds in the northeast follows a seasonal pattern of warming and cooling. As the sun's rays penetrate the water column during the summer, the water warms; but the depth extent of this warming is dependent on the water's clarity. Clearer water allows for more sunlight penetration and deeper water column warming.

Water temperature governs the distribution of nearly everything in a lake. Water movement in lakes occurs due to the uneven distribution of heat in the water column, which is caused by wind and heat energy only being available at the top of the water column. Lakes shift from a turbulently mixed water column in the spring to a thermally stratified but stable water column in the summer. The stratification of the water column is recognized by the development of a thermocline, where there is a steep gradient in water temperature within a one-meter layer of water. The water column returns to a turbulently mixed state in the fall. This process of seasonally shifting thermal patterns affects the distribution of all the water quality constituents discussed in this report.

Water temperature is also an important component of fish habitat. If the water temperature in the upper layer of a thermally stratified lake is too warm during the summer, and this is coupled with a lack of oxygen in the deeper waters, then fish habitat is poor.

Highland Lake was fully mixed in April 2020, with a constant temperature throughout the water column (**Figure 4**). By late May, the lake had become stratified, and remained stratified through September at the two deeper stations (Center Bay and South Bay). North Bay, the shallowest of the three stations, was returning to a mixed state during the September sampling.

The raw profile data from volunteers frequently had deep-water measurements taken in the bottom mud, which is why there appeared to be a slight increase in bottom temperature on certain dates. These measurements were removed from the figures due to inaccuracy. The remainder of the water column data appears accurate.

Relative Thermal Resistance to Mixing (RTRM)

The amount of energy required to mix water of different temperatures is expressed as the Relative Thermal Resistance to Mixing, or RTRM. RTRM is a calculated parameter that helps quantify the intensity of thermal stratification, which is related to nutrient cycling, water clarity, algae, and other parameters. RTRM values are unit-less ratios that describe the difference in water density between each meter, and thus, quantifies how the lake is or is not mixing with respect to layers of water at specific depths. Higher RTRM values indicate stronger thermal stratification. RTRM measurements are important for predicting cyanobacteria blooms because cyanobacteria thrive during periods with very high RTRM.

Figure 5 depicts the RTRM values in the three bays over the 2020 season. The longest bars depict the strongest resistance to mixing between two layers of water. The highest RTRM values occurred in July at 6m in North Bay, and at 7m in August in Center Bay and South Bay. The lack of horizontal bars in April depicts the fully mixed state the lake was in during this month.

Over at least the past 10 years, this cycle of stratification and mixing within the lake has remained relatively consistent (**Figure 6**). The resistance to mixing between layers within the water column increases gradually in the early summer, until typically experiencing the greatest stratification (greatest resistance to mixing) in July. Between August and September, the resistance to mixing lessens, until the lake returns to a fully mixed state by November.

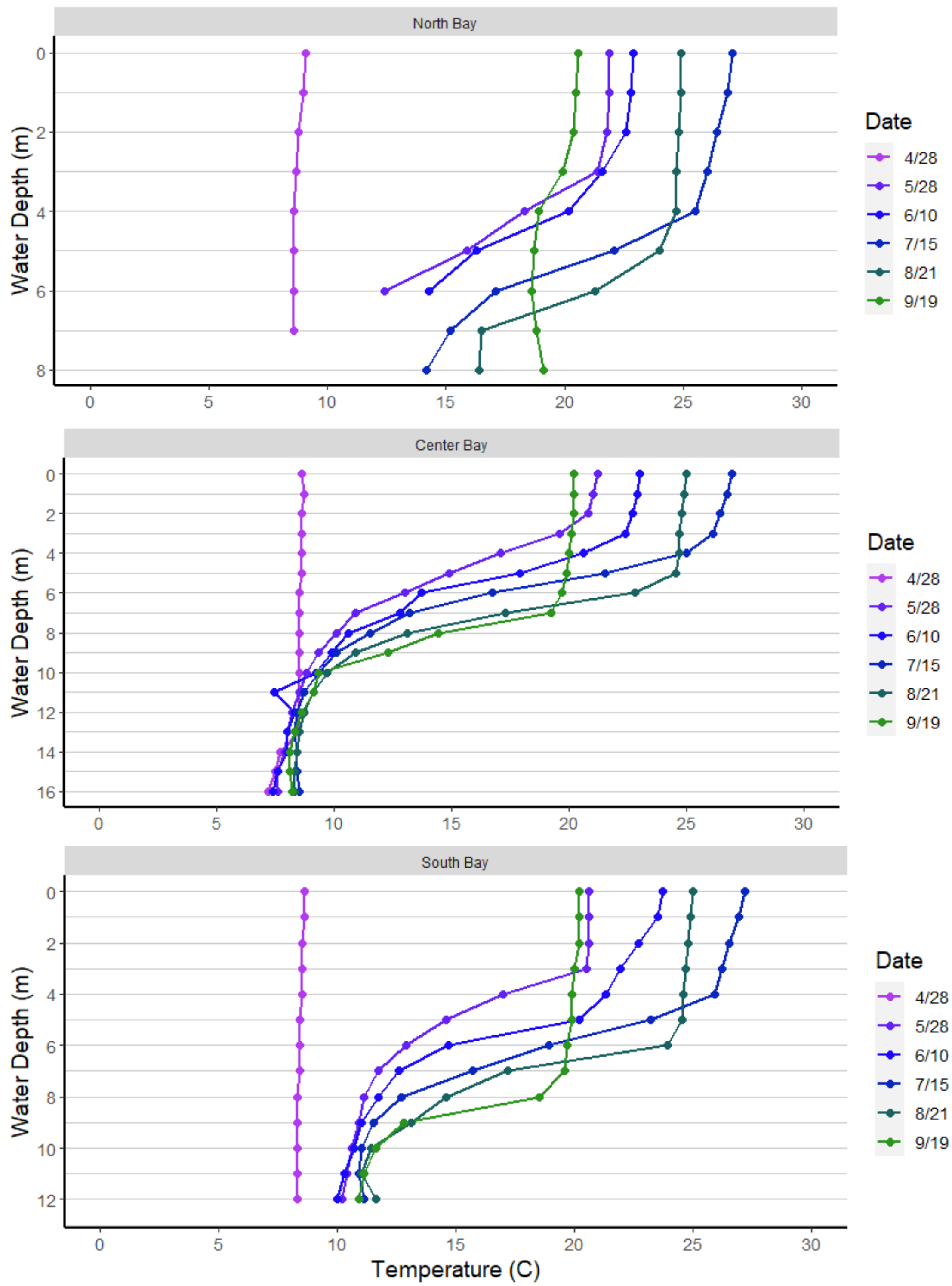


Figure 4. Water temperature profiles at North, Center and South Bays, 2020.

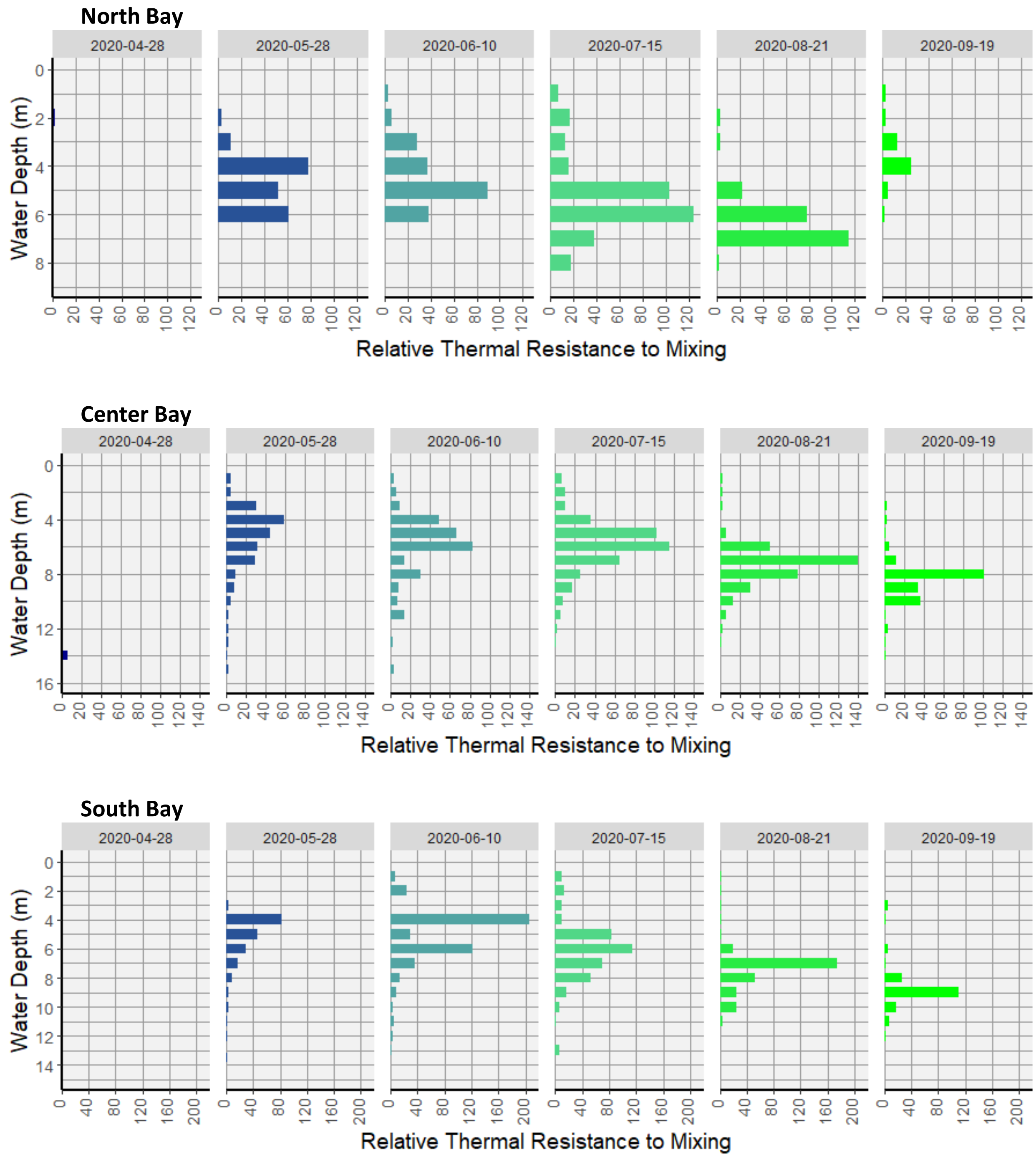


Figure 5. Relative Thermal Resistance to Mixing (RTRM) in North, Center, and South Bays in 2020. Note variations in the x- and y-axes between stations.

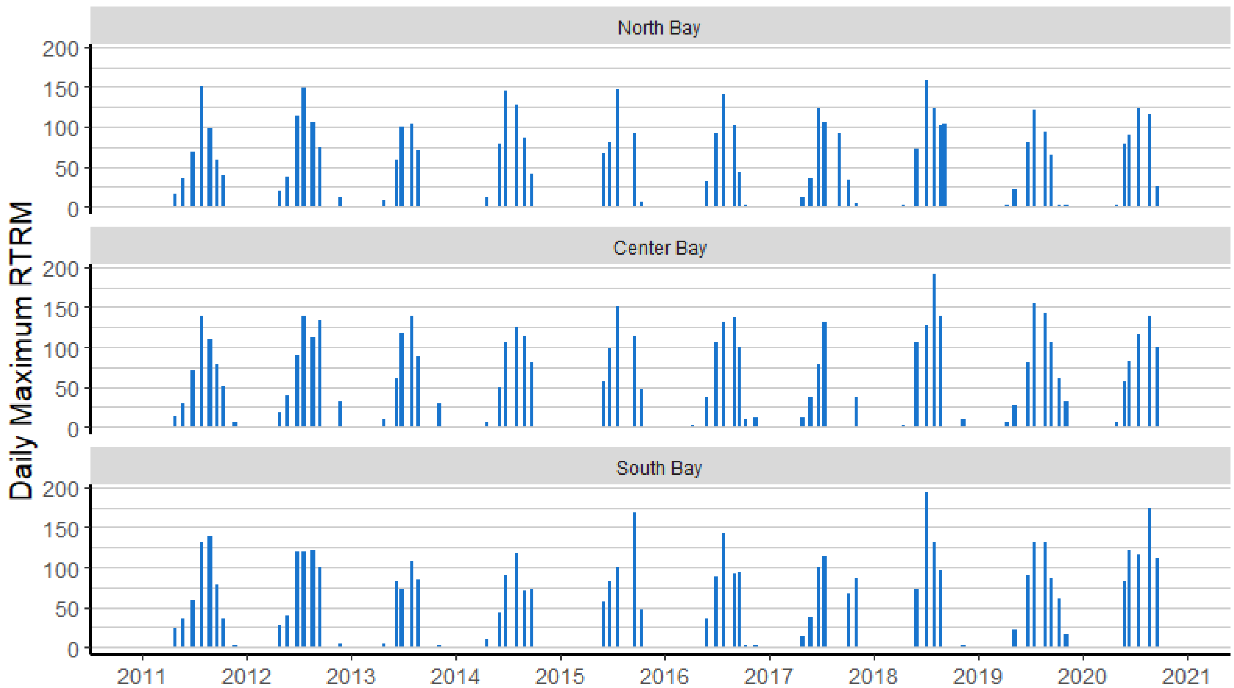


Figure 6. Daily maximum RTRM, 2011-2020.

Dissolved Oxygen

Dissolved oxygen (DO) in lake water is essential to aquatic organisms. At the surface of the lake, the water is in contact with the air, and atmospheric oxygen is dissolved into the water through diffusion and wind mixing. As the lake water is mixed, dissolved oxygen is circulated throughout the water column. The decomposition of rooted aquatic plants and algae by bacteria requires dissolved oxygen (Biological Oxygen Demand) and can deplete the oxygen levels in the bottom waters below the thermocline. This phenomenon can lead to anoxic (<1 mg/L of DO) conditions in the deeper waters. Water that is anoxic (devoid of oxygen) is not suitable for fish and other aerobic aquatic organisms. When the water at the bottom of a lake is anoxic, nutrients trapped in the sediment at the lake bottom are released into the water through the process of internal loading.

In Highland Lake in April 2020, oxygen was just slightly reduced in the bottom water in North Bay and South Bay (**Figure 7**). At Center Bay, dissolved oxygen was reduced below 13 meters. Oxygen in the bottom water became further depleted in the following months. Center Bay is the deepest of the three stations and became anoxic first, in early June. The bottom water in North Bay and South Bay was anoxic by mid-July.

The anoxic water in the lake expanded in volume over the 2020 summer months, pushing the anoxic boundary higher up in the water column (**Figure 8**). In September, the anoxic boundary reached maximum seasonal heights of 4 meters above the bottom at North Bay, 5 meters above the bottom at South Bay and 6 meters above the bottom at Center Bay. Historically, the anoxic boundary typically reaches a maximum height in August or September.

The height of the anoxic boundary each month has remained fairly consistent over the past 16 years. The dissolved oxygen profile that was recorded at Center Bay in 1938, however, does show a notably lower October anoxic boundary compared to recent years and suggests that the lake oxygen demand has increased over time. The anoxic boundary recorded in September 1970 was higher in the water column than the 1938 depth, but still lower than any boundaries recorded during that month in recent years. This suggests that the amount of anoxic water in the lake during the summer months has increased over the past ~80 years. For reference, the Highland Lake wastewater sewers conversion occurred circa 1992.

Data from recent years suggests that the bottom water at North Bay and South Bay re-oxygenates by October or November. Center Bay often contains anoxic bottom water through the last sampling trip of the year, which is typically in November. Oxygen likely returns to the bottom water of Center Bay before the lake freezes over. Oxygen is present in the bottom water each April, though it is typically undersaturated.

On certain dates, Highland Lake experiences a Metalimnetic oxygen maximum (termed ‘MOMax’), where the water is super saturated relative to water temperature, and/or a Metalimnetic oxygen minimum (termed ‘MOMin’), where the water is under saturated relative to water temperature. Oxygen saturation values that are over 100% saturation may indicate increased quantities of phytoplankton (and thereby oxygen release) at that depth. The occurrence of a MOMin is typically related to water density and/or zooplankton presence.

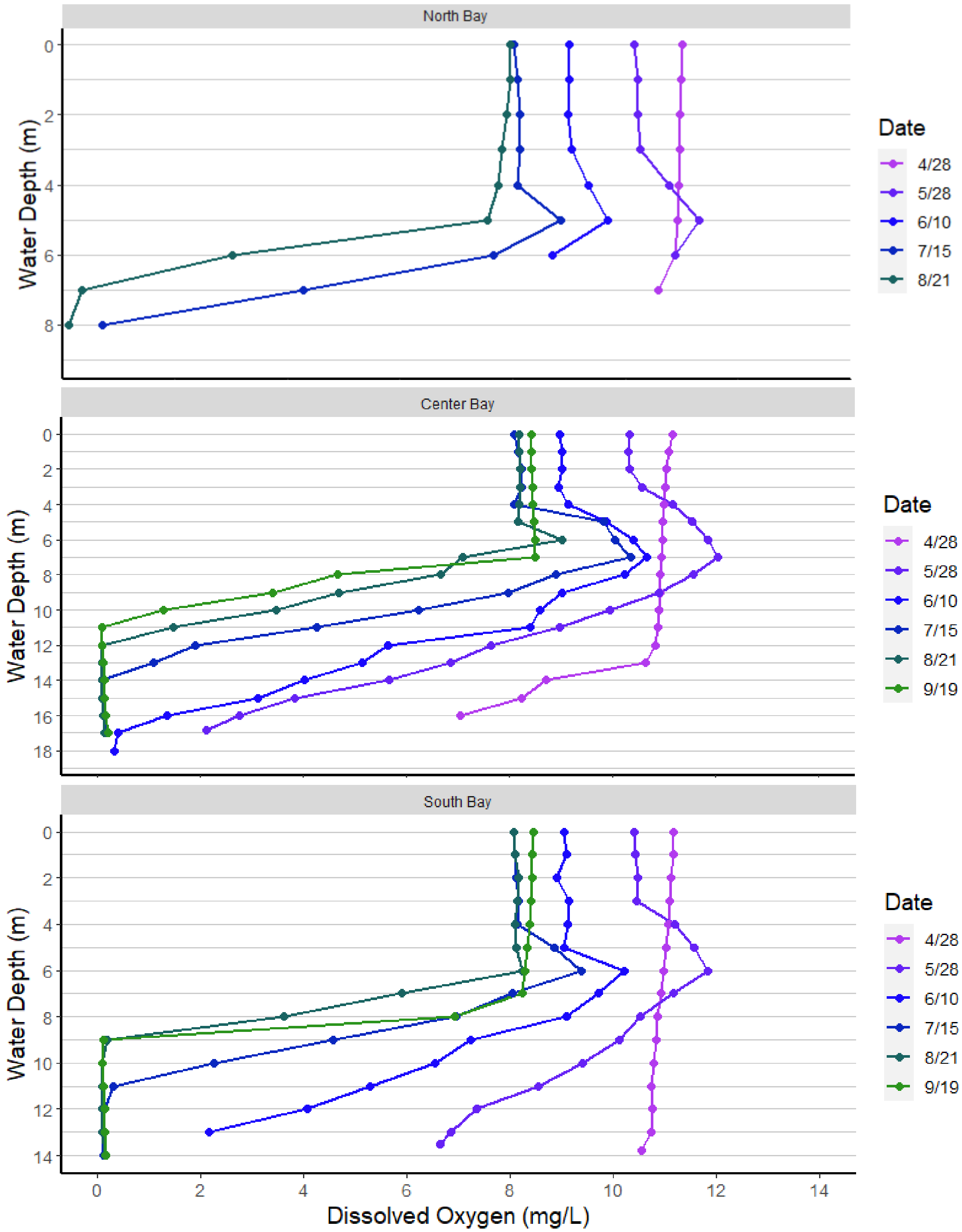


Figure 7. Dissolved oxygen profiles in North, Center, and South Bays, 2020.

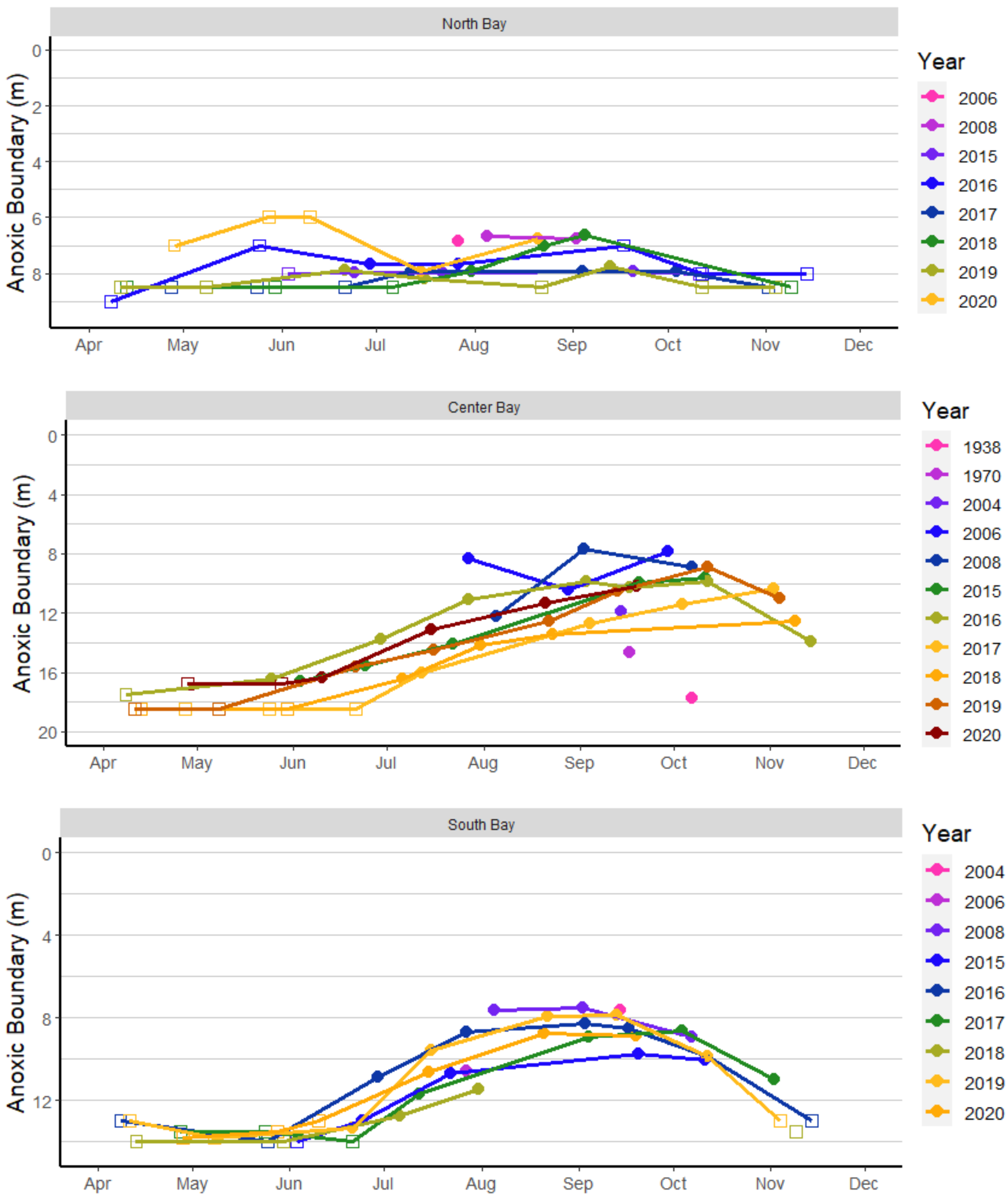
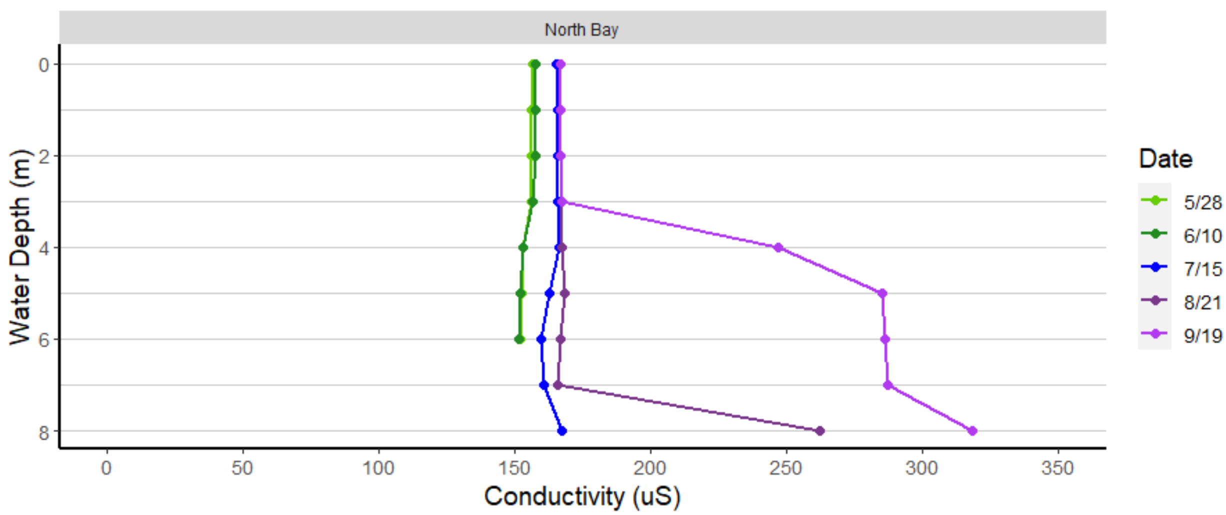


Figure 8. Anoxic boundary depths in North, Center, and South Bays, 2015 - 2020. Squares indicate absence of anoxic water. Circles indicate presence of anoxic water.

Conductivity

Conductivity is the measure of the total ionic strength of all the cations and anions in the water. The conductivity of lake water is the measure of the ability of water to carry an electric charge. Higher conductivity readings indicate a greater concentration of cations and anions in the lake water and are indications for salt addition and nutrient loading.

In 2020, conductivity ranged from approximately 150-325uS at North Bay and approximately 150-225uS at Center Bay and South Bay (**Figure 9**). Conductivity tends to increase near the lake bottom, particularly after the bottom water becomes anoxic, due to the release of ions from the sediments. North Bay had particularly elevated conductivity in September, which is interesting because the other two basins tend to have more prominent internal nutrient loading and anoxia. Over time, North Bay is expected to be more heavily impacted by road salts than the other two bays, simply because of the density of development around North Bay compared to Center and South Bays. Stormwater, wastewater, and anoxic water can all increase conductivity in a lake.



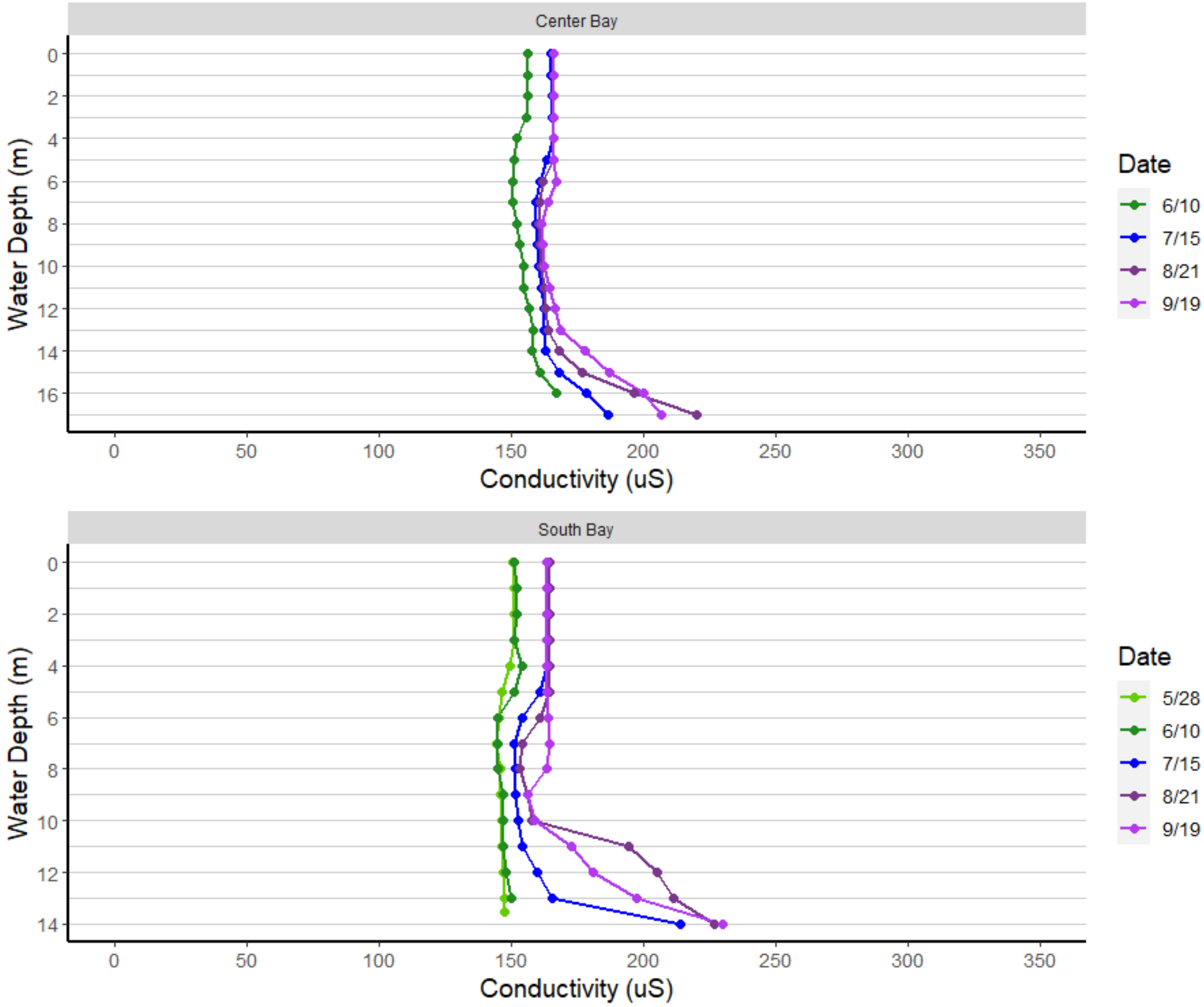


Figure 9. Conductivity profiles in North, Center, and South Bays, 2020.

Nutrients

Total phosphorus (TP) and total nitrogen (TN) are the two key nutrients that drive aquatic plant and algae growth in lakes. Nutrients can come from the watershed in the form of natural wetland inputs, septic leachate, farm runoff, lawn fertilizers, and sedimentation from roads or streams. In freshwater systems, phosphorus tends to be the limiting factor for algal productivity. Low phosphorus in a waterbody typically equates to lower phytoplankton abundance and greater overall Secchi clarity.

Total Phosphorus

Total phosphorus in 2020 remained below 20ppb at the top of the water column (**Figure 10**), but nutrients were significantly above the long-term mean monthly values. TP concentration in the bottom waters began to increase after thermal stratification of the water column. The highest bottom water TP concentrations are typically observed between July and September in North Bay and in September or October in South Bay. In Center Bay, bottom water TP typically reaches a maximum concentration in November because this station does not re-mix until after the last sampling event, and therefore internal loading continues through most of the fall.

Between 2005 and 2015, the average TP concentration was ~10ppb in the surface waters, and ~12ppm in the middle of the water column across all three stations. Between 2016 and 2020, TP averaged ~12ppb in the surface waters and ~13ppb in the middle of the water column across the three stations. TP in the bottom water is more variable between the three stations due to the differences in depth (**Figure 11**). Top and middle total phosphorus concentrations are also more reliable than concentrations in samples collected from the bottom water. There is an inevitable natural variation in bottom water concentration based on how far off the bottom the sample was collected. A sample that is collected slightly further from the bottom sediment could contain considerably lower TP concentrations. For that reason, all future bottom-water samples should be collected 1.0 meter off the lake bottom, as measured on any one day.

There do appear to be patterns of increasing nutrients and decreasing nutrients over certain periods of time at the top and middle of the water column. This appears to be watershed or climate related. TP concentrations in 2020 were higher at the top and middle of the water column compared to the 2005 to 2019 long-term average at all stations and in most months.

The quantity of nutrients present in a water body is determined by calculating the nutrient mass. Nutrient mass is a measure of the amount of nutrients contained within a certain volume of water. A high concentration of nutrients within a very small volume of water will have a smaller nutrient mass than a low concentration of nutrients within a very large volume of water. In Highland Lake, the majority of the phosphorus is contained in the top and middle of the water column because while the TP concentration is typically higher in the bottom water, there is a much larger volume of water in the upper approximately two thirds of the water column. Likewise, South Bay contains the largest mass of phosphorus because it is the largest of the three bays and therefore contains the largest volume of water.

Historically, water samples have been collected from the top, middle, and bottom of the water column at the three sampling stations. Three water samples per station is the minimum amount of data that can provide insight into nutrient processes within the lake, but it is not sufficient for accurately calculating the lake's nutrient mass. Mass models were attempted using historical data, but the low vertical resolution created a very high error range for the mass model and calculated values over time. Highland Lake is deep and therefore an excessive amount of interpolation is required between the three sampling depths to model nutrient mass over time. To accurately calculate the nutrient mass in Highland Lake, samples need to be collected at 2-meter increments at each station in April and September and tested for total phosphorus and total nitrogen concentration. The 2-meter increments will allow for much higher accuracy of the mass model, because much less interpolation is required. This change is suggested for future monitoring.

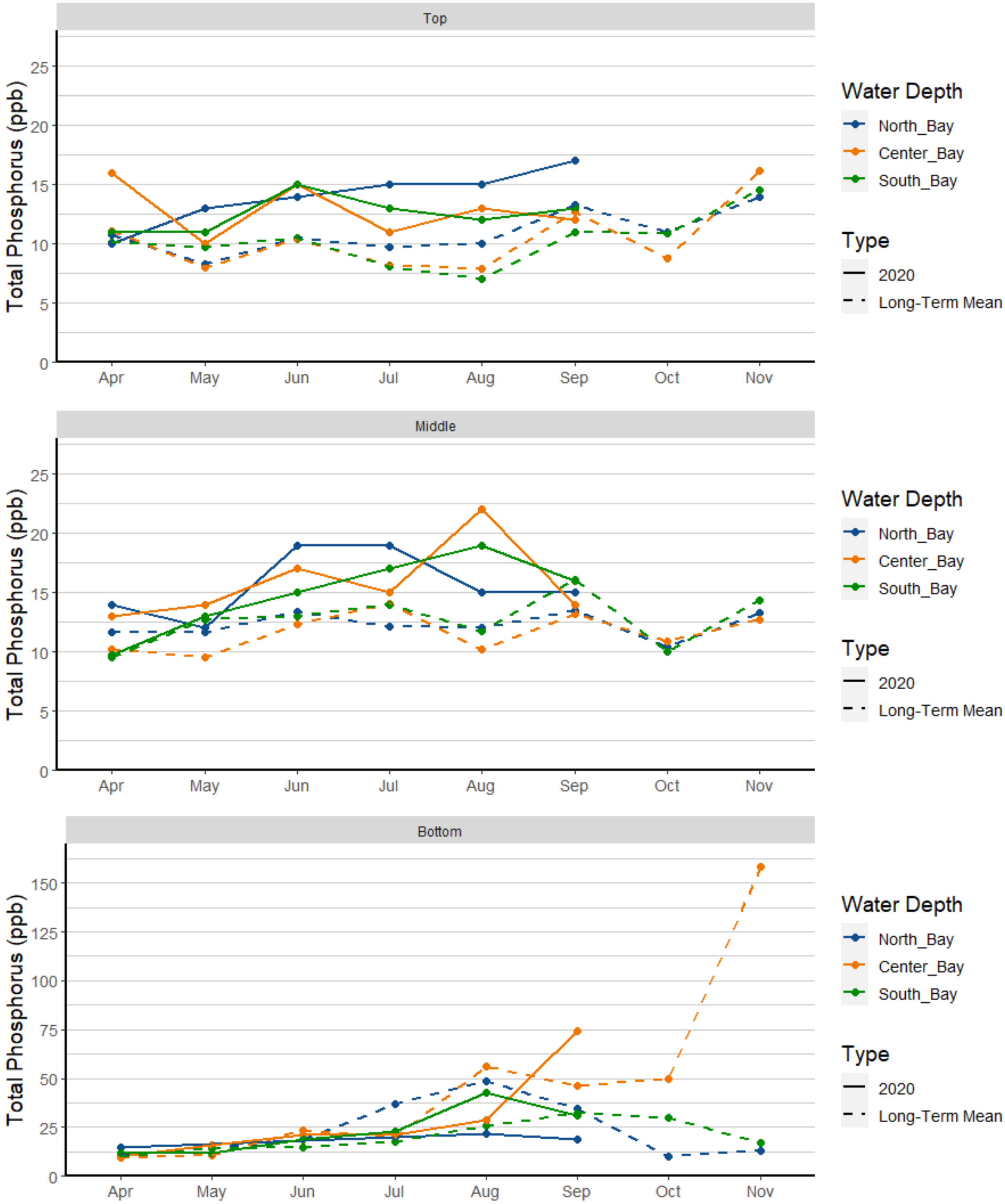


Figure 10. Long-term mean (2005-2019) and 2020 total phosphorus concentrations in North, Center and South Bays. Note variation in y-axis scales between stations.

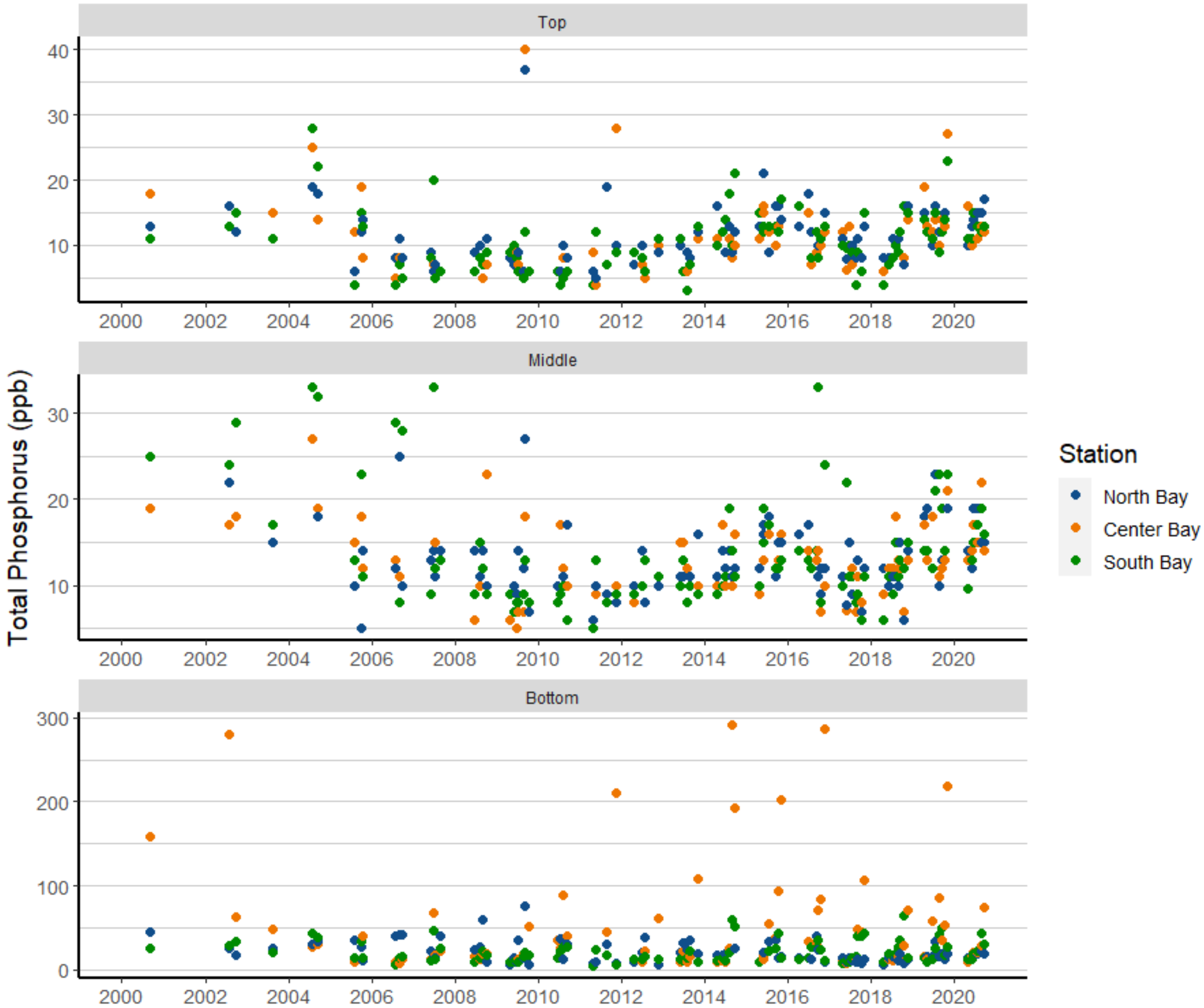


Figure 11. Total phosphorus concentrations at North, Center, and South Bays, 2000-2020. Note variation in y-axis scales between stations.

Total Nitrogen

Testing of total nitrogen (TN) in Highland Lake began in 2011, with more regular sampling beginning in 2013. Over this time period, total nitrogen at the top and middle of the water column has typically remained below 250ppb, though concentrations were more elevated in the first few years of testing (**Figure 12**). Similar to TP, TN in the bottom water reaches much higher concentrations, particularly at Center Bay, due to internal loading.

Total nitrogen in the surface water was generally lower in 2020 compared to the 2011 to 2019 long-term mean (**Figure 13**). This is opposite of surface TP concentrations. The elevated TN values in the surface water in 2012 may have been caused by a cyanobacteria bloom. During periods of high TP, TN in surface waters could be excessively high as certain types of cyanobacteria may fix atmospheric nitrogen during dense blooms. This is just one way to explain anomalous TN increases. Phosphorus does not have an atmospheric phase like nitrogen gas does. The trend of the long-term TN mean suggests that TN in the surface water is often highest in April. In 2020, this trend was observed at Center Bay. At North Bay and South Bay, TN remained relatively consistent for the duration of the season, remaining between 150ppb and 200ppb.

In the bottom water, TN was similar to or lower than the long term means at North Bay and South Bay, remaining near or below 250ppb. TN data measured in Center Bay in 2020 was below average in all months except May.

The November 2012 Center Bay bottom sample had a TN value of 2,490ppb, which skews the average for that month. TP was only 62ppb in the same sample, so the sample was most likely not contaminated. However, if this TN value is removed, the long-term mean for November is 1,082ppb.

Overall, TN concentrations in Highland Lake are relatively low and do not appear to have a distinct surface-water pattern over the years like TP showed in top and middle concentrations.

Figure 12. Total nitrogen concentrations at North, Center, and South Bays, 2011-2020. Note variation in y-axis scales.

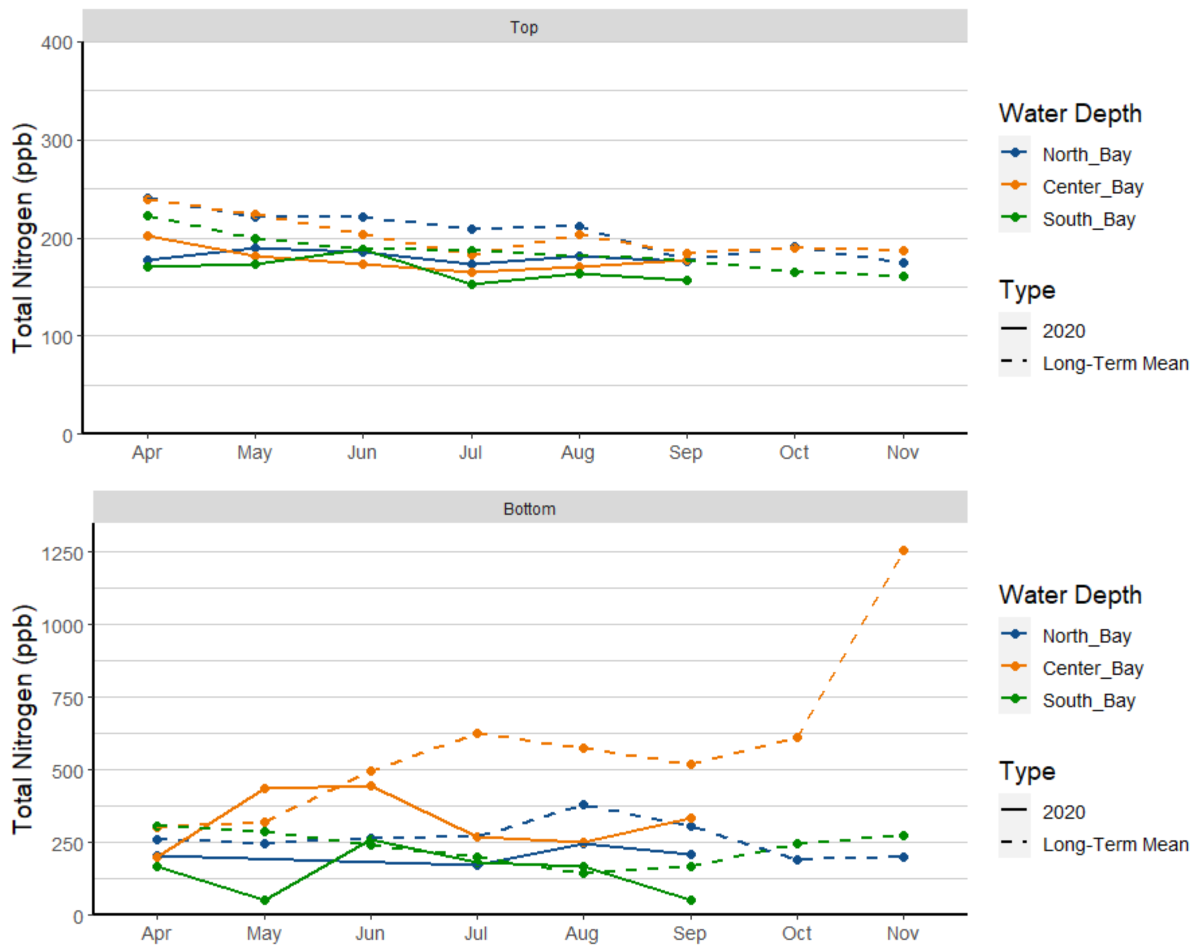


Figure 13. Long-term mean (2011-2019) and 2020 total nitrogen concentrations in North, Center and South Bays. Note difference in y-axis scales.

Ammonia

Over the past 10 years of sampling, Ammonia (NH_3) concentrations in the surface water at all three stations have generally remained in the range of 150-250ppb (**Figure 14**). This is very high for surface waters. In 2020, all top and middle water column samples, across all three stations, fell within the relatively small range of 150-200ppb. These concentrations are concerning and suggest that there is a constant source of ammonia being added to the lake. However, none of the stormwater samples collected in October 2020 contained elevated ammonia concentrations, indicating that the source of the elevated ammonia cannot be explained by stormwater alone. Additional examination and data collection within the watershed is necessary to determine the source.

Ammonia concentrations in the bottom water are more variable between the three stations. In North Bay, bottom water ammonia concentrations have remained near or below 50ppb for the past four years. In the six prior years, ammonia reached higher concentrations each season.

Bottom water ammonia in South Bay remained below 200ppb in 2020. In comparison, from 2014 through 2018, ammonia concentrations exceeded 300ppb at least once each summer.

Bottom water ammonia concentrations in Center Bay are typically much higher than in the two shallower stations. From 2011 through 2018, maximum concentrations ranged from ~800ppb to 1,200ppb in most years. Concentrations rose even higher in 2019. In 2020, ammonia never exceeded 400ppb. However, it is possible that concentrations increased after the last sampling event in September. It is important to recognize that if a water sample is collected even slightly closer to the sediments at the lake bottom than usual, the sample may contain disproportionally higher ammonia. This can cause inflated variation in ammonia concentration within the dataset and will be rectified if all bottom-water samples are taken 1.0 meter off the sediment surface on a given day.

Figure 14. 1 meter ammonia concentrations in North, Center and South Bays, 2011-2020. Note variation in y-axis scales.

Phytoplankton

The phytoplankton (algae) in a lake are a vast community of microscopic single celled photosynthetic plants and quasi-plants that form the base of the food chain. They are adapted to be in constant suspension in lake water and are dependent on water currents for movement. The typical groups of phytoplankton observed in lakes are Cyanobacteria, Diatoms, Greens, Chrysophytes, Cryptophytes, Dinoflagellates, and Euglenoids. Phytoplankton are an indicator of the nutrient concentrations in a lake because increased phosphorus usually causes a predictable increased growth of phytoplankton.

In 2020, phytoplankton samples were collected from Center Bay in April and from all three sampling stations in May and June. In April, the phytoplankton in Center Bay were dominated by cyanobacteria, mainly Planktothrix and Planktolyngbya, both of which are known toxin producers. In May and June, the phytoplankton community was composed of Chrysophytes, Diatoms, Greens and Euglenophytes.

NEAR has observed wispy cyanobacteria often present on the lake's surface near the shoreline in the early summer, usually coinciding with the period of pollen release. The surface accumulations are typically a mixture of pollen and cyanobacteria that get blown to shore. Additionally, benthic cyanobacteria have been observed at the bottom of North Bay, laying on top of and within the sediments.

The fact that cyanobacteria are known to occur in Highland means that that lake could be vulnerable to a severe bloom in the future if TP levels were high enough and weather conditions were right.

In June 2021, volunteers were trained to collect phytoplankton samples and were provided with the necessary sampling equipment. Monthly phytoplankton sample collection going forward will provide better insight into the phytoplankton population in Highland Lake.

It is important to closely monitor phytoplankton, particularly cyanobacteria, because certain cyanobacteria species can produce toxins that are harmful to humans and animals. Cyanobacteria blooms are increasing in both frequency and severity across the northeast and understanding the dynamics of cyanobacteria within Highland Lake would be helpful for understanding and predicting blooms and implementing a rapid response program when blooms arise. Continuous temperature data loggers may be able to better pinpoint partial mixing and subsequent thermal stratification events that drive cyanobacteria prevalence at Highland Lake. The newly available high-frequency data dramatically increases our understanding of seasonal and spatial change in lakes.

In general, phytoplankton are difficult to track. They can move up and down in the water column and reproduce quickly, depending on factors such as nutrient concentration, water clarity, and weather conditions. During very calm, warm weather with poor clarity, phytoplankton will move to the surface water. Conversely, heavy winds disrupt the phytoplankton, causing them to mix throughout the water column. Therefore, monthly sampling alone is not sufficient for a complete understanding of phytoplankton dynamics within the lake. The best way to understand the movement and proliferation of phytoplankton is with the deployment of several high frequency temperature loggers positioned at multiple depths along the water column. Data collected by these loggers can provide insight into the rapid movement of phytoplankton, which is often closely linked to physical limnological properties such as temperature.

Filamentous algae, a cloud-like green algae suspended in the water column, can be indicative of localized elevated nutrient concentrations. Filamentous algae are often observed near inlets that are carrying excess nutrients into the lake. Clouds of filamentous algae were observed in North Bay and Sucker Brook Cove in 2020.

If algae or cyanobacteria blooms increase in frequency or severity, a copper algaecide treatment can be administered to kill algae and cyanobacteria. This is discussed in detail in the '*In-Lake Management*' section of this report, on **page 32**. However, copper products are considered 'band-aid' treatments and there are better, albeit more expensive, options for nutrient and algae control. Options are discussed in the '*In-Lake Management*' section of this report.

Winter Drawdown

The water level in Highland Lake is lowered each winter to control the growth of invasive Eurasian milfoil and variable-leaved milfoil, to allow access to shoreline structures, and to protect shoreline structures from ice damage. In most years, the lake is lowered to approximately 40 inches below the spillway (**Table 3**, **Figure 15**). This is referred to as a 'shallow drawdown'. In select years, the lake has been lowered to 96 inches below the spillway. This is referred to as a 'deep drawdown'.

When the lake is drawn down, sediment that is typically underwater is exposed. During rain events and snow melt, water erodes exposed sediment, carrying particulate matter and nutrients into the lake. Evidence of this drawdown-related erosion was documented during the watershed investigations and stormwater sampling event. This has led to concerns that deep drawdowns, which expose more sediment and lead to more erosion, can cause reduced spring water clarity. However, an analysis of the drawdown depth relative to the spring water clarity shows that there is not a statistically significant difference in spring clarity between deep and shallow drawdown years.

Table 3. Annual maximum drawdown depths, 2000 – 2020.

Beginning Winter Year	Deep/Shallow	Maximum Drawdown	Records Available
2000	Shallow	41	Full
2001	Deep	96	Partial (January 1 on)
2002	Shallow	40	Partial (January 1 on)
2003	Deep	96	Full
2004	Shallow	45	Full
2005	Shallow	42	Full
2006	Deep	96	Full
2007	Shallow	42	Full
2008	Shallow	45	Full
2009	Deep	96	Full
2010	In-between	64	Full
2011	Shallow	43	Full
2012	Shallow	42	Full
2013	Shallow	52	Full
2014	Deep	96	Full
2015	Shallow	40	Partial (missing January)
2016	Shallow	40	Full
2017	Shallow	42	Full
2018	Shallow	40	Full
2019	Shallow	41	Full
2020	Deep	89	Partial (ends 12/31/2020)

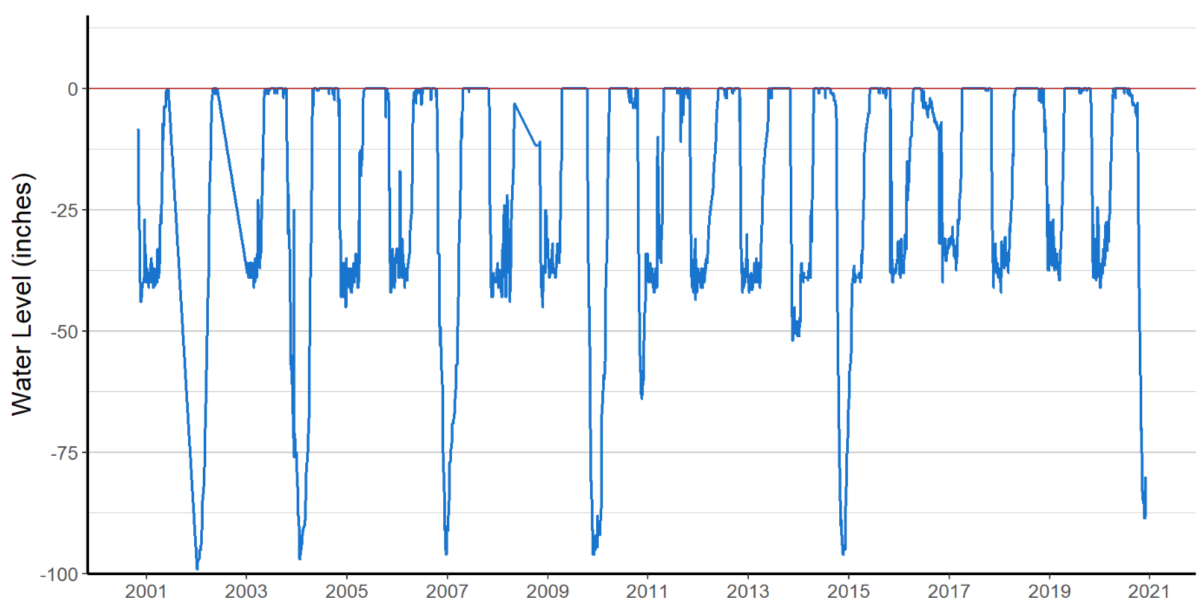


Figure 15. Winter drawdown water level data, 2000-2020.

In-lake Management

While watershed management is critical to long-term water quality and lake health, in-lake management may become necessary in the future. The following are some of the commonly utilized in-lake management techniques for reducing nutrient concentrations and/or algae. These management techniques are not recommended for Highland Lake at this time. This information is simply meant to provide a general understanding of methods that may be utilized in the future, if the need arises. It is our professional perspective that certain techniques are considerably better than others, especially for large lakes like Highland.

Circulation Aeration

These systems circulate water within the lake, typically bringing anoxic bottom water to the surface to re-oxygenate it by exposing the water to the atmosphere. The purpose is to reduce or eliminate anoxic bottom water, thereby reducing internal loading of nutrients. However, anoxic release of nutrients is not the only method of sediment nutrient release. Some forms of nutrients can also be released during oxygenated conditions, so it is very important to understand the amount and various forms of nutrients in your sediments. Circulation systems use a series of compressed air hoses and diffuser plates, placed along the bottom sediments. A large shoreline air compressor station is required. The compressed air creates an upwards bubble stream that causes the surrounding water to move upwards, creating an artificial upwelling current in the water near the diffuser plate. Multiple diffusers and upwelling currents are required to mix even small lakes. Circulation systems work best in shallow ponds and lakes, where thermal stratification is not as intense. Circulation systems generally do not work as well in deeper water and large surface area lakes, such as Highland Lake. In cases where circulation systems have been undersized, they can worsen cyanobacteria blooms by continuously supplying bottom nutrients to the surface[2].

Non-Circulating Aeration and Oxygenation

Aeration and oxygenation have been used for more than 50 years in reservoirs and there are many types of available technologies. Compared to circulation aeration, these systems tend to be better at limiting internal nutrient loading by eliminating anoxic bottom water, but non-circulation systems tend to be more expensive and complex than simple circulation aeration systems. Instead of relying on atmospheric oxygen replenishment, non-circulation systems directly resupply either air or 100% oxygen to anoxic bottom waters and are capable of preventing iron-bound phosphorus release from deep lake sediments without disturbing the natural thermal stratification of a large lake (no artificial mixing). These systems

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[2] Wagner, Kenneth J. *Oxygenation and Circulation to Aid Water Supply Reservoir Management*. Water Research Foundation, 2015.

are more effective in reducing overall nutrient concentrations in lakes than circulation systems because they do not dramatically increase bottom-water temperatures.

Both circulation and non-circulation aeration/oxygenation systems require constant electricity and maintenance. When the systems are shut down, they are no longer able to reduce internal loading. There are no known cases where any type of circulation, aeration, or oxygenation system can be used for a period of time and then “restore” long term water quality after the system is switched off.

Aluminum-based Phosphate Binders

Aluminum sulfate (Alum) is the most common liquid-phase phosphorus binder used in lake management. Alum technologies emerged from use in the water treatment process, where it is used to remove phosphorus and other impurities from water. Alum has been used in lake management to bind phosphorus both in the water column and in sediments, as an internal phosphorus loading treatment. Unlike iron, aluminum hydroxides are not subject to reductive dissolution of phosphate, meaning that a successful Alum treatment can bind phosphorus in the lake sediments even during summer periods of anoxia.

When applied to surface waters, or injected to hypolimnetic waters, aluminum sulfate reacts with water to form aluminum hydroxide, a form that has a high affinity to binding available phosphate and a form of Al that is not bioavailable or harmful to organisms. The aluminum hydroxide “floc” is whiteish in appearance and frequently makes a lake temporarily appear bright blue. Because the reaction releases hydrogen ions, the reaction of Alum in water can dramatically low the water pH, which can be dangerous for fish and other organisms. For that reason, it is imperative to stabilize the lake water pH by using a buffering agent during the treatment, most commonly sodium aluminate. Sometimes poly-aluminum chloride (PAC) is used instead of aluminum sulfate, partly to prevent the addition of sulfate into a lake.

Solid Phosphorus Binders

There are many different types of solid-phase phosphorus binders that use calcium, iron, magnesium, silica, aluminum, or lanthanum. The most effective phosphorus binder on the market is Phoslock, manufactured by SePro. It is a lanthanum-modified bentonite clay, which is applied to waters either as a powder slurry or in small granular form. It can be applied at different dosages for either short-term or long-term control. Higher dosages have the capacity to bind more phosphorus, either in the water column or in the lake sediments. Phoslock is typically applied at a rate of 100:1, Phoslock to free-reactive phosphate that needs to be bound. The stable mineral that is formed is called Rhabdophane, which is not redox sensitive and will form in oxygenated and anaerobic environments. Phoslock also has the added benefit of being effective at a wide range of pH levels and does not have a reaction that dramatically reduces water pH, like alum does. Therefore, Phoslock is considered very safe for aquatic organisms and is much easier to apply than alum, which requires careful additions of buffer agent to maintain a stable pH.

If applied to the water column, Phoslock does similarly act as a flocculation agent, where it will pull phosphate and tiny particulates from the water column and settle out to the bottom, in a form where it cannot be recycled annually. Phoslock also is more stable over time and potentially more effective than alum in its ability to continually bind phosphate. If the Highland Lake Watershed Association were to try any phosphorus-reducing treatments, Phoslock would be a good product to start with, particularly in small coves and in the entire north bay basin. SePro, the manufacturer, also claims that the product can be used to prevent cyanobacteria blooms by covering akinetes in the sediment prior to germination and preventing high-nutrient conditions that cause the cells to germinate. No large-scale Phoslock treatments have been performed in CT, so it is expected that CT DEEP would require a Temporary Authorization permit for a Highland Lake treatment.

Algaecides

Copper algaecide products directly kill algae and cyanobacteria. The CT DEEP tracks algaecide usage in lakes and ponds, and a permit is required for use. Copper products may only be applied by a CT licensed herbicide applicator and the dosage is strictly regulated. Copper products, depending on the dosage, can have adverse toxicity impacts on insects, zooplankton, and small fish, which is why it is applied in very low amounts so as to only target algae cells. Copper does accumulate in lake sediments over time after years of continued use, so we do not recommend frequent use of copper algaecides. It is, however, a good choice for short term cyanobacteria control to prevent beach closures and can be used in addition to other products.

Peroxide-based algaecides also directly kill phytoplankton like cyanobacteria. These products tend to be more expensive than copper algaecide and have similar, but slightly less effect on algae. Both types of algaecides do not guarantee successful seasonal control of cyanobacteria blooms. Depending on nutrient concentrations in the water column, algaecides can generally offer just 2-3 weeks of control before algae are able to repopulate. Algaecides do not control nutrient concentrations.

Microbial Additives

This section on microbial additives is included because it is becoming more common for applicator companies to offer “biological” treatments for lakes. There is some early research that indicates that certain types of naturally occurring soil bacteria are capable of cyanobacteria cell lysis. Therefore, many pond applicator contractors will add in a microbe treatment after an herbicide or algaecide treatment. There are not very many well-researched case studies on the efficacy of microbial products used as algaecides, and unfortunately many applicators use products that were not intended for lake use but were instead manufactured for soil additions in gardens and agricultural practices. These products are currently not marketed as “bio-pesticides” because they can then escape federal pesticide regulations. State environmental departments usually don’t have a good method for preventing usage of these microbes in the environment, simply because they are not federally regulated. Some states have come up with their own regulations for case-by-case lake uses. However, these products are widely used in small pond management all over the country, despite the lack of scientific case studies to support applicator and manufacturer claims.

Certain microbial additives are marketed and used as “muck-reducing” agents. The claim is that by adding additional soil bacteria and enzymes to the sediments, the aerobic bacteria will be able to increase the rate of decomposition of organic matter in the sediments, thus consolidating mucky sediments over time. However, there are no good scientific case studies documenting this effectiveness. Similarly, if adding high quantities of soil microbes to lake sediments actually can increase the rate of organic matter breakdown, that would subsequently increase the rate of aerobic “internal loading.” Microbes do not store nutrients indefinitely like stable minerals can. Instead, bacteria recycle nutrients, which will be released into the water after the cells die to then be used by other, potentially algae, cells.

Highland Lake Watershed

The Highland Lake watershed spans approximately 4,550 acres, consisting mainly of developed impervious land, developed open space, forests, and wetlands (**Figure 16**). Previous watershed size estimates have been 4,481 acres, but actual acreage depends on the diversion of water from roadways and underground culverts. The majority of the land immediately surrounding Highland Lake is heavily developed, with a large quantity of impervious surface, along with numerous dirt roads and driveways. There are very few areas where the immediate shoreline is forested/undeveloped.

In a natural, undeveloped landscape, rainwater is mostly absorbed and filtered by native vegetation and natural soils. However, when rainwater falls onto impervious surfaces such as paved roads, parking lots, and houses, the rain cannot sink into these materials and instead “runs off”. This runoff then flows downhill into an area where the water is either able to infiltrate into the ground, or to where it meets a roadway storm drain and is then carried through an underground culvert system.

In the Highland Lake watershed, most runoff flows into storm drains and then into culverts and pipes that output directly into Highland Lake. This runoff is the primary source of high-nutrient concentrations to the lake.

NEAR conducted stormwater sampling in the Highland Lake watershed during a rain event on October 29th, 2020. During this event, approximately 1/4” of rain fell during the four-hour time period in which the sampling was taking place. Approximately 1/4” of rain had also fallen in each of the prior two days, meaning that this stormwater sampling did not collect “first flush” samples, which are samples collected at the very beginning of a heavy rain event. It is good to collect first flush samples because a large amount of sediment and nutrients are washed off roadways and other impervious surfaces at the beginning of a rainstorm. However, first flush samples are difficult to collect due to the challenges with predicting the timing and magnitude of rainfall. Though the samples collected during the October 29th rainfall were not first flush, they still provide valuable data. It is a good rule of thumb to attempt to collect samples from a number of storms and note the range in concentrations. First flush samples usually have the highest concentrations.

During the rain event, twenty-four water samples were collected from inlets to the lake, including pipes, streams, culverts, and overland flow (**Figure 17**). Most samples were tested for concentrations of total phosphorus, total nitrogen, nitrate nitrogen, and ammonia. A few samples, from sites with a small volume of flow or of lesser concern for another reason, were tested for concentrations of only total phosphorus and total nitrogen (**Table 4**).

Stormwater nutrient concentrations are expected to be higher than baseflow concentrations. Stormwater with TP over 200ppb and/or TN over 600ppb is generally considered elevated, especially for non-first-flush samples. However, the level to which a particular stormwater source affects the lake is based on both the concentration and the water volume. Stormwater with a TN concentration over 1,000pbb can be an indicator of fertilizer or nearby wastewater contaminations.

Streams (as opposed to overland road runoff) should ideally remain below 50ppb, even during large rain events. Streams with TP concentrations over 50ppb during a rain event are a concern because it means they are being impacted severely by the overland runoff.

Possible 'hot-spots' identified in this first round of stormwater sampling were locations 1, 10, 17, 23, 24, and 25. But we recommend at least three more stormwater sampling events in 2022-2023 to verify and resample all areas. More samples will allow for verification of the accuracy of runoff estimates produced by a land-use based watershed loading model. The stormwater data will also identify abnormally high runoff areas that occur because of erosion events or excessive local fertilizer usages, which land-use based models cannot recognize. That is why we recommend both stormwater sampling and the use of a land-use based watershed loading model, in tandem.

Filamentous green algae that is present in patches in the water along the lake's shoreline can be indicative of elevated nutrient concentrations entering the lake via a nearby inlet. During the June 2020 aquatic plant survey, filamentous algae was observed in Sucker Brook Cove and in several locations in North Bay (**Figure 18**). These areas should be inspected for inlets that may be carrying elevated nutrient concentrations into the lake.

NEAR conducted a watershed investigation on January 21st, 2021, which involved inspecting the roads surrounding the lake and making note of areas in need of improvement. Special attention was paid to catch basins, parking areas, dirt roads and driveways, trench drains, signs of erosion, and areas with potential for the installation of vegetated patches. Photos, notes, and site-specific recommendations from this investigation are included in Appendix A. This initial watershed investigation will lay the foundation for a future EPA-format Nine Element Watershed Based Plan for Highland Lake. This type of a plan can be developed with CT DEEP involvement and oversight and would guide the Town through long-term land-use planning and ecologically sound maintenance practices, including potential private-public partnerships.

The quantity of nutrients entering the lake can be reduced through site-specific improvements such as:

- Install sediment and phosphorus filters in catch basins and culverts to filter out nutrients before the water enters the lake.
- Construct trench drains to disconnect driveways from town roads and catch basins. This is particularly important for dirt roads, where runoff picks up a significant amount of nutrients.
- Add permeable paving material to dirt roads and driveways.
- Divert water to vegetated rain gardens, buffer zones, and vegetated swales where water can infiltrate into the ground. As soil moves through the ground, the soil acts as a natural nutrient filter. Ensure that construction practices are careful to NOT compact soils.
- Regulate and rectify harmful or illicit discharge from private properties, particularly house downspouts, garden/yard drainage pipes, sump-pumps, etc.
- Educate homeowners on "lake safe" practices through efforts such as information sessions, distributing educational pamphlets, and incentive programs.

Site specific recommendations for the Highland Lake Watershed are included in Appendix A - 'Highland Lake Watershed Recommendations'.

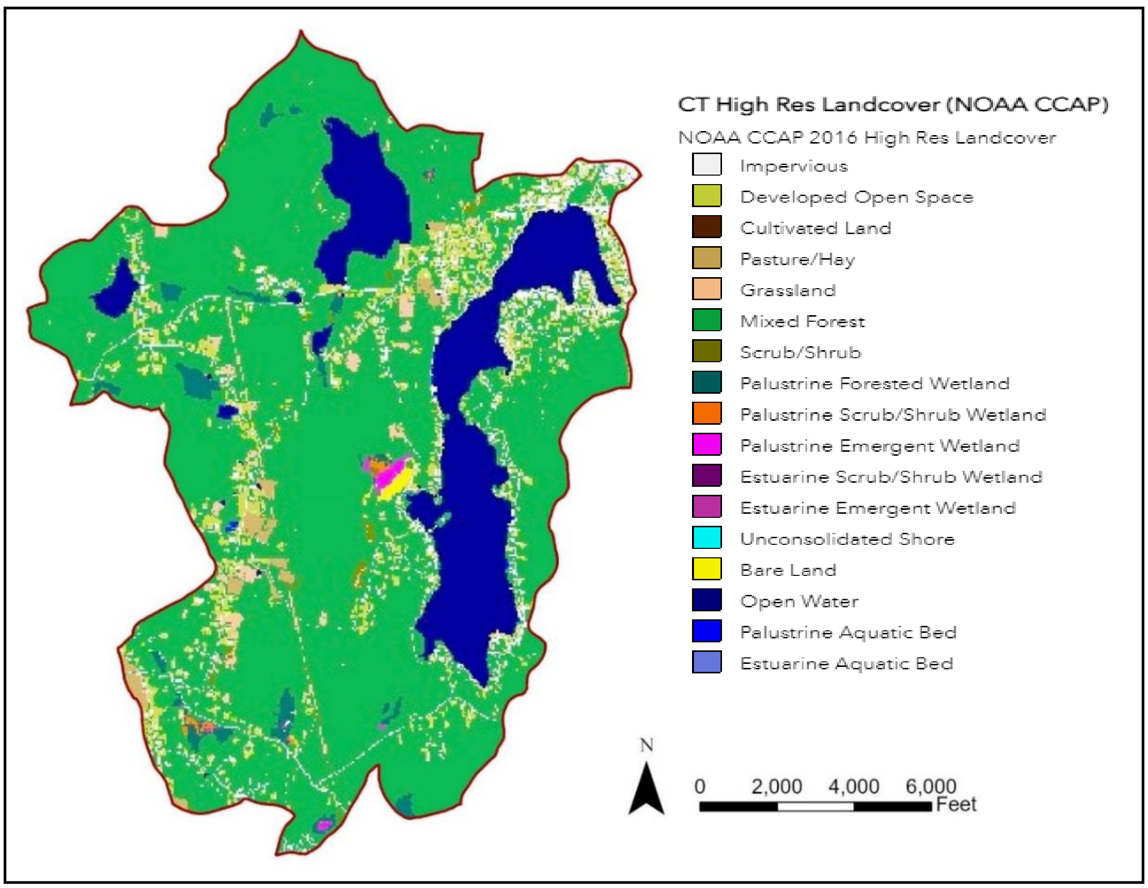

Figure 16. Highland Lake watershed land use (NOAA CCAP 2016).

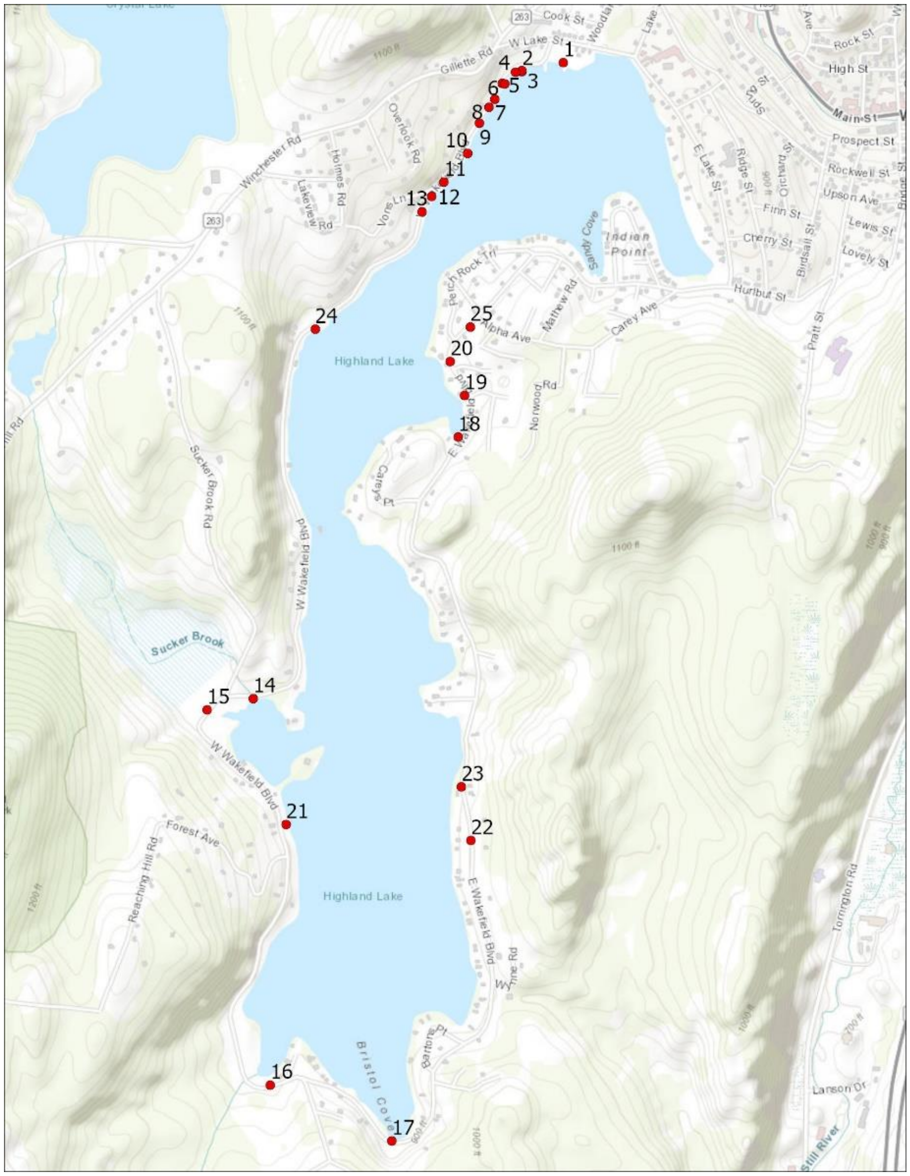

Figure 17. October 29th, 2020 stormwater sampling locations.

Table 4. October 29th, 2020 stormwater sampling nutrient results.

Waypoint	Description	NH3	NOX	TN	TP
1	Boat ramp. Light flow alongside of ramp.			131	239
2	2 black plastic pipes coming from road basin.	99	109	277	47
3	2 black plastic pipes coming from road basin.	6	56	191	89
4	White metal pipe. Source unclear.			282	52
5	Cement pipe, mostly buried in sand but some flow, plus flow from road over berm.	13	141	275	61
6	Flow from wpt 5, plus non-point source close to water line.	6	84	221	95
7	Cement pipe in berm. No flow.				
8	White metal pipe in berm. Good flow.	16	34	225	48
9	Black pipe in cement wall.			205	65
10	Pipe in wall, possible water pump in front. Heavy flow.	4	1127	1400	38
11	Cement pipe in berm. Heavy flow.	9	ND	314	162
12	Cement pipe in rocks. Road intersection.			279	156
13	Black pipe in rocks.			80	24
14	Sucker Brook.	ND	34	194	33
15	Taylor Brook.	4	17	196	56
16	Stream coming from woods. Platt Hill Stream?	4	ND	279	66
17	Culvert from storm drain. Opens onto beach.	11	444	703	170
18	Black pipe.	7	ND	167	75
19	Stream under 344 E. Wakefield Rd. Runoff from dirt road (Norcross Rd).	5	ND	428	98
20	Road runoff into culvert. Half of water coming from Demonstronti Rd.	3	ND	111	61
21	Pipe with erosion of beach. Runoff from Forest Ave.	ND	18	196	80
22	Road runoff.	8	90	465	95
23	Road runoff.	49	397	990	202
24	Big pipe, maybe drains at route 263?	40	326	725	111
25	Storm drain, lots of runoff from dirt road.	40	ND	320	524

* ND = Non-Detect (result below the detection limit of 3ppb).

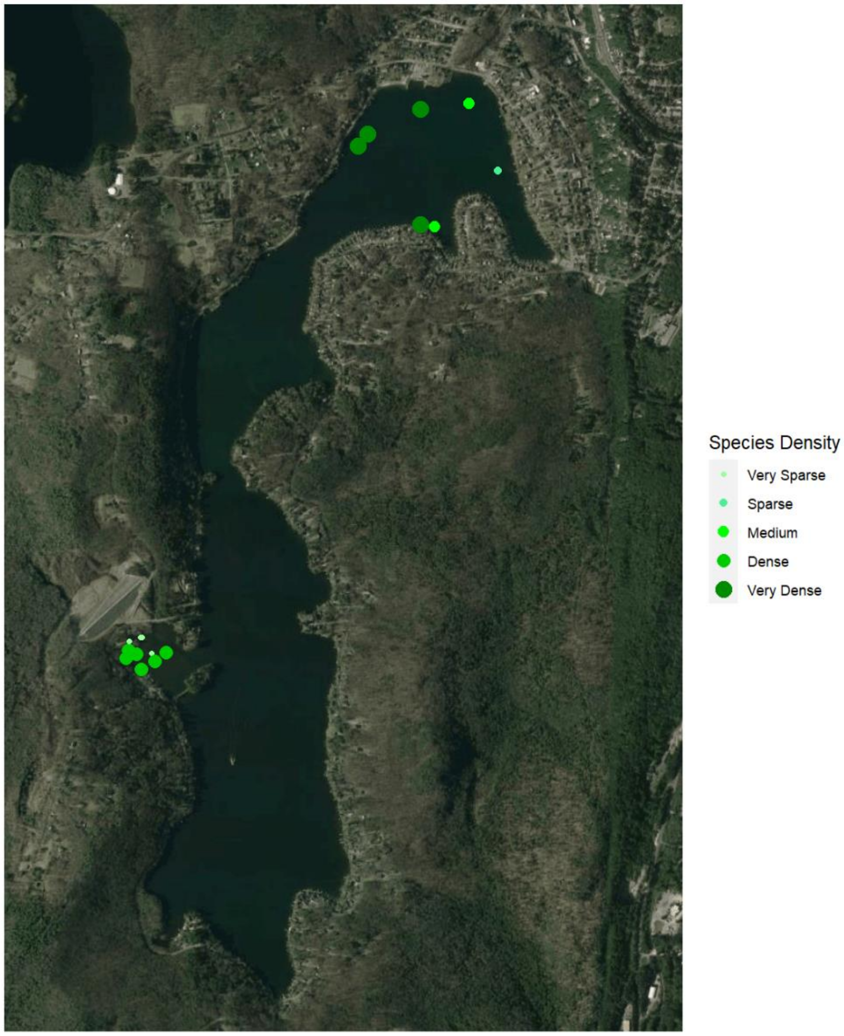

Figure 18. Locations of filamentous algae in Highland Lake, June 2020.

Conclusion and Recommendations

Based on the Connecticut DEEP lake trophic categories (**Table 1**), Highland Lake is defined as oligo-mesotrophic bordering on mesotrophic. Total phosphorus in the surface waters rarely exceeds 20ppb and the yearly average in surface waters rarely exceeds 15ppb. However, surface water TP concentrations in recent years (2016 to 2020) are, on average, ~2ppb higher than historical surface water concentrations. Total nitrogen in the surface waters has not exceeded 250ppb on record since 1979 and for the past seven years, the yearly average has remained near or below 200ppb. Water clarity in the lake typically remains better than 3 meters, with the yearly average falling between approximately 3 meters and 5 meters over the past 16 years. These data suggest that overall, the lake condition is relatively good overall.

In the absence of efforts to reduce nutrient loads, the lake condition will inevitably worsen over time at a faster rate than would occur in a natural, undeveloped landscape. The Highland Lake community has the fortunate and increasingly rare opportunity to proactively protect the lake from accelerating decline by making improvements to the watershed.

Watershed Management

Watershed improvements are the best long-term strategy for nutrient management because they reduce the quantity of nutrients that are added to the lake. Once nutrients are in the lake, they are very expensive to remove. Therefore, we recommend taking a proactive approach and focusing on nutrient reduction efforts in the Highland Lake watershed at this time, with potential for in-lake nutrient reduction efforts in the future.

We recommend the HLWA, with support from the Town, focus on the following watershed improvements. **Appendix A** includes recommendations for site-specific, actionable improvements within the watershed, in line with these recommendations:

- Install sediment and phosphorus filters in priority areas, as this is a relatively low-cost technique for nutrient reduction.
- Reduce nutrient loading from dirt roads and driveways through the following methods:
    - Install Filtrexx SiltSoxx or Siltsacks in catch basins that received flow from dirt roads and driveways. Filters need to be replaced and maintained and are best used in places where the landscape makes it very difficult to build permanent improvements, i.e. steep grades, exposed bedrock, private property, etc.
    - Construct trench drains to divert water from dirt roads and driveways into vegetated areas that can filter the nutrients.
    - Add permeable paving material to dirt roads and driveways, where possible. Gravel is the cheapest permeable paving material but is not the best option for nutrient filtration.

- Educate homeowners on how they can implement "lake safe" practices on their properties. NEAR can help create educational materials and organize and elective property inspection program. Incentive programs can help encourage homeowners to implement lake safe practices, such as installing rain barrels. A list of specific recommendations for private property nutrient reduction is included in Appendix A.
    - Educate local landscaping companies on the harms of fertilizer use at shoreline properties, including phosphorus and nitrogen fertilizers.

We recommend conducting a site inspection of priority areas with NEAR, the Town Engineer, and the Department of Public Works to discuss potential improvement projects. Following this inspection, we will be able to provide the HLWA and the Town with more specific information regarding attainable projects and general cost estimates.

Recommendations for In-lake and Watershed Monitoring

There are several improvements to water quality monitoring that can be implemented to improve understanding of Highland Lake.

- Deployment of high frequency oxygen and temperature sensors at Center Bay and South Bay to better understand phytoplankton dynamics and cyanobacteria blooms. Sensors should be placed at two depths towards the upper heights of anoxia. Specific depths should be chosen in consultation with the CT DEEP, as permits are required for logger installation.
- Collect water samples from additional depths (2-meter increments) in April and September to gather more information about how nutrient concentrations vary between depths and to provide the necessary data to accurately calculate the lake's nutrient mass.
- Collect all future bottom-water samples 1.0 meters off of the bottom of the sediment surface, as measured on the same of sampling.
- Conduct stormwater sampling during at least three more heavy rain events in 2022-2023 to gather samples from additional inlets and to determine the amount variation present within individual inlets between rain events. Additional samples will allow for verification of nutrient loading estimates produced by a land-use based watershed loading model. They will also identify abnormally high runoff areas that occur because of erosion events or excessive local fertilizer usage. Land-use based models cannot properly identify these areas.

Recommendations for In-lake Management

If the HLWA and the Town wish to pursue a phosphorus-reducing treatment in the near future, Phoslock would be a good product to start with, particularly in small coves and in North Bay. SePro, the manufacturer, also claims that the product can be used to prevent cyanobacteria blooms. CT DEEP would likely require a Temporary Authorization permit for a Phoslock treatment in Highland Lake. Depending on the size of the treatment and dosage used, there will be varied levels of observable change. Any treatments require careful planning and documentation of effectiveness relative to the dosage and method of treatment employed. Watershed development pressures will continue to increase over time, and in the face of future development concerns, it is possible that periodic smaller Phoslock treatments could prevent long-term water quality decline over the next fifty years.

Thank you for the opportunity to serve the Highland Lake Watershed Association.

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