WATER QUALITY ANALYSIS | MEMORANDUM

TO: Town of Kingston, Kingston Lake Association, YMCA Camp Lincoln
FROM: Laura Diemer & Evan Ma, FB Environmental Associates
SUBJECT: Kingston Lake Water Quality Analysis
DATE: May 29, 2024
CC: Forrest Bell, FB Environmental Associates

This memo summarizes water quality data available for the Kingston Lake watershed for assessment and modeling as part of the development of a watershed-based management plan, which was funded in part by a grant awarded to the Town of Kingston from the federal government through the American Rescue Plan Act (ARPA) to the State of New Hampshire, Governor's Office of Emergency Relief and Recovery (GOFERR), and NH Department of Environmental Services (NHDES), as approved by the Governor and Executive Council. This memo also proposes additional water quality data to be collected in the future to fill in gaps that would help improve assessment and modeling.

PROBLEM BACKGROUND

According to the 2021 and 2022 Data Summary of the New Hampshire Volunteer Lake Assessment Program (VLAP) Individual Lake Reports for Kingston Lake, the lake suffers from low dissolved oxygen and worsening trends in conductivity across the north and south stations, though trends in chlorophyll-a appear to be improving. NHDES assessed Kingston Lake as potentially not supporting (3-PNS) for Aquatic Life Integrity due to elevated turbidity and marginally impaired (5-M) for Aquatic Life Integrity due to low dissolved oxygen saturation and low pH. NHDES Lake Trophic Survey Reports (1976, 1985, 2004, 2009) classify the lake as mesotrophic or eutrophic with an abundance of rooted plants across all surveys, with pickerelweed being the most common. The most recent assessment in 2009 classifies the lake as eutrophic and describes it as a "borderline meso-eutrophic pond." Kingston Lake is known to be tea-colored, which signifies high levels of dissolved organic carbon in the water. Three cyanobacteria blooms have been reported in the past 15 years, leading to warnings for a cumulative 44 days. The most recent bloom in 2021 was likely a result of the high amount of summer precipitation, which increased lake phosphorus levels, according to the 2021 Data Summary of the NH VLAP Individual Lake Report. Both deep spots of Kingston Lake are known to experience anoxia, which can trigger the release of phosphorus from bottom sediments and be mixed up into the water column for use by phytoplankton such as cyanobacteria. This phenomenon known as internal loading is already evident in Kingston Lake. Enhanced loading of phosphorus to surface waters, whether from internal or external sources, particularly when compounded by the impacts from climate change, can stimulate excessive plant, algae, and cyanobacteria growth and degrade water quality.

Other waterbodies in the Kingston Lake watershed can impact the water quality of Kingston Lake because they contribute water, and therefore nutrients, to the lake. Other waterbodies include Long Pond, Greenwood Pond, and Halfmoon Pond. Long Pond is a similarly tea-colored, meso-eutrophic lake that suffers from invasive aquatic plant infestations (milfoil and fanwort). Long Pond flows into Kingston Lake via the Powwow River. Greenwood Pond has been classified as eutrophic with worsening trends in chloride and conductivity and has experienced cyanobacteria blooms each summer since 2016. Halfmoon Pond is a eutrophic, darkly tea-colored lake with poor water clarity. Each of these ponds have been noted to have depleted dissolved oxygen at lower depths, which can cause stress on fish and stimulate the release of phosphorus from bottom sediments.

WATER QUALITY SUMMARY

Trophic State Indicators

Total phosphorus, chlorophyll-a, and Secchi disk transparency are trophic state indicators, or indicators of biological productivity in lake ecosystems. The combination of these parameters helps determine the extent and effect of eutrophication in lakes and helps signal changes in lake water quality over time. For example, changes in Secchi disk transparency may be due to a change in the amount and composition of algae communities (typically because of greater total phosphorus availability) or the amount of dissolved or particulate materials in a lake. Such changes are likely the result of human disturbance or other impacts to the lake's watershed.

For the north and south deep spots of Kingston Lake, no statistically significant trends were found for epilimnetic total phosphorus or Secchi disk transparency over the time period of 1995-2022 (Figure 1). Statistically significant decreasing trends were found for chlorophyll-a at both the north and south deep spots of Kingston Lake. The 2021 and 2022 Data Summary of the NH VLAP Individual Lake Reports for the north and south deep spots on Kingston Lake also indicate similar trends for these parameters.

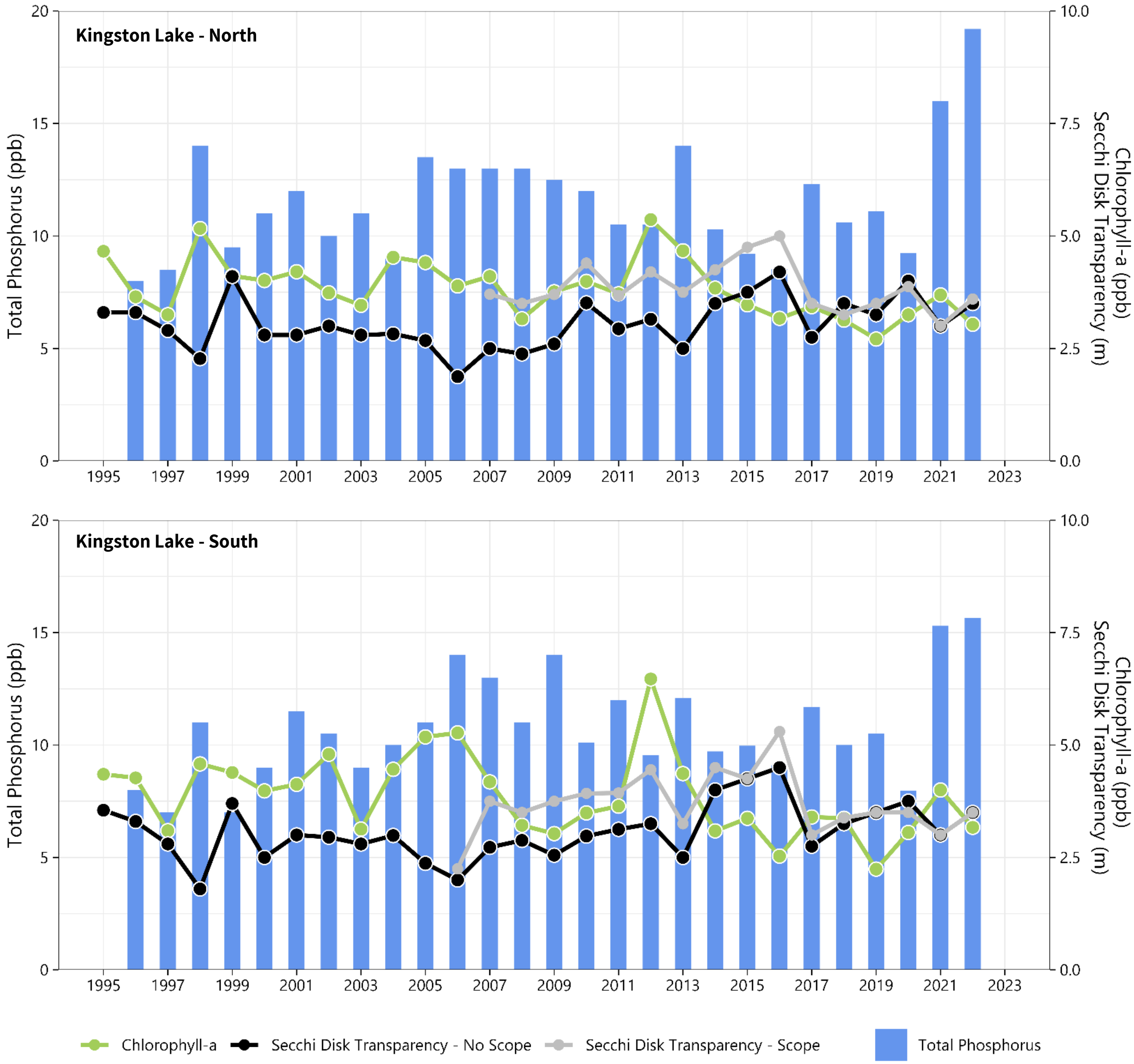

FIGURE 1. Median epilimnion total phosphorus, epilimnion chlorophyll-a, and water clarity (Secchi disk depth for scope and no scope methods) measured at the north deep spot of Kingston Lake [GRTKINND] (top) and the south deep spot of Kingston Lake [GRTKINSD] (bottom) largely in June-September from 1995-2022. Statistically significant decreasing trends in chlorophyll-a for both stations were detected by the Mann-Kendall nonparametric trend test using *rkt* package in R Studio.

For the deep spots of Kingston Lake and Greenwood Pond, generally higher total phosphorus concentrations were measured in the hypolimnion compared to the epilimnion and metalimnion, indicating some amount of internal phosphorus loading is occurring in these waterbodies (Figure 2). Long Pond is shallow (~3 m deep) and does not stratify, so no true discrete depth total phosphorus data exists and the limited data show no significant difference among the depth zones. Winter samples collected in Long Pond show total phosphorus concentrations lower than summer samples, which suggests some amount of internal phosphorus loading is occurring. Halfmoon Pond was not included due to limited data. Both deep spots of Kingston Lake show similar median total phosphorus concentrations for respective depth zones.

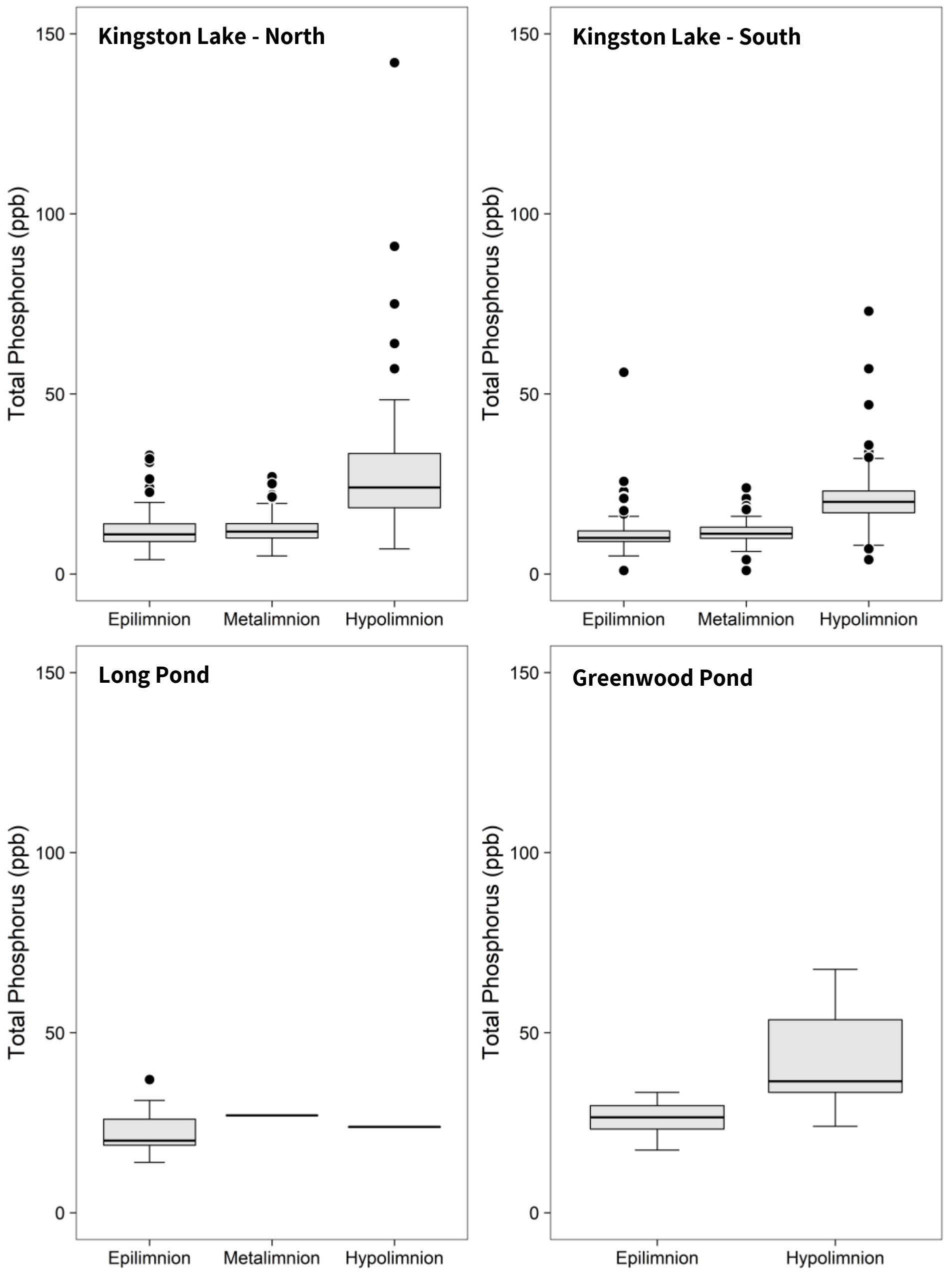

FIGURE 2. Boxplots showing median total phosphorus concentration in the epilimnion, metalimnion, and hypolimnion of the north deep spot of Kingston Lake [GRTKINND] (top left), the south deep spot of Kingston Lake [GRTKINSD] (top right), the deep spot of Long Pond [LONDVLD] (bottom left), and the deep spot of Greenwood Pond [GREKIND] (bottom right). Long Pond has limited data for metalimnetic (n=1) and hypolimnetic (n=3) total phosphorus.

Phytoplankton and Zooplankton

Bloom History

There have been three NHDES-issued cyanobacteria bloom warnings for Kingston Lake, the first of which lasted for two days in 2009. The bloom had a cell count of 144,000 cyanobacterial cells/mL and was primarily composed of *Anabaena* (now *Dolichospermum*). Another bloom in September 2017 that lasted eight days was composed of *Microcystis* and had a much higher cell count of 1,300,000 cells/mL. The longest warning lasted for 34 days beginning in September 2021 following a high amount of rainfall that summer. The dominant type of cyanobacteria was *Microcystis/Dolichospermum*, which are potentially toxin-producing taxa, with a cell count of 7,500,000 cells/mL.

The waterbodies upstream of Kingston Lake also have a history of cyanobacteria blooms. Greenwood Pond had 11 NHDES-issued bloom warnings, starting with its first warning in 2004. Warnings have lasted between one and 56 days, usually beginning in July. Blooms on Greenwood Pond were typically dominated by *Oscillatoria* until around 2019 when *Planktothrix* became the most abundant taxon. In 2021, *Planktothrix* formed mats on the bottom of the pond. Greenwood Pond has had a bloom warning every year since 2016. A water sample from the *Oscillatoria* bloom in 2016 was analyzed for microcystin, a hepatotoxin that cyanobacteria can produce. The sample had a microcystin concentration of 3.2 µg/L, which falls under recreational guidelines but exceeds the drinking water standard recommended by EPA.

Halfmoon Pond has had two recorded NHDES-issued bloom warnings. The first occurred in late July of 2008 and was dominated by *Oscillatoria*. The most recent bloom warning was issued in August 2022, with *Planktothrix* as the most abundant taxon. Both blooms lasted about 30 days.

Phytoplankton/Zooplankton Results

Phytoplankton and zooplankton samples were collected and analyzed during the 1976, 1985, 2004, and 2009 NHDES Trophic Surveys of Kingston Lake, as well as during the 1999 Great Pond Diagnostic/Feasibility Study. The dominant phytoplankton species were *Asterionella* (diatom), *Chrysosphaerella* (golden-brown), *Tabellaria* (diatom), *Dinobyron* (golden-brown), *Ceratium* (diatom), *Anabaena* (cyanobacteria), and *Oscillatoria* (cyanobacteria). The dominant zooplankton species were *Nauplius* larvae (copepod), *Keratella* (rotifer), *Calanoid* (copepod), and *Vorticella* (rotifer). The Great Pond Diagnostic/Feasibility Study finds that *Daphnia* and *Bosmina* are also common crustaceans. Bosmina are small and inefficient grazers. Copepods are small crustaceans that eat phytoplankton and provide an important food source to fish. *Daphnia* are among the most efficient grazers of phytoplankton. The relative abundance of each type of phytoplankton changes seasonally, with diatoms dominating in the spring and fall and cyanobacteria most abundant in late summer.

Dissolved Oxygen & Water Temperature

A common occurrence is the depletion of dissolved oxygen in the deepest part of lakes throughout the summer months. This occurs when thermal stratification prevents warmer (less dense), oxygenated surface waters from mixing with cooler (denser), oxygen-depleted bottom waters in the lake. Chemical and biological processes occurring in bottom waters deplete the available oxygen throughout the summer, and because these waters are colder and more dense, the oxygen cannot be replenished through mixing with surface waters. Dissolved oxygen levels below 5 ppm (and water temperature above 24 °C) can stress and reduce habitat for coldwater fish and other sensitive aquatic organisms. In addition, anoxia (low dissolved oxygen) at lake bottom can result in the release of sediment-bound phosphorus (otherwise known as internal phosphorus loading), which can become a readily available nutrient source for algae and cyanobacteria. While thermal stratification and depletion of oxygen in bottom waters is a natural phenomenon in dimictic lakes such as Kingston Lake, it is important to track these parameters to make sure the extent and duration of low oxygen does not change drastically because of human disturbance in the watershed resulting in excess phosphorus loading.

Figure 3 shows temperature and dissolved oxygen profiles averaged across sampling dates (1991-2021) during thermal stratification largely in summer (between spring and fall turnover) for the north and south deep spots of Kingston Lake. The change in temperature, seen most dramatically between 4 and 7 m, indicates thermal stratification in the water column. The average dissolved oxygen of <2 ppm at 10-14 m depth indicates the possibility of internal loading under anoxic conditions. Historic recording of temperature and dissolved oxygen profiles includes only one water column profile per sampling season. While these data are useful in tracking major trends over time, monitoring consisting of several profiles per sampling season can provide better insight to seasonal changes in the lake. The 1999 NHDES Great Pond Diagnostic/Feasibility Study describes the seasonal variations of anoxia in the two deep spots. At the north deep spot of Kingston Lake [GRTKINND], the bottom three meters can become anoxic in early

June. By late August, the extent of anoxia can extend from 6 m depth to the bottom of the lake. At the south deep spot of Kingston Lake [GRTKINSD], anoxia in the bottom three meters occurs in late July, later than at the north deep spot. The extent of anoxia extends from 5 m depth to the bottom by late August. The Diagnostic/Feasibility Study attributes the differences between the two stations to differences in lake morphometry.

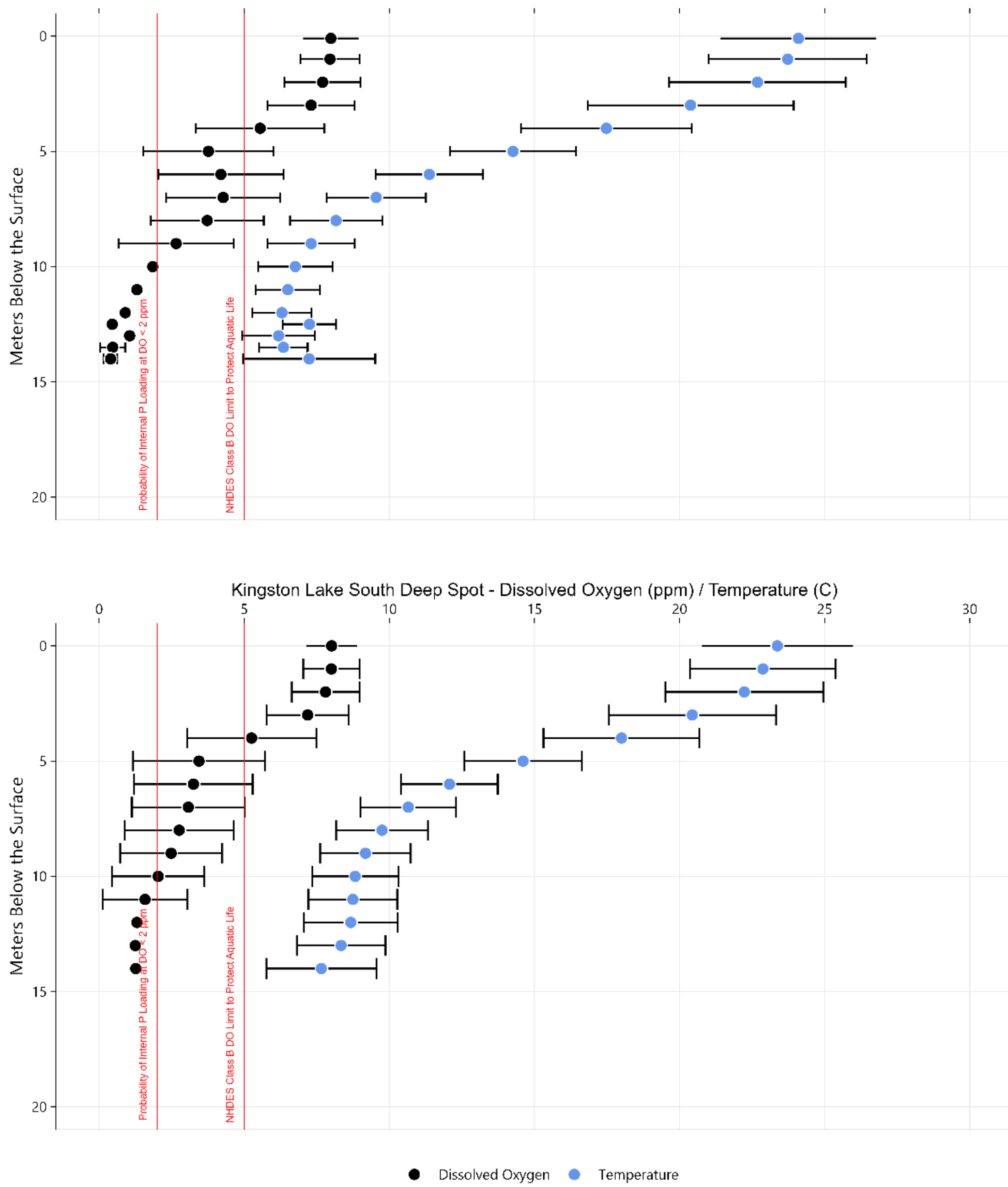

FIGURE 3. Dissolved oxygen (black) and water temperature (blue) depth profiles for the north deep spot [GRTKINND] (top) and south deep spot [GRTKINSD] of Kingston Lake. Dots represent average values across sampling dates for each respective depth. Error bars represent standard deviation. Profiles were collected in 1995-2021 with a few additional observations from 1976 and 1995 for the north deep spot (n=27). For the south deep spot, profiles were collected from 1991-2021 (n=31). Maximum depth for Kingston Lake is 16 m.

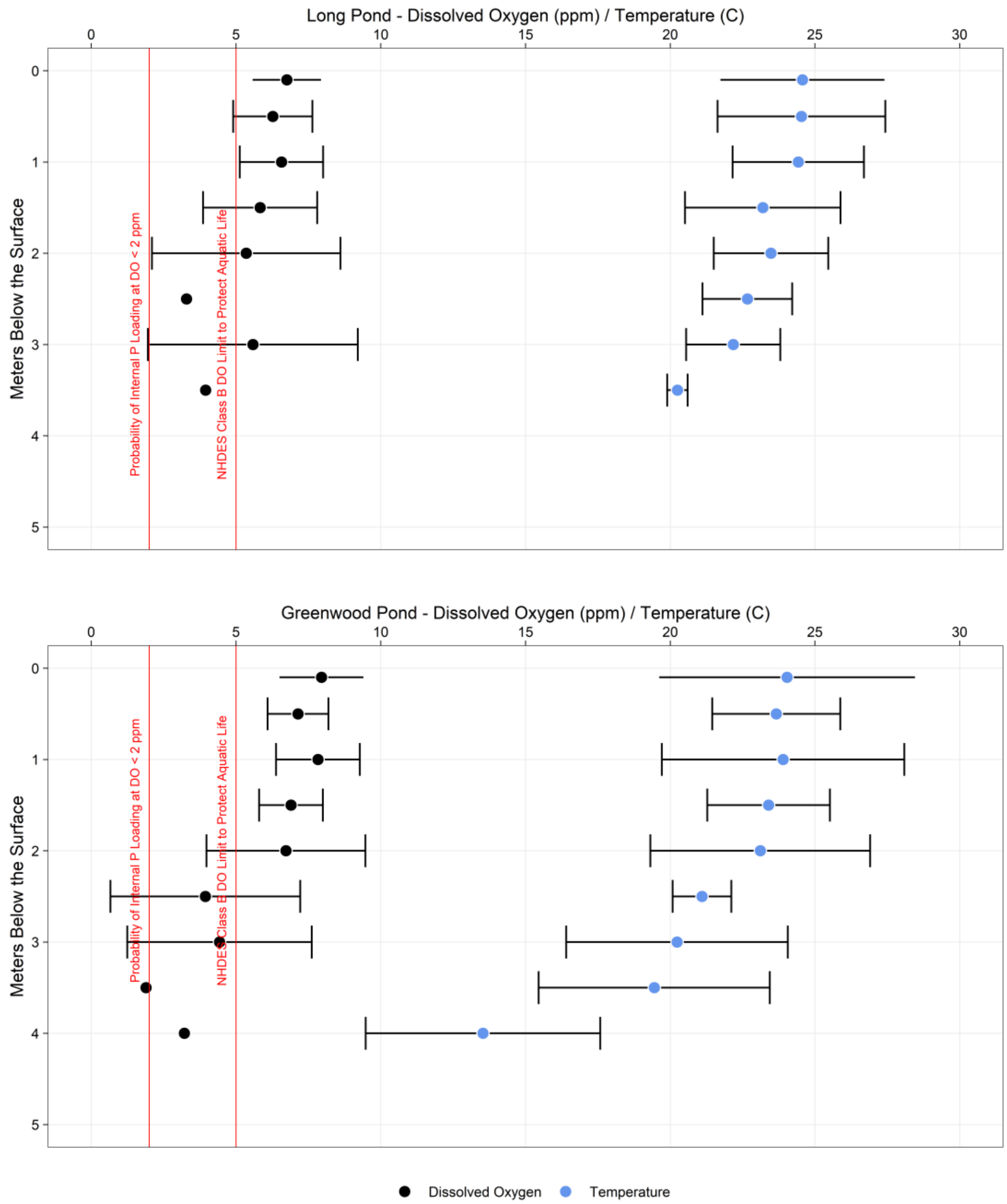

FIGURE 4. Dissolved oxygen (black) and water temperature (blue) depth profiles for the deep spots of Long Pond [LONDVLD] (top) and Greenwood Pond [GREKIND] (bottom). Dots represent average values across sampling dates for each respective depth. Error bars represent standard deviation. Profiles were collected in 1995 and 2016-2021 for Long Pond (n=6). For Greenwood Pond, profiles were collected in 1995 and 2017-2020, with one additional observation in 1982 (n=5). One winter observation was removed from each station.

Figure 4 shows temperature and dissolved oxygen profiles averaged across sampling dates largely in the summer between spring and fall turnover in Long Pond and Greenwood Pond. Despite the shallow maximum depths of these ponds, there is evidence of weak thermal stratification in the water column, though there is no defined metalimnion or hypolimnion in either waterbody. There is an observed decline in dissolved oxygen with depth, but the average dissolved oxygen does not decline below 2 ppm in either lake except at 3.5 m depth in Greenwood Pond and occasionally at 2-3 m depth in Long Pond. Dissolved oxygen of <2 ppm indicates the possibility of internal loading under anoxic conditions. Data on these two lakes are limited, with consistent collection of one profile per season starting around 2016, so expanding monitoring to include multiple profiles each year could provide better insight to seasonal variations in temperature and dissolved oxygen.

Chloride & Specific Conductivity

Chloride pollution can cause harm to aquatic organisms and disrupt internal mixing processes when chloride concentrations reach toxic levels. The State of New Hampshire sets a chronic threshold of 230 ppm for chloride (which roughly equates to 835 µS/cm for specific conductivity). Chloride concentrations at both deep spots of Kingston Lake are well below the chronic threshold, though the 2022 Data Summary of the NH VLAP Individual Lake Reports for both stations on Kingston Lake indicate that chloride and specific conductivity are higher than state medians. Both parameters show statistically significant increasing trends over time for each respective station (1977/1995-2022) (Figure 4). The increasing trends indicate that chloride from winter salting practices for deicing roads and other surfaces in the watershed may be contaminating the lake. While not an immediate concern for the health of the lake, chronic chloride toxicity will likely become an issue in the future without a proactive reduction in salt use in the watershed.

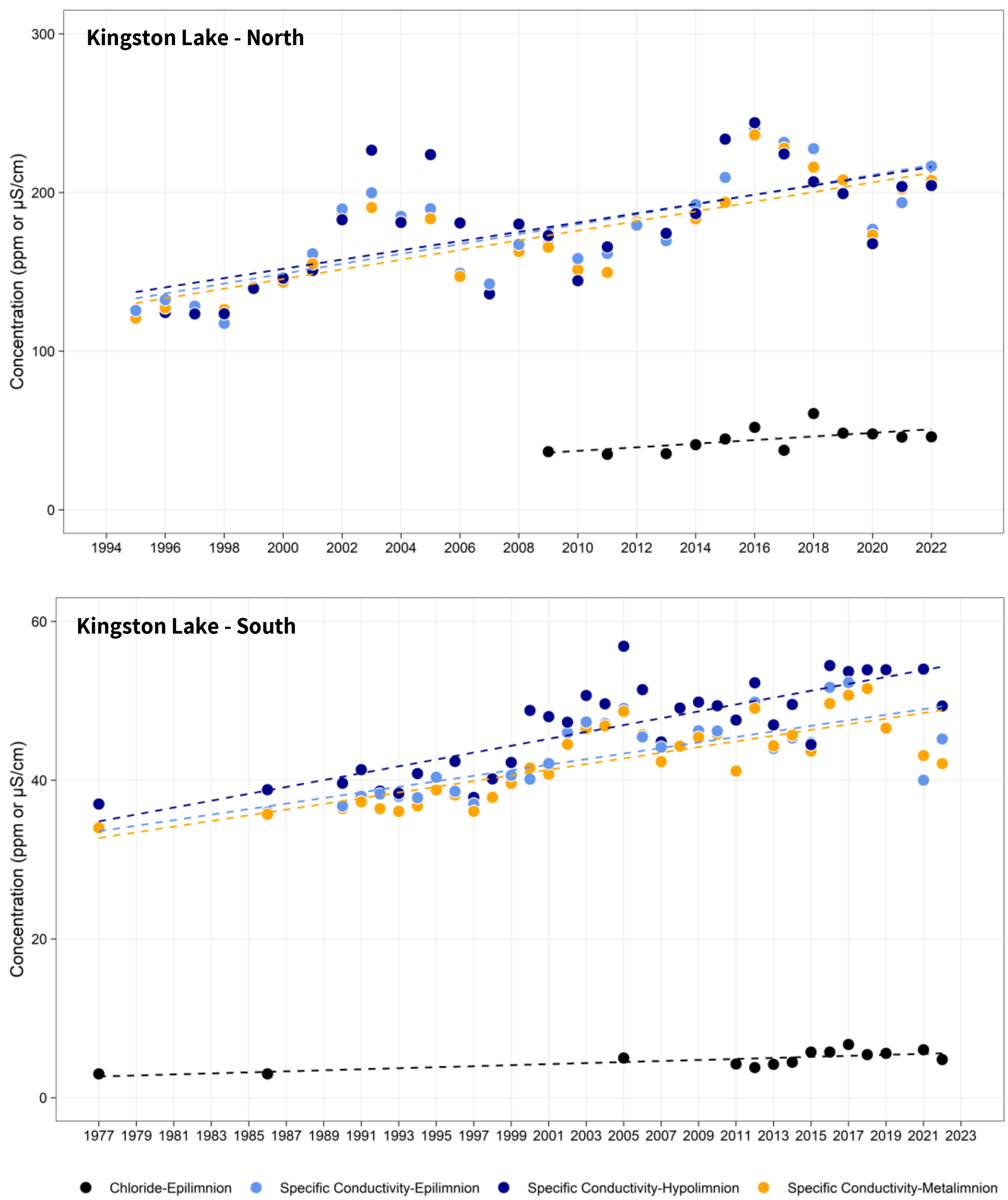

FIGURE 4. Yearly median of monthly medians for chloride and specific conductivity in the north deep spot [GRTKINND] (top) and south deep spot [GRTKINSD] (bottom) of Kingston Lake. Dashed lines indicate a statistically significant increasing (degrading) trend.

ASSIMILATIVE CAPACITY

The assimilative capacity of a waterbody describes the amount of pollutant that can be added to a waterbody without causing a violation of the water quality criteria and is based on lake trophic designation. Kingston Lake is a borderline mesotrophic/eutrophic waterbody, though it is currently classified as eutrophic. For enhanced protection of water quality, both mesotrophic and eutrophic designations were used to run the assimilative capacity analysis for Kingston Lake. For mesotrophic waterbodies, the water quality criteria are set at 12 ppb for total phosphorus and 5.0 ppb for chlorophyll-a, above which the waterbody is considered impaired (28 ppb and 11 ppb, respectively, for eutrophic waterbodies). NHDES requires a portion of the difference between the best possible water quality and the water quality standard be kept in reserve as described in the 2020/2022 Section 305(b) and 303(d) Consolidated Assessment and Listing Methodology (CALM); therefore, according to Table 3-17 of the CALM, total phosphorus and chlorophyll-a must be at or below 11.6 ppb and 4.8 ppb, respectively, to achieve Tier 2 High Quality Water status under a mesotrophic designation. Under an eutrophic designation, the parameters must be at or below 26.4 ppb and 10.4 ppb, respectively, to achieve Tier 2 High Water Quality status. Support determinations are based on the nutrient stressor (phosphorus) and response indicator (chlorophyll-a), with chlorophyll-a dictating the assessment if both chlorophyll-a and total phosphorus data are available and the assessments differ. Results of the assimilative capacity analysis show that Kingston Lake and Long Pond meet Tier 2 (High Water Quality) for both trophic class designations (Table 1). Greenwood Pond would be considered impaired based on total phosphorus under both trophic class designations and chlorophyll-a under a mesotrophic designation. For Long Pond and Greenwood Pond, high total phosphorus levels for the trophic class paired with low chlorophyll-a levels suggest that there may be other controls on phytoplankton than just phosphorus.

TABLE 1. Assimilative capacity (AC) analysis results for Kingston Lake and other waterbodies within its watershed using mesotrophic and eutrophic thresholds. Chlorophyll-a dictates the assessment results.

Parameter	Mesotrophic AC Threshold (ppb)	Existing Median WQ (ppb)*	Remaining AC (ppb)	Results
KINGSTON LAKE – NORTH DEEP SPOT [GRTKINND]				
Total Phosphorus	11.6	11.1	0.5	Tier 2 (High Water Quality)
Chlorophyll-a	4.8	3.3	1.5	
KINGSTON LAKE– SOUTH DEEP SPOT [GRTKINSD]				
Total Phosphorus	11.6	10.5	1.1	Tier 2 (High Water Quality)
Chlorophyll-a	4.8	3.4	1.4	
LONG POND – DEEP SPOT [LONDVLD]				
Total Phosphorus	11.6	19.6	-8.8	Tier 2 (High Water Quality)
Chlorophyll-a	4.8	4.0	0.8	
GREENWOOD POND – DEEP SPOT [GREKIND]				
Total Phosphorus	11.6	27.7	-16.1	Impaired
Chlorophyll-a	4.8	9.0	-4.2	
Parameter	**Eutrophic AC Threshold (ppb)**	**Existing Median WQ (ppb)***	**Remaining AC (ppb)**	**Results**
KINGSTON LAKE – NORTH DEEP SPOT [GRTKINND]				
Total Phosphorus	26.4	11.1	15.3	Tier 2 (High Water Quality)
Chlorophyll-a	10.4	3.3	7.1	
KINGSTON LAKE– SOUTH DEEP SPOT [GRTKINSD]				
Total Phosphorus	26.4	10.5	15.9	Tier 2 (High Water Quality)
Chlorophyll-a	10.4	3.4	7.0	
LONG POND – DEEP SPOT [LONDVLD]				
Total Phosphorus	26.4	19.6	6.8	Tier 2 (High Water Quality)
Chlorophyll-a	10.4	4.0	6.4	
GREENWOOD POND – DEEP SPOT [GREKIND]				
Total Phosphorus	26.4	27.7	-1.3	Tier 2 (High Water Quality)
Chlorophyll-a	10.4	9.0	1.4	

** Existing water quality data truncated to May 24-Sept 15 in the previous 10 years (2013-2022) for composite, epilimnion, or upper samples (in order of priority on a given day). Data were summarized by day, then month, then year using median statistic.*

FUTURE MONITORING RECOMMENDATIONS

For lake assessment purposes, NHDES requires the following criteria for dissolved oxygen: no more than two or 10% of samples (whichever is greater), collected from the epilimnion (defined from the surface to the first 1 or more °C change in temperature) between the days of June 1 and September 30 and the hours of 10am and 2pm in the last 10 years, can be less than 5 mg/L for a Class B waterbody such as Kingston Lake. Four (4) dissolved oxygen and temperature profiles were collected from each deep spot of Kingston Lake in the last 10 years; two (2) out of those 6 profiles for each station were collected prior to 10am and likely cannot be used. For the north station, the remaining two profiles were collected in June or July, with both profiles showing depleted dissolved oxygen concentration (< 2 mg/L) beginning at 9-10 meters depth; the zone with dissolved oxygen below 5 ppm begins at 4-5 meters below the surface for these profiles. The south deep spot exhibited similar trends. The 1999 Great Pond Diagnostic/Feasibility study suggests that the extent of anoxia in the deep spots of the lake worsens as the season progresses. We conclude that more frequent profile data collection throughout the season, particularly in August and September when stratification can reach its peak, is needed for assessment purposes.

- If the lake association has access to a dissolved oxygen and temperature meter, we recommend that profiles are collected biweekly from June 1 to September 30 between the hours of 10am and 2pm.
- Collect Secchi disk transparency with each profile or total phosphorus sample.
- Additional profiles from surrounding waterbodies, such as Long Pond and Greenwood Pond would help better characterize the watershed.
- If additional funding is available, we also recommend the following to better characterize the contribution of phosphorus from internal loading:
    - Discrete grab samples for total phosphorus collected every 2 meters from the surface (1 meter) to the bottom (15 meters) at both deep spots of Kingston Lake, for a total of 2-3 times in late July through September.
    - Sediment samples (top 4 inches) collected from both deep spots of Kingston Lake to analyze elemental ratios of phosphorus, aluminum, and iron and characterize biologically labile fractions of phosphorus.