LAKE WAUKEWAN & LAKE WINONA **WATER QUALITY ANALYSIS**

TO:	Angela Labreque, Town of Meredith
FROM:	Evan Ma, FB Environmental Associates
SUBJECT:	**Lake Waukewan and Lake Winona Water Quality Analysis**
DATE:	June 24, 2026
CC:	Laura Diemer & Tim Kirsten, FB Environmental Associates

This memo summarizes available water quality data for Lake Waukewan and Lake Winona in Meredith, Center Harbor, and New Hampton, NH through 2025 for total phosphorus, chlorophyll-*a*, Secchi disk transparency, dissolved oxygen/temperature profiles, phytoplankton and zooplankton populations, chloride, specific conductivity, and pH. Existing data was gathered from the New Hampshire Department of Environmental Services (NHDES) Environmental Monitoring Database which includes data from the NHDES Volunteer Lake Assessment Program (VLAP). In addition, FB Environmental collected extensive data in Lake Waukewan as part of a source water protection grant project in 2024. The analyses and results presented here focus on the two deep spots of Lake Waukewan (Winona Deep Spot – WAUMERWD, and Mayo Deep Spot – WAUMERMD) and the Lake Winona Deep Spot (WINNWHD) to inform the Lake Waukewan Watershed Management Plan Update.

BACKGROUND

Lake Waukewan is the primary drinking water supply for the Town of Meredith, meaning its water quality is important to the town for both public health and recreation. In lakes, maintaining a low-nutrient trophic status supports human uses of the lake and aquatic life. There are three trophic states which define lakes: oligotrophic, mesotrophic, and eutrophic. All lakes naturally eutrophy or move toward a eutrophic state over thousands of years. Humans are speeding up this process with eutrophication due to increased nutrient input from fertilizers, erosion, septic system wastewater, and stormwater runoff occurring on the timescale of decades (Figure 1). The trophic status of Lake Waukewan was assessed by NHDES in 1982 and 1994 as oligotrophic (NHDES, 1982; NHDES, 1994), which indicates low nutrient levels and excellent water quality. The trophic reports also provide a snapshot view of a lake's physical characteristics (area, depth, volume), water quality, phyto- and zooplankton communities, and aquatic plant abundance. Both trophic surveys, conducted in July, recorded relatively low dissolved oxygen levels near the bottom of the lake. Low dissolved oxygen levels threaten cold-water fish and invertebrate species and increase the likelihood of phosphorus being released from bottom sediments into the water column.

Lake Winona was assessed as eutrophic by NHDES in 1977 (NHDES, 1977), and mesotrophic in 1987 and 2005 (NHDES, 1987; NHDES, 2005). Dissolved oxygen levels decreased near the lake bottom in all survey years. The 1987 report noted that if the lake had been sampled later in the summer, it would have been classified as eutrophic again because of the typically low dissolved oxygen levels in late summer, while the 2005 report noted that trophic conditions had remained relatively similar to the previous assessments. The 2005 report also noted that Lake Winona had experienced an increase in sodium, chloride, and conductivity from 1977 to 2005. Lake Winona was treated with a copper sulphate algaecide in 1967 and 1968 to control algal blooms (NHDES, 2005).

Figure 1. Graphic of lake eutrophication and how it is impacted by humans.

Every two years, NHDES assesses the state's lakes to determine if each lake is attaining their designated uses. In the most recent assessment (2024), NHDES has designated both Lake Waukewan and Lake Winona as impaired for aquatic life integrity (ALI) due to low dissolved oxygen levels (severe) and low dissolved oxygen saturation (marginal), as well as impaired for primary contact recreation due to elevated cyanobacteria hepatotoxic microcystins. Multiple inlet streams, including "Unnamed Brook - To Winona Lake - North Inlet," and "Snake River - To Lake Waukewan" are also assessed as impaired for aquatic life integrity (ALI) due to slightly acidic pH (NHDES, 2024a). Hawkins Pond (upstream of Lake Winona) is also impaired for ALI due to low dissolved oxygen, and Bear Pond (upstream of Hawkins Pond) is impaired for ALI because of low pH.

Annual water quality monitoring at Lake Waukewan has been conducted by the NHDES Volunteer Lake Assessment Program (VLAP) since 1991, and since 1985 for Lake Winona. VLAP volunteers sample two deep spots in Lake Waukewan to capture the distinct environmental dynamics of each basin. While both locations share similar maximum depths, they exhibit key differences in sediment composition and dissolved oxygen levels. The Mayo Deep Spot features mucky sediments and typically maintains higher dissolved oxygen alongside lower hypolimnion total phosphorus. Conversely, the Winona Deep Spot is characterized by harder, clay sediments and higher phosphorus levels. Sampling both spots provides critical data on these contrasting aquatic microenvironments. NHDES VLAP produced two reports for Lake Waukewan in 2024, one for the Winona deep spot and one for the Mayo deep spot (NHDES, 2024b; NHDES, 2024c), shown in Figure 2. These reports noted that the lake is meeting oligotrophic conditions but highlighted a worsening trend in conductivity at both locations. The Winona deep spot also showed worsening hypolimnetic total phosphorus concentrations, indicating that internal phosphorus loading may be worsening. Water clarity was improving, while other parameters (chlorophyll-*a* concentration, epilimnetic total phosphorus, and pH) were stable. Hypolimnetic phosphorus was highest in late summer when dissolved oxygen levels were lowest. The latest VLAP report for the Lake Winona deep spot (NHDES, 2024d) highlights worsening trends in chlorophyll-*a*, hypolimnetic phosphorus, and conductivity.

Intensive water quality sampling was conducted in Lake Waukewan in 2024 as part of a source water protection grant from the NHDES Drinking Water and Groundwater Bureau (FBE, 2025). The project was initiated over concerns that cyanobacteria blooms are becoming more frequent in the lake and could threaten Meredith's drinking water supply. Results indicated generally excellent water quality, relatively low phytoplankton biomass, and a significant correlation between phytoplankton biomass and epilimnion total dissolved phosphorus, highlighting the importance of phosphorus for lake productivity. Chemical analyses showed that Lake Waukewan is phosphorus-limited and that internal phosphorus loading was detected in 2024, especially around the time of lake turnover.

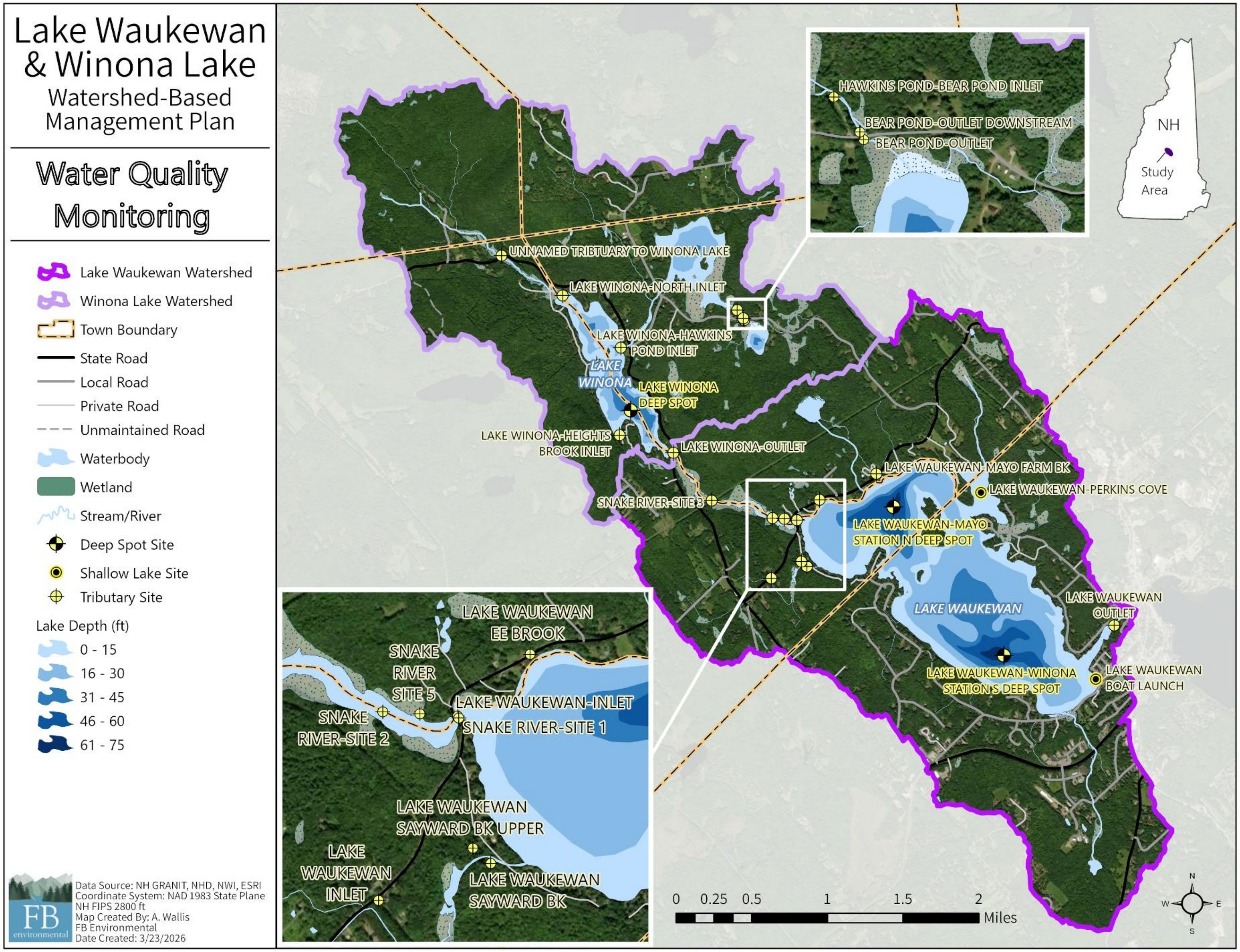

Figure 2. Map of the bathymetry and water quality sampling sites for Lake Waukewan and Lake Winona.

WATER QUALITY SUMMARY

Dissolved Oxygen & Water Temperature

A common occurrence in New Hampshire's lakes is the depletion of dissolved oxygen in the deepest waters throughout the summer months. This occurs when thermal stratification (the separation of distinct temperature layers) prevents warmer, less dense, oxygen-rich surface waters from mixing with cooler, denser, oxygen-depleted bottom waters in the lake (Figure 3). As summer progresses, chemical and biological activity in the bottom layer consumes oxygen, but that oxygen cannot be replenished because mixing with the surface is blocked by stratification (Figure 4).

Dissolved oxygen and temperature are important for lake health, because low dissolved oxygen (below 5 ppm) combined with warmer water temperature (above 24 °C) can stress and reduce habitat for cold-water fish and other sensitive aquatic organisms. In addition, very low dissolved oxygen (called anoxia) at the lake bottom can trigger the release of sediment-bound phosphorus, a process known as internal phosphorus loading. This phosphorus then becomes available to fuel algae and cyanobacteria growth. Thermal stratification and depletion of oxygen in bottom waters is a natural phenomenon in dimictic lakes, meaning those which mix fully in spring and fall but stratify in summer and winter.

Tracking oxygen and temperature over time is important to detect whether conditions are changing due to human impacts, such as excess phosphorus entering from the watershed.

Lake Stratification and Mixing

Lake Waukewan and Lake Winona are **dimictic lakes**, meaning they go through two cycles of layering (stratification) and mixing each year. In summer, warm surface waters sit on top of cooler, denser bottom waters, creating a thermal barrier that prevents mixing. In winter, when the lake is frozen, colder water stays at the surface while warmer water remains at the bottom. During spring and fall, these temperature layers break down in what's called **"turnover,"** allowing the entire water column to mix.

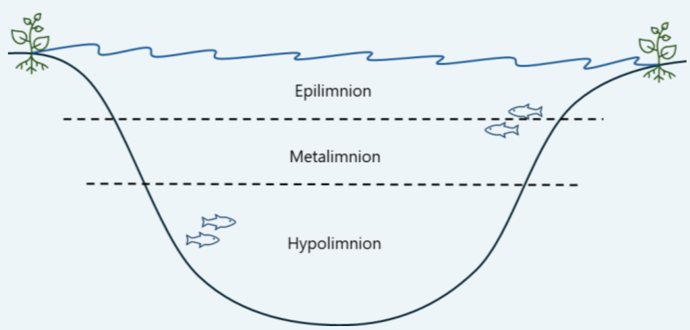

Figure 3. Lakes experiencing thermal stratification have three layers, epilimnion, metalimnion, and hypolimnion.

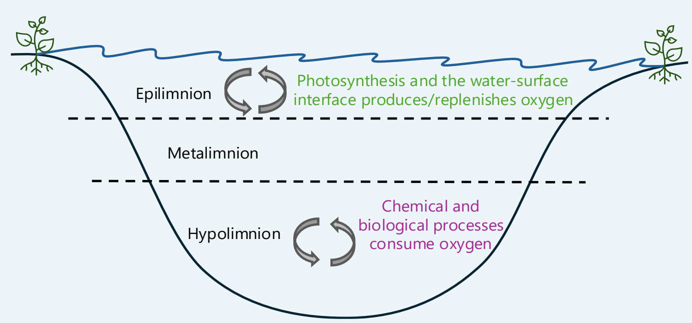

Figure 4. Thermal stratification limits whole lake mixing, with ample oxygen in the epilimnion but depleted oxygen in the hypolimnion.

Figure 5 shows average temperature and dissolved oxygen profiles for Lake Waukewan during summer stratification from 1990 to 2025. A sharp change in temperature between approximately 4 and 12 meters depth marks the metalimnion at the Winona deep spot while the Mayo deep spot metalimnion occurs at 5 to 13 meters. Dissolved oxygen below 5 ppm is observed in areas as shallow as 10 meters at both deep spots, indicating potential impacts to aquatic life. Dissolved oxygen levels below 2 ppm are regularly observed at the Winona deep spot as shallow as 11 meters. Dissolved oxygen is lowest as the lake approaches turnover. These conditions are typically associated with peak internal phosphorus loading.

Figure 6 shows average temperature and dissolved oxygen profiles for Lake Winona during summer stratification for the period of 1977 to 2024. No profiles were collected in 2025. Sharp temperature drops between 4 and 9 meters indicate the approximate metalimnion depth. Dissolved oxygen drops below 5 ppm around 9 meters and below 2 ppm at 12 meters, indicating a vulnerability to internal phosphorus loading at the deep spot.

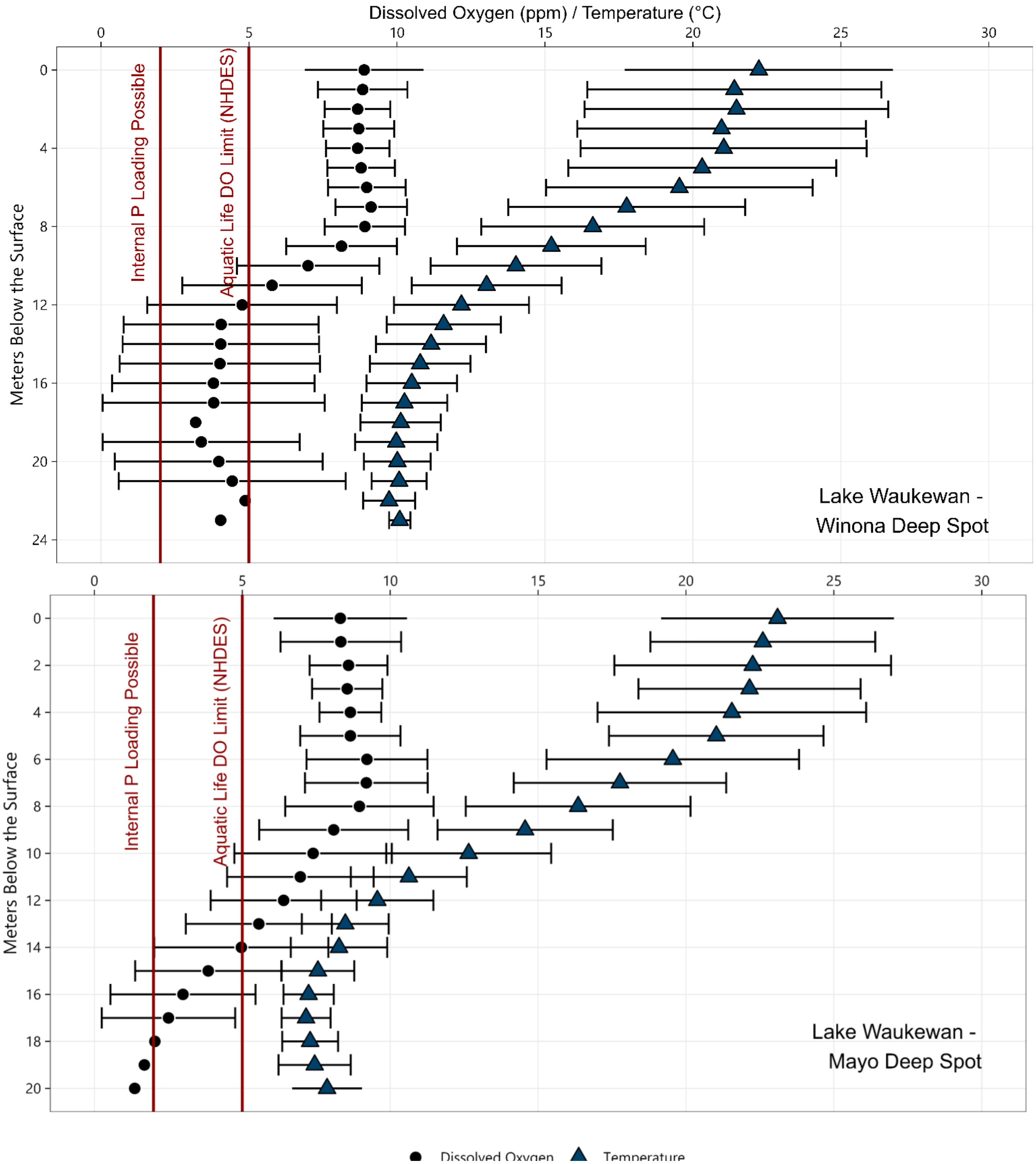

Figure 5. Dissolved oxygen and water temperature depth profiles for the Winona (top) and Mayo (bottom) deep spots of Lake Waukewan (WAUMERWD and WAUMERMD, respectively). Dots represent average values across sampling dates for each respective depth, rounded to the nearest meter. Error bars represent standard deviation. Data represents profiles collected from 1990 to 2025 (number of unique dates=101 for temperature and n=83 for dissolved oxygen) for the Winona deep spot, and 1990-2024 (n=55 for temperature and n=37 for dissolved oxygen) for the Mayo deep spot.

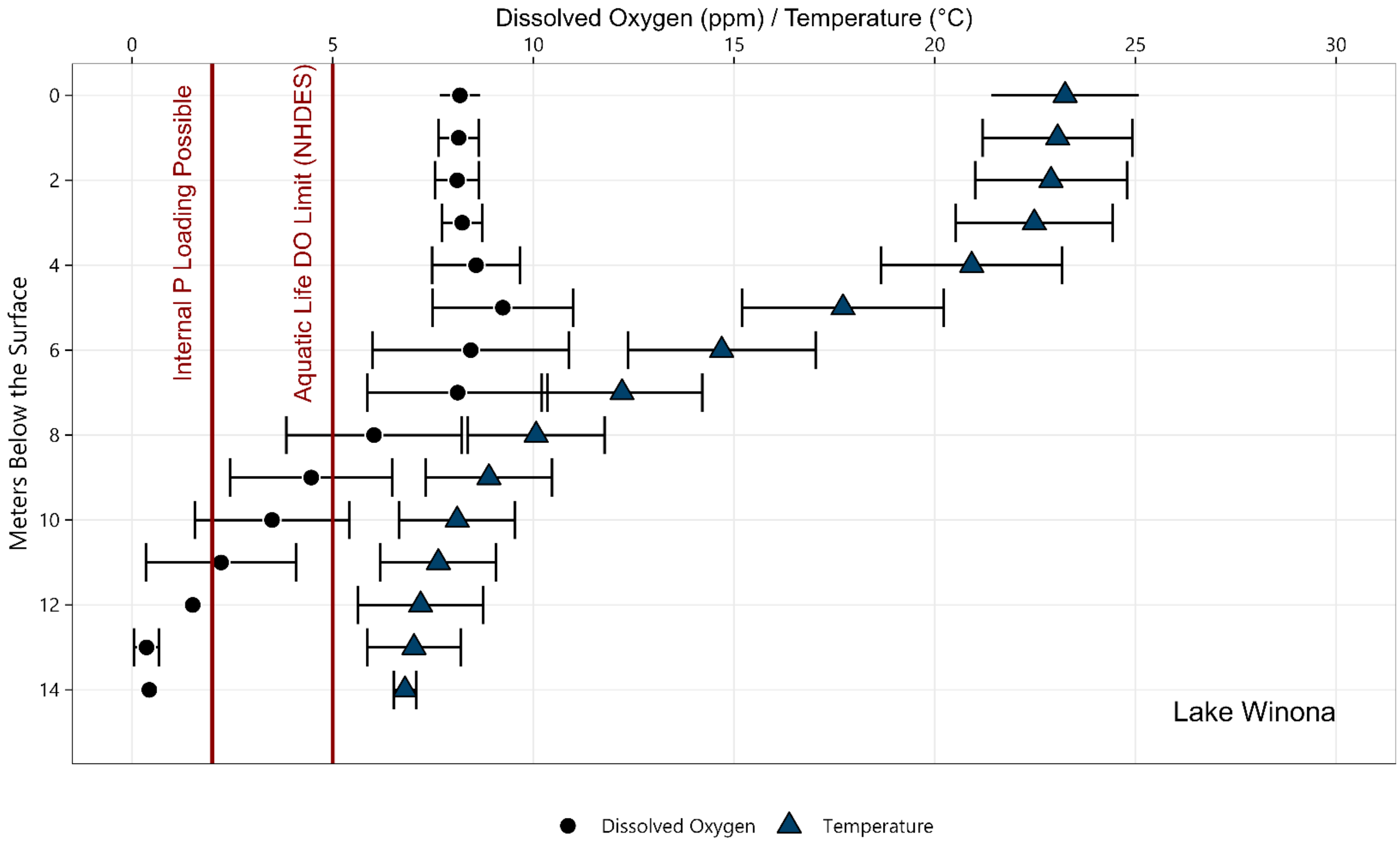

Figure 6. Dissolved oxygen and water temperature depth profiles for the Lake Winona deep spot (WINNWHD). Dots represent average values across sampling dates for each respective depth, rounded to the nearest meter. Error bars represent standard deviation. Data represents profiles collected from 1977-2024 (number of unique dates=39 for temperature and n=41 for dissolved oxygen).

Trophic State Indicators – Total Phosphorus, Chlorophyll-*a*, and Secchi Disk Transparency

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 of dissolved or particulate materials in a lake or the amount and community composition of algae. Changes in the algal community are typically due to greater total phosphorus availability which are often the result of human disturbance or other impacts within the lake's watershed.

Trends in the trophic state indicators were investigated for each monitoring station and depth, when applicable, for three time periods: (1) the full dataset including all observations through 2025, (2) historical data including all observations through 2015, and (3) recent data including all observations from 2016 to 2025. For total phosphorus, only the historic data for the hypolimnion in the Lake Waukewan Mayo deep spot (WAUMERMD) had a significant decreasing (improving) trend. No other statistically significant trends were found for total phosphorus concentrations at any depths in Lake Waukewan at WAUMERWD or WAUMERMD for the full, historic, or recent datasets. The lack of trends in total phosphorus indicates stable conditions for this nutrient in Lake Waukewan over time. However, the total phosphorus concentration increased with depth in the water column from the epilimnion to the hypolimnion at both deep spots in the recent data (Figure 7).

Peak concentration during this period in the hypolimnion was 65 ppb for the Winona deep spot and 30 ppb for the Mayo deep spot. The elevated total phosphorus concentration in the hypolimnion indicates internal loading in Lake Waukewan. Lake Winona has an increasing (worsening) trend in epilimnetic total phosphorus for the recent data (p=0.02) and in the hypolimnion for the full dataset (p=0.02; Figure 8).

No statistically significant trends were detected for epilimnetic composite samples of chlorophyll-*a*, for the full, historical, or recent dataset at either of the Lake Waukewan deep spots (Figure 9). An increasing (improving) trend for Secchi disk transparency, a measure of water clarity, was observed for the full dataset at the Lake Waukewan Winona deep spot (p=0.01).

In Lake Winona, Secchi disk transparency significantly decreased (worsened) in the full and historic data, but no trends were detected in the most recent data (Figure 10). The lack of change in the recent 10-year period indicates water clarity has been more stable since 2016. Epilimnetic composite chlorophyll-*a* has statistically increased (worsened) for the full dataset, but no significant trend was detected in the historic or recent data.

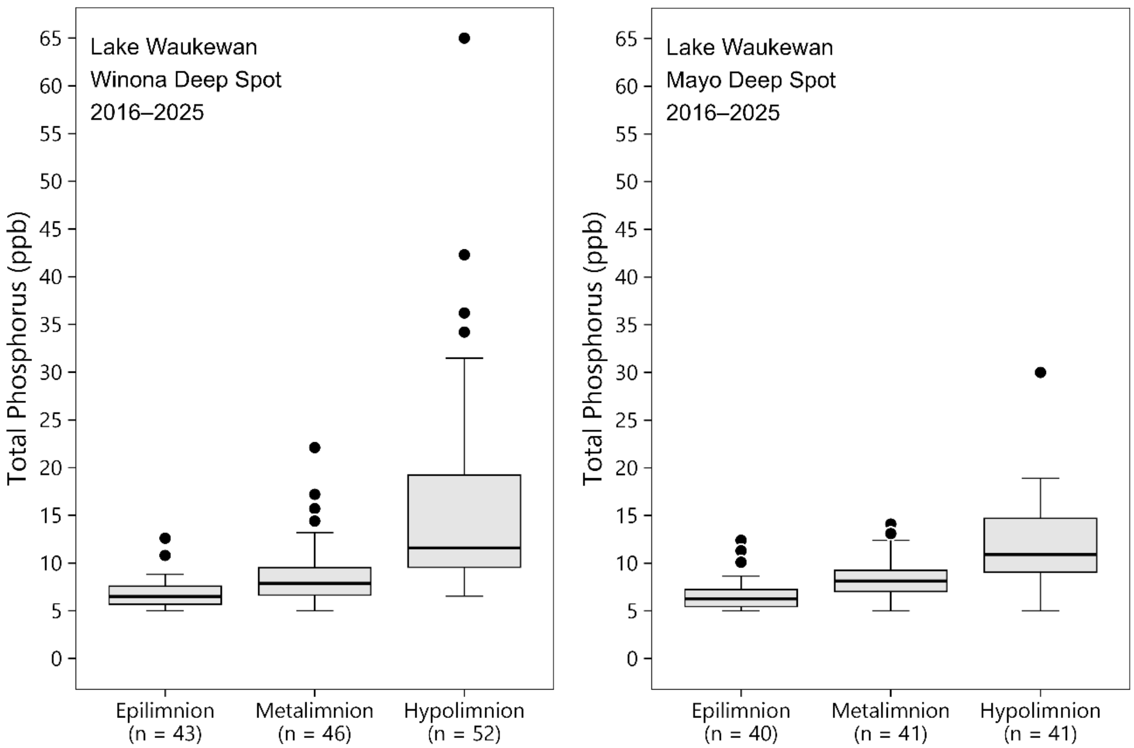

Figure 7. Boxplots showing median total phosphorus concentration in the epilimnion, metalimnion, and hypolimnion of the two Lake Waukewan deep spots from the recent data (2016-2025).

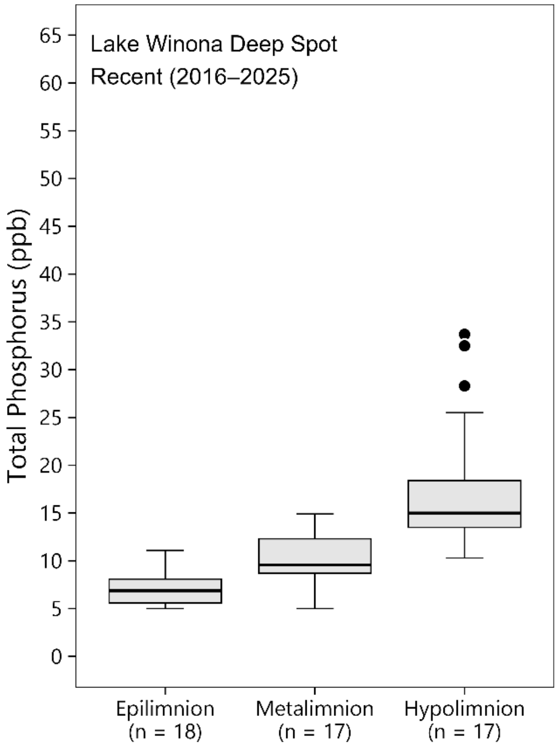

Figure 8. Boxplot showing median total phosphorus concentration in the epilimnion, metalimnion, and hypolimnion at the Lake Winona deep spot from the recent data (2016-2025).

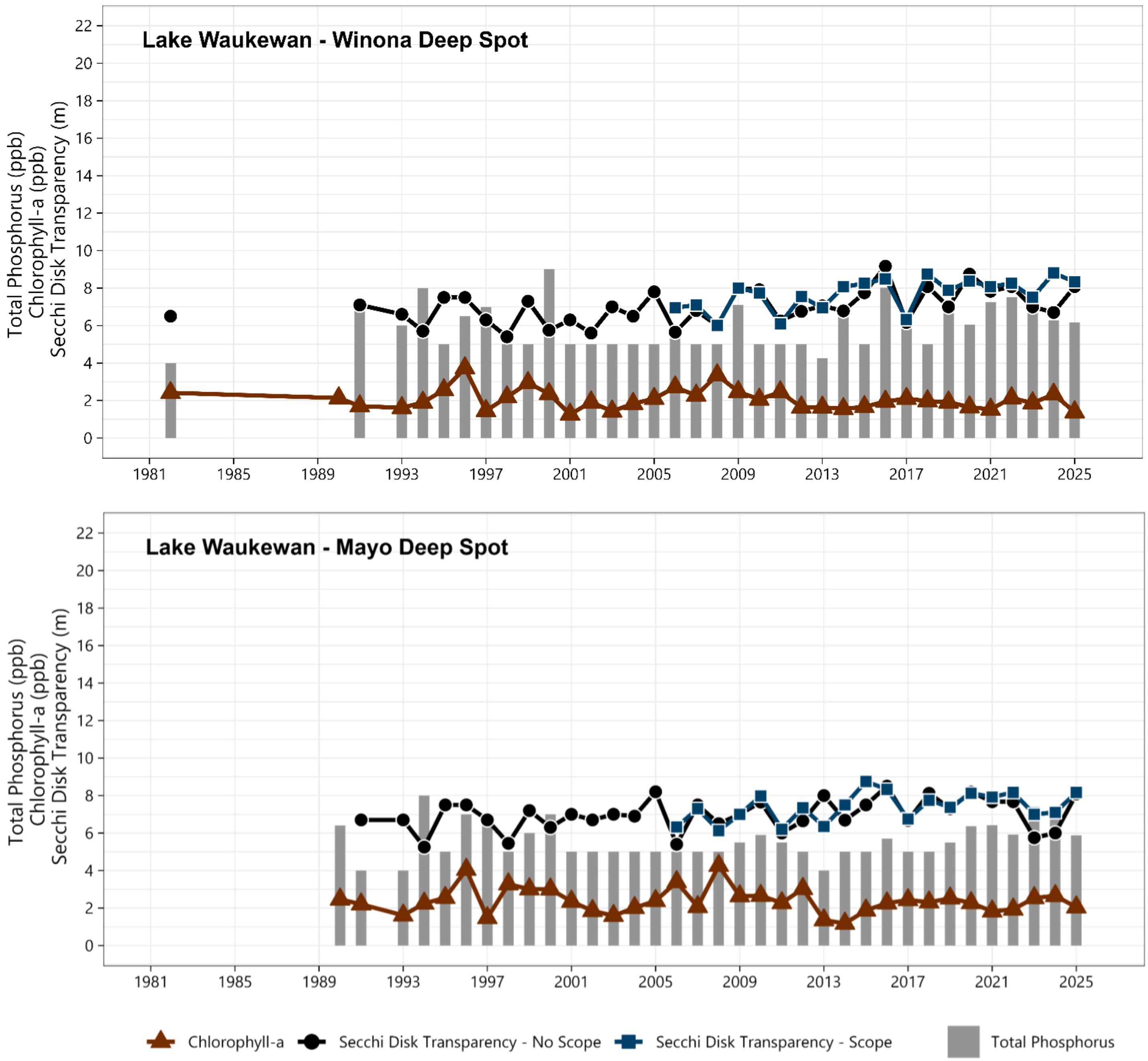

Figure 9. Median epilimnion total phosphorus, median epilimnion chlorophyll-*a*, and median water clarity (Secchi Disk depth for scope and no scope methods) measured at the Lake Waukewan Winona (top) and Mayo (bottom) deep spots largely in May-September from 1982-2025.

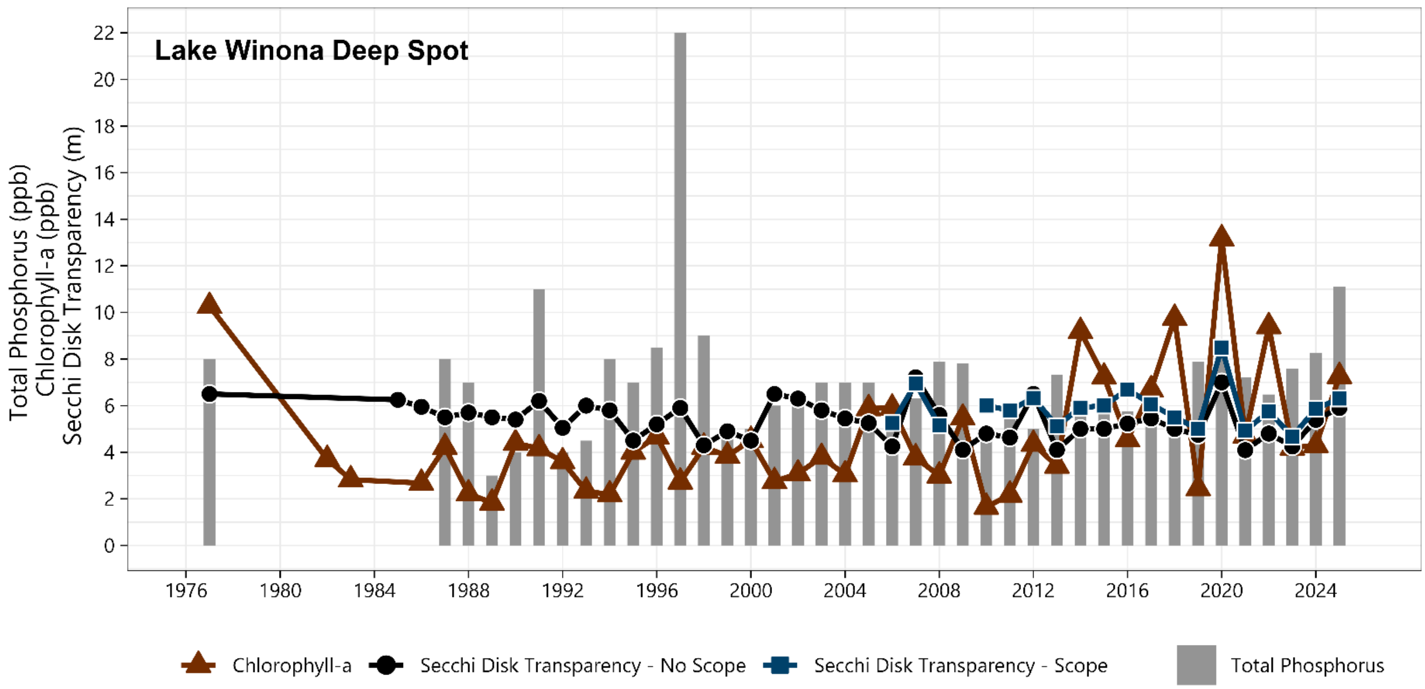

Figure 10. Median epilimnion total phosphorus, median epilimnion chlorophyll-*a*, and median water clarity (Secchi disk depth for scope and no scope methods) measured at the Lake Winona deep spot largely in June-September from 1977-2025.

Stream Total Phosphorus

The water quality of tributaries to Lake Waukewan and Lake Winona can reveal areas throughout the watershed that are contributing disproportionate quantities of certain pollutants (Figure **2**). Stream health is also critical because tributaries often abut wetland habitat essential for pollution sensitive aquatic biota including macroinvertebrates. Excess phosphorus loading in streams can lead to eutrophication in downstream lakes and increases the risk of potentially toxic cyanobacteria blooms. Phosphorus can enter streams from watershed sources such as soil erosion, agriculture, and other human disturbances.

Three tributaries to Lake Winona, including the Lake Winona-North Inlet (WINNWHI4), Lake Winona-Heights Brook Inlet (WINNWHI1) and the East Tributary from Hawkins Pond (Lake Winona-Hawkins Pond Inlet, WINNWHI6) have consistent, annual data collection for total phosphorus (Figure 11). The Snake River, which connects Lake Winona to Lake Waukewan, has six sites that are regularly sampled: the Lake Winona Outlet (WINNWHO), Snake River-Site 3 (SNANWH3), Snake River-Site 2 (SNANWH2), Snake River-Site 5 (SNANWH5), Snake River-Site 1 (SNANWH1), and the Lake Waukewan Inlet (WAUMERI) (Figure 12). Lake Waukewan has three additional streams with consistent data (2013-2025), including Mayo Farm Brook (WAUMER6), EE Brook (WAUMER9) and multiple sites along Sayward Brook (in order of upstream to downstream. WAUMER7B, WAUMER7A, WAUMER7) (Figure 13).

Total phosphorus is generally low in all streams to both lakes though still elevated relative to reference undisturbed levels. The highest total phosphorus concentration observed at any site across all sampling events was 53.5 ppb at the Heights Brook Inlet to Lake Winona. This total phosphorus concentration is well below the maximum in-stream total phosphorus observed in highly disturbed or high loading watersheds throughout New Hampshire. NHDES sets guidelines for total phosphorus in streams, stating that streams are potentially attaining support for aquatic life if the median total phosphorus concentration is below 50 ppb and there are no dissolved oxygen impairments (NHDES, 2024e).

The EPA also provides stream reference values for total phosphorus, which represent undisturbed or natural stream conditions. The EPA's Ambient Water Quality Criteria Recommendations for Rivers and Streams in Nutrient Ecoregion VIII reports a reference condition of 10 ppb for total phosphorus. The reference value for the sub ecoregion containing New Hampshire is 5 ppb (EPA, 2001).

All streams with available data have median total phosphorus concentrations below the 50 ppb threshold. Streams with the highest median total phosphorus concentration over the past ten years are the East Tributary Hawkins Pond Inlet to Lake Winona (WINNWHI6) with 17 ppb, Sayward Brook with 14 ppb at the inlet site (WAUMER7), and Heights Brook Inlet to Lake Winona (WINNWHI1) with 13 ppb. These sites all have relatively low total phosphorus concentrations compared to streams with more highly disturbed watersheds throughout the state. All other sites included in this analysis have median total phosphorus concentrations below 10 ppb, which is evidence of excellent stream water quality. Because the median total phosphorus concentrations for all streams in the Lake Waukewan and Lake Winona watershed exceed the EPA reference value of 5 ppb for Ecoregion VIII, it is likely that all streams are impacted by watershed development, though not at levels indicative of impairment.

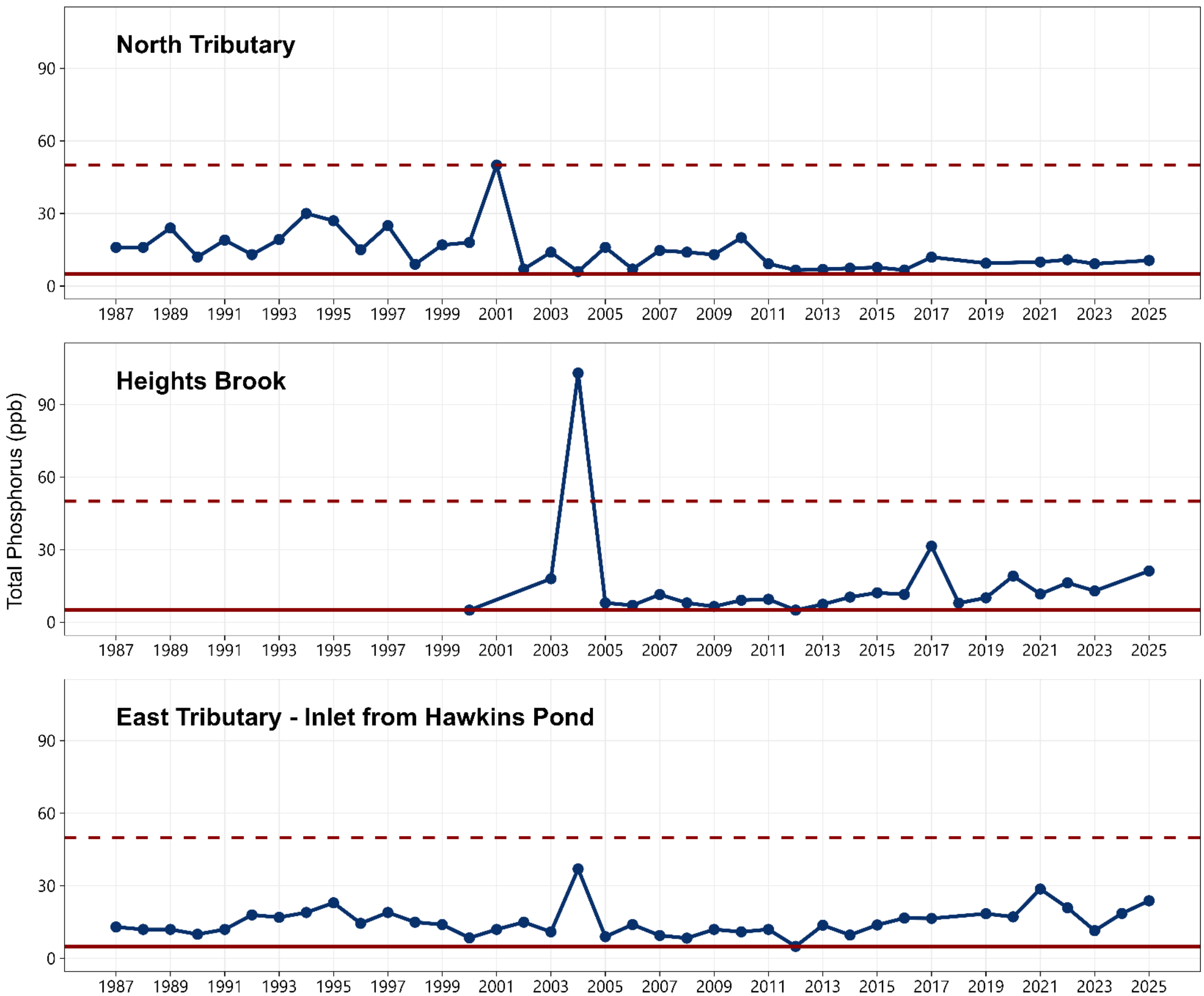

Figure 11. Median annual total phosphorus for the Lake Winona North Inlet from 1987-2025 (WINNWHI4) (top), the Heights Brook Inlet from 2000-2025 (WINNWHI1) (middle) and the East Tributary - Hawkins Pond Inlet from 1987-2025 (WINNWHI6) (bottom). The solid red line represents the reference value (5 ppb) for undisturbed streams from the EPA's Level VIII Ecoregion Sub-ecoregion 58. The dashed red line represents the NHDES threshold (50 ppb) for potentially not supporting aquatic life integrity.

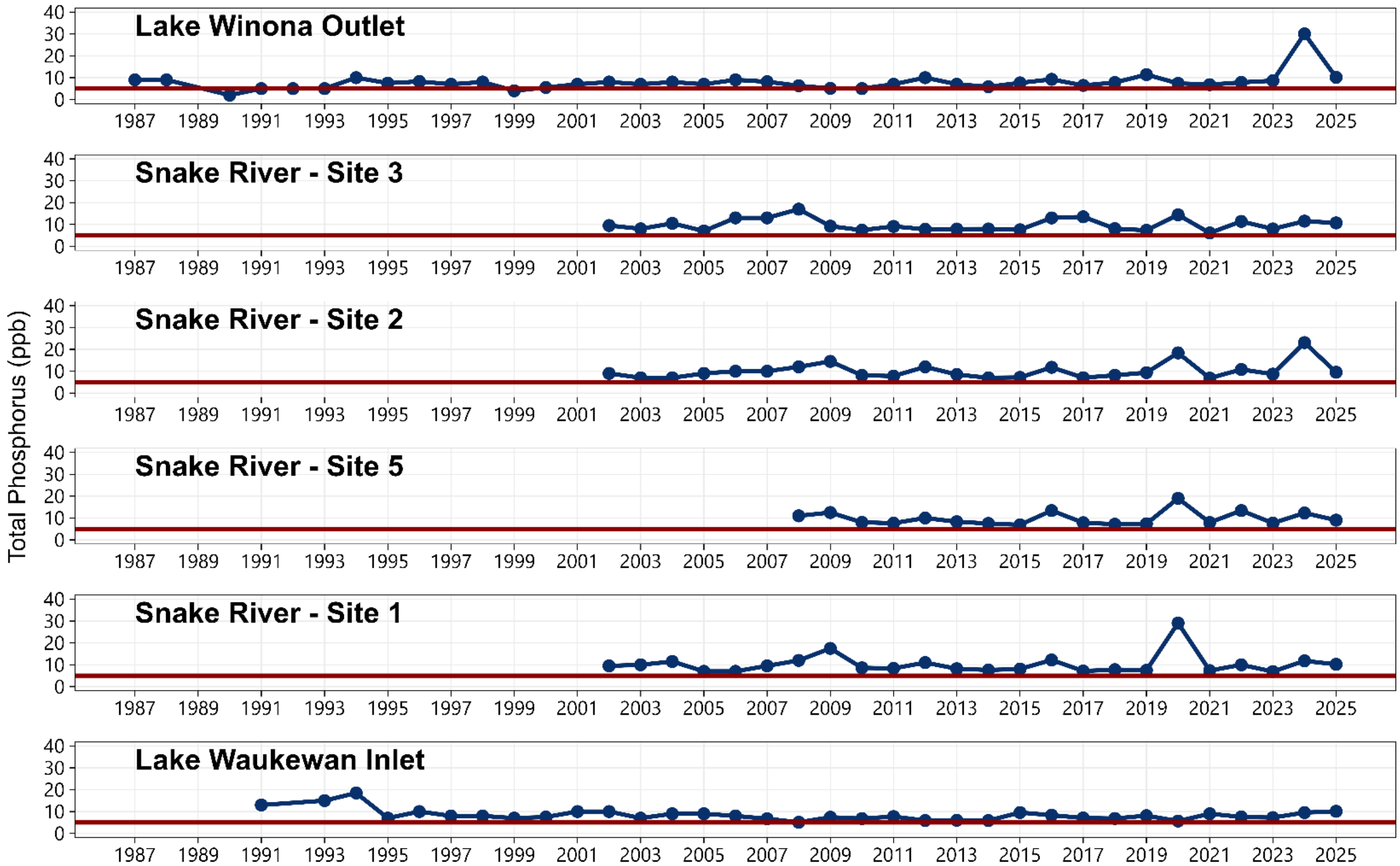

Figure 12. Median annual total phosphorus for the sites along the Snake River, ordered from upstream to downstream (top to bottom). The site IDs, from top to bottom, are as follows: Lake Winona Outlet = WINNWHO, Snake River-Site 3 = SNANWH3, Snake River-Site 2 = SNANWH2, Snake River-Site 5 = SNANWH5, Snake River-Site 1 = SNANWH1, Lake Waukewan Inlet = WAUMERI. The red line represents the reference value (5 ppb) for undisturbed streams from the EPA's Level VIII Ecoregion Sub-ecoregion 58.

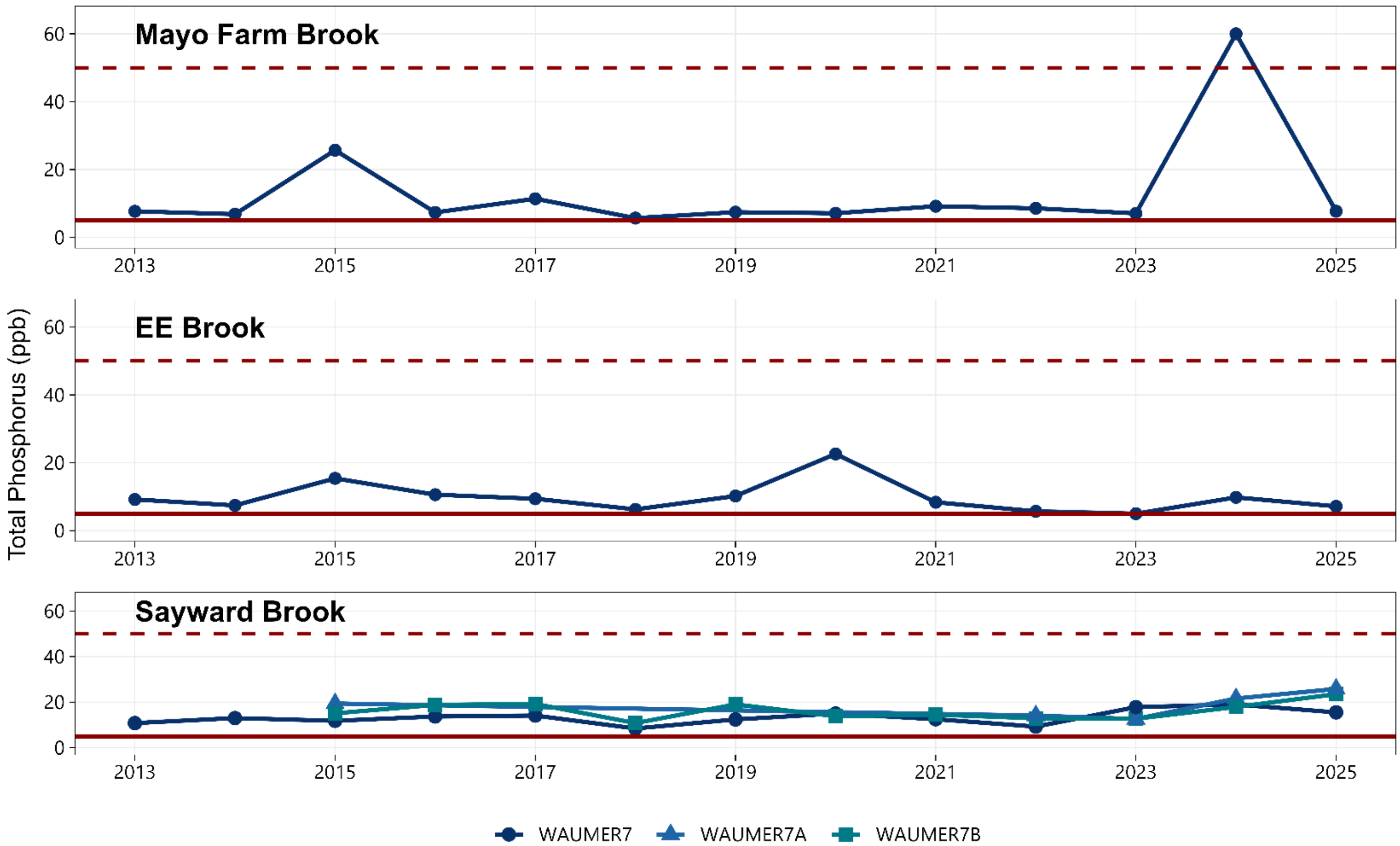

Figure 13. Median annual total phosphorus for Mayo Farm Brook from 2013-2025 (WAUMER6) (top), EE Brook from 2013-2025 (WAUMER9) (middle) and three sites on Sayward Brook, ordered from downstream to upstream (WAUMER7, WAUMER7A, WAUMER7B) (bottom). The red line represents the reference value (5 ppb) for undisturbed streams from EPA's Level VIII Ecoregion Sub-ecoregion 58. The dashed red line represents the NHDES threshold (50 ppb) for potentially not supporting aquatic life integrity.

Shallow Lake Site Total Phosphorus

Total phosphorus concentrations in shallow coves are often higher than those at deep lake sites because they can be strongly influenced by tributaries, pollution sites, and nearshore septic systems with potentially less flushing depending on the lake morphology. High total phosphorus at nearshore sites can signal that pollutants are entering the lake from a specific sub-watershed or shoreline area. Lake Waukewan's VLAP volunteers sample numerous nearshore sites, including Perkins Cove (WAUMERP) and the Lake Waukewan Boat Launch (WAUMER1).

As expected, total phosphorus at the Perkins Cove site shows slightly higher total phosphorus concentrations than deep water sites, nearing or exceeding the NHDES threshold for oligotrophic waterbodies of 8.0 ppb (Figure 14). In the past ten years, the site has a median total phosphorus concentration of 7.5 ppb total phosphorus concentration at this site reached 157 ppb in 2019. Phosphorus concentrations at this site regularly exceed mesotrophic and occasionally even eutrophic thresholds (Figure 14), indicating that pollutant sources near the site are impacting water quality. This nearshore site is especially critical given its proximity to the water supply intake pipe.

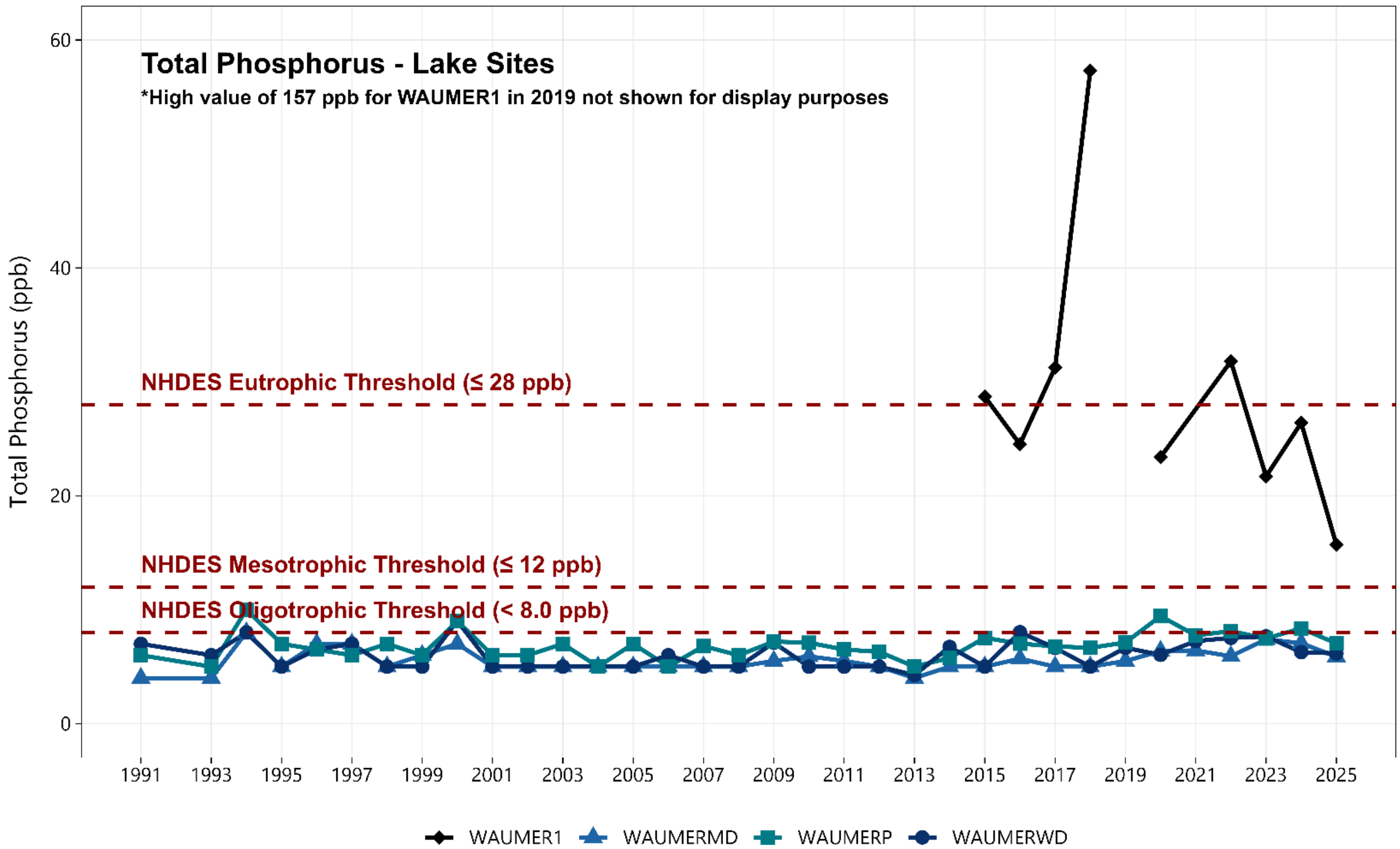

Figure 14. Yearly median total phosphorus concentrations at monitoring locations in Lake Waukewan from 1991-2025, including the boat launch (WAUMER1), Perkins Cove (WAUMERP), and the epilimnion of the Winona Station deep spot (WAUMERWD) and the Mayo Station deep spot (WAUMERMD). A high value of 157 ppb was removed for WAUMER1 in 2019 for display purposes.

Phytoplankton and Zooplankton

Cyanobacteria Bloom History

Cyanobacteria can form blooms in lakes under the right conditions. These blooms can be characterized by surface scums, benthic mats, or green, soupy water. Cyanobacteria blooms can be potentially toxic and can also deplete dissolved oxygen in the lake's hypolimnion as the cells decay, reducing cold-water fish habitat and triggering internal phosphorus loading from bottom sediments.

Lake Waukewan has only had one officially reported NHDES cyanobacteria bloom warning (Table 1). The warning lasted four days in August 2009 and was dominated by *Anabaena* (now *Dolichospermum*) with over 70,000 cells/mL. However, as noted in FBE (2025), seven other bloom conditions not reported as official warnings occurred on the lake between 2011 and 2020 that were often around the time of fall turnover and had accumulations consistent with *Dolichospermum* blooms. Cyanotoxin testing in Lake Waukewan in 2024 indicated low levels of the toxins that cyanobacteria are capable of producing (FBE, 2025). The dominant cyanobacteria were picocyanobacteria, which are tiny, unicellular (0.2–2 µm) cyanobacteria that are too small to be seen by the human eye, even when magnified under a microscope. A high relative abundance of picocyanobacteria is reflective of low-nutrient conditions.

Lake Winona has had three cyanobacteria warnings and one watch issued by NHDES, as of January 2026 (Table 1). These have all been dominated by *Dolichospermum,* a dominant cyanobacteria type in the Lakes region. Though the types of toxins produced by this group are dependent upon the species, *Dolichospermum* can produce microcystin (hepatotoxin), cylindrospermopsin (hepatotoxin), and anatoxin-a (neurotoxin).

Table 1. Cyanobacteria bloom history of Lake Waukewan and Lake Winona.

Waterbody	Notification Type	Date Issued	Date Removed	# Days issued	Dominant Taxa	Initial Cyanobacteria Cell Density (cells/mL)
Lake Waukewan	Warning	8/24/2009	8/28/2009	4	*Anabaena*	>70,000 or >50%
Lake Winona	Warning	8/29/2018	9/7/2018	9	*Anabaena / Dolichospermum*	1,000,000
Lake Winona	Warning	6/19/2020	6/24/2020	5	*Anabaena / Dolichospermum*	365,000
Lake Winona	Watch	8/9/2020	**	**	**	**
Lake Winona	Warning	7/27/2023	8/3/2023	7	*Dolichospermum*	950,000

Phytoplankton and Zooplankton

A detailed overview of the phytoplankton community in Lake Waukewan for the 2024 summer season, as well as for 2017-2024 based on VLAP data, is provided in FBE (2025). The phytoplankton community in Lake Waukewan is typically dominated by diatoms and golden-brown algae, with cyanobacteria dominating occasionally but often comprising less than 10% of the total algal colonies or units. However, composition changes by season and is associated with lake stratification. Overall phytoplankton abundance is low, while diversity and evenness is high, indicating a balanced ecological community and a low productivity trophic state (FBE, 2025).

Zooplankton samples were collected for Lake Waukewan during the 1982 and 1994 Lake Trophic Surveys (NHDES, 1982, 1994). Each survey includes two biological sampling events; first in summer and in the following winter. During the 1982 survey, no zooplankton taxa were identified as dominant, and zooplankton counts were low with only 18 Microcrustacea per liter. In the 1994 survey, crustaceous zooplankton far outnumbered rotifers in the summer sample, while zooplankton abundance was lower overall in the winter sample compared to the summer sample. Abundant zooplankton taxa included *Nauplius* larvae (copepod), *Calanoid* copepods, *Gastropus* (rotifer), *Keratella* (rotifer), and *Synchaeta* (rotifer).

Enhanced zooplankton monitoring in 2024 indicated a diverse community at the intake and deep spot sites, with 4-12 unique genera observed in each sample, and high diversity and evenness indices (FBE, 2025). This indicates a well-balanced zooplankton community that can graze on various phytoplankton and is more resilient to environmental changes. However, zooplankton biomass was relatively low.

Cladocerans and copepods comprised most of the zooplankton biomass. Cladocerans found in Lake Waukewan included *Bosmina, Daphnia dubia, Daphnia pulex*, and *Holopedium*. These crustaceans (especially *Daphnia*) tend to be the most efficient grazers in the lake ecosystem and are often the largest zooplankton depending on the species.

In the Lake Winona NHDES Trophic Surveys (NHDES, 1977; 1987; 2005), phytoplankton communities were dominated by *Dinobryon* (golden-brown), *Asterionella* (diatom), *Urosolenia* (formerly *Rhizosolenia,* a diatom), *Synura* (golden-brown), and *Chrysosphaerella* (golden-brown) in the summer samples. In winter, dominant taxa included *Asterionella, Urosolenia, Mallomonas* (golden-brown), *and Melosira* (diatom). Zooplankton communities consisted primarily of unidentified Protozoan species, *Keratella* (rotifer), *Nauplius* larva (crustaceans), *Kellicottia* (rotifer), and unidentified rotifer species in the summer surveys. Dominant zooplankton in winter consisted of *Kellicottia*, *Synchaeta* (rotifer), *Nauplius* larva, *Polyarthra* (rotifer), and unidentified ciliate and rotifer species. Rotifers are small zooplankton that eat small phytoplankton and that are consumed by fish or larger zooplankton whose population can respond quickly to environmental changes. *Daphnia* are among the most efficient grazers of phytoplankton but were not shown to be a dominant zooplankton in Lake Winona. Maintaining a balanced and sustainable food web of phytoplankton and zooplankton are necessary components of a healthy lake ecosystem.

Chloride and Specific Conductivity

Chloride pollution can cause harm to aquatic organisms and interfere with natural lake mixing when concentrations reach toxic levels. In New Hampshire, the chronic impairment threshold is 230 ppm for chloride which equates to about 835 µS/cm specific conductivity. Chloride concentrations in Lake Waukewan and Lake Winona are well below the chronic impairment threshold. However, chloride and specific conductivity in the epilimnion of both lakes are above the median for New Hampshire lakes (NHDES, 2024b) (Table 2), and chloride and specific conductivity levels at the Lake Waukewan Boat Launch site (WAUMER1) are markedly higher than those at both lake deep spots and other shallow sites. The median chloride concentration at the boat launch site is more than four times greater than the median chloride concentration in the rest of the lake (Figure 15, Table 2). High concentrations at the site suggest that direct runoff from the roads and outfalls near the boat launch may have a disproportionate impact on levels throughout the lake. Locally high chloride concentrations may have a large impact on aquatic wildlife immediate to the inlet area.

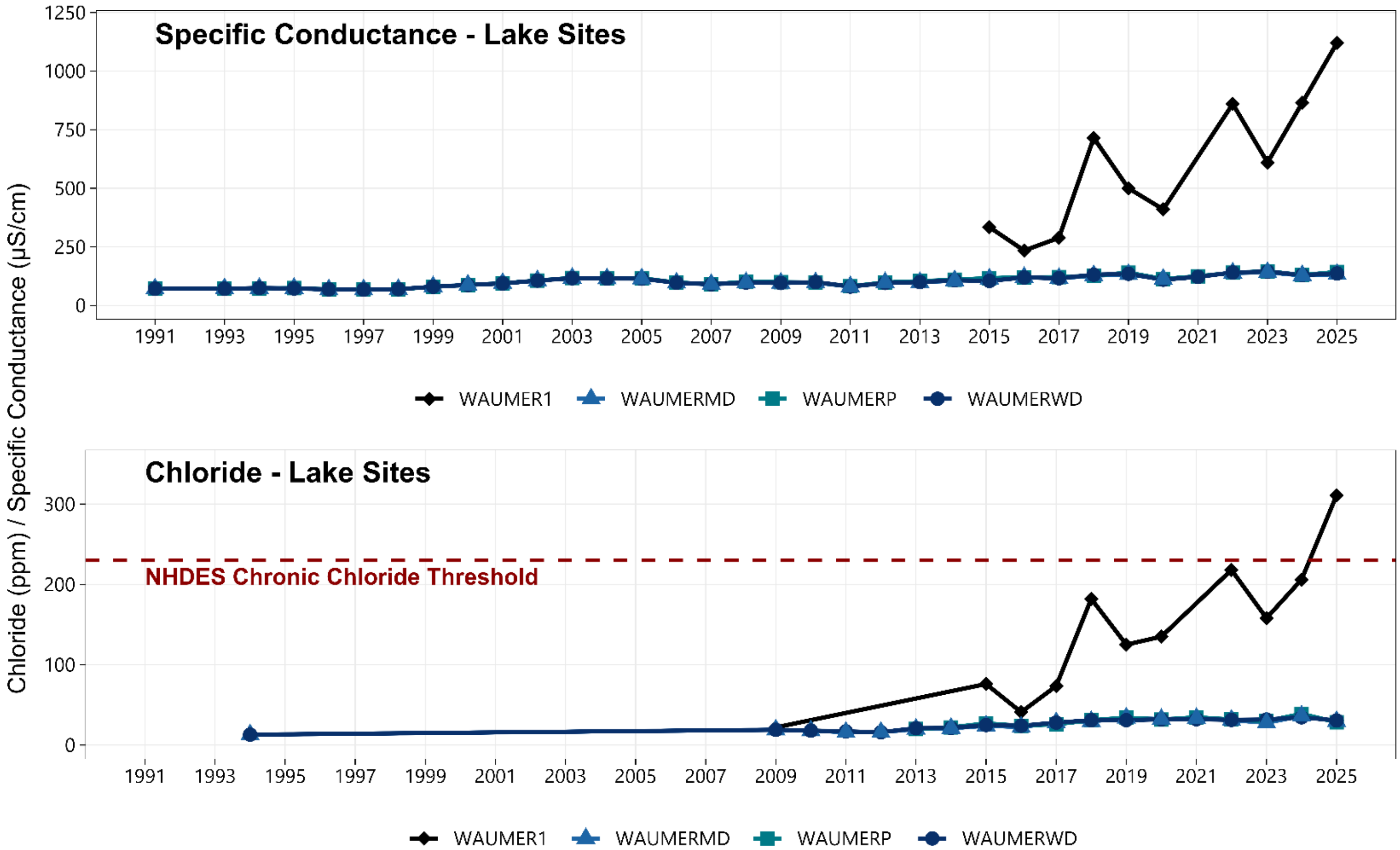

Figure 15. Yearly median specific conductivity (top) and chloride (bottom) concentrations at monitoring locations in Lake Waukewan, including the boat launch (WAUMER1), Perkins Cove (WAUMERP), and the epilimnion of the Winona Station deep spot (WAUMERWD) and the Mayo Station deep spot (WAUMERMD).

Table 2. Median chloride and specific conductance values for New Hampshire lakes and in the epilimnion of Lake Waukewan and Lake Winona deep spots and select shallow sites on Lake Waukewan for the period 2016-2025.

Parameter	New Hampshire	Lake Waukewan – Winona Deep Spot (Epilimnion)	Lake Waukewan – Mayo Deep Spot (Epilimnion)	Lake Winona Deep Spot (Epilimnion)	Lake Waukewan – Perkins Cove	Lake Waukewan – Boat Launch
Chloride (Median)	5 mg/L	32 mg/L	31 mg/L	17 mg/L	31 mg/L	135 mg/L
Specific Conductivity (Median)	42.3 µS/cm	129 µS/cm	127 µS/cm	81 µS/cm	130 µS/cm	510 µS/cm

Specific conductivity shows an increasing (worsening) trend in epilimnion and hypolimnion layers at the Lake Waukewan and Lake Winona deep spots between 1982 and 2025 (Figure 16 and Figure 17), suggesting that salt impacts to the lakes have worsened over time. This overall increasing trend was detected despite periods of decreasing specific conductivity in both lakes. Chloride in the epilimnion is also statistically increasing (worsening) at all three sites, while chloride samples from hypolimnion depths are too sparse to detect a trend.

The increasing trends indicate that chloride from winter salting practices in the watershed, water softeners, and seepage from septic systems may be contaminating the lakes. Applying de-icing road salts is a common practice in New Hampshire for maintaining road safety during the winter months, and there is no natural process that uses or breaks down chloride (NHDES, 2021). Chloride levels may also be increasing due to the use of water softeners within the watershed. In a water softening system, salts are often added to remove calcium and magnesium from household water. The result is a salty byproduct that enters the wastewater treatment system, and septic systems are traditionally not designed for salt removal (NH Lakes, 2024). Another potential source of chloride and specific conductivity is sediment loading from eroding, unpaved roads throughout the watershed. Steep slopes located in some areas of the watershed may make it more susceptible to soil loss and road erosion. Other sources of pollution that may increase chloride and specific conductivity levels include inputs from fertilizers and agricultural runoff. Specific conductivity and chloride levels have increased sharply over the past ten years at the boat ramp site, reaching levels very close to or exceeding chronic toxicity to aquatic life at that site in recent years. For example, specific conductivity reached 1,121 µS/cm and chloride reached 311 mg/L in 2025, exceeding the chronic chloride threshold of 230 mg/L. Road salt applications in that area should be urgently investigated and opportunities for salt reduction pursued. While not an immediate concern at other lake sites, chronic chloride toxicity will likely become an issue in the future without a proactive reduction in salt use in the watershed.

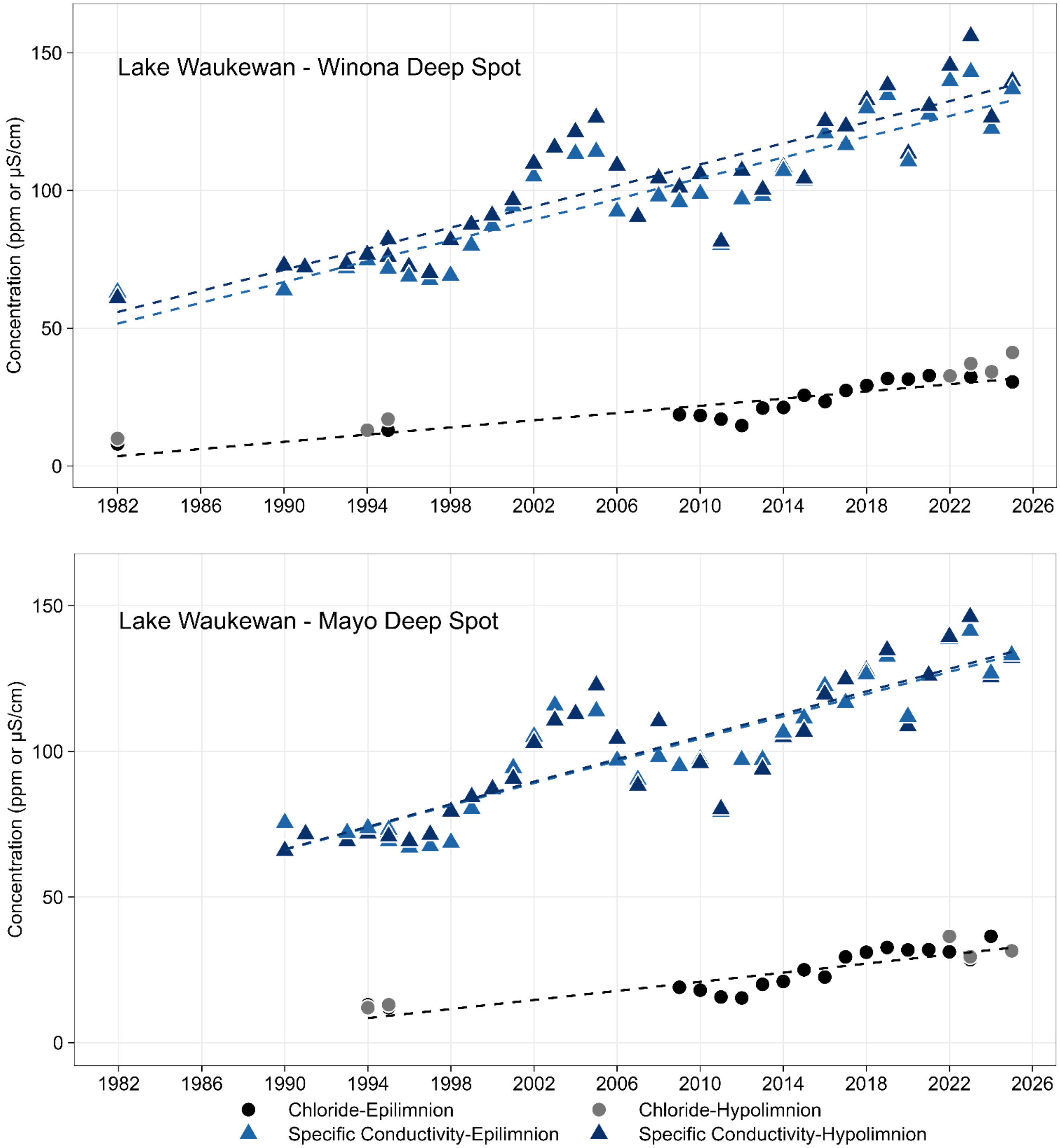

Figure 16. Yearly median of monthly medians for chloride and specific conductivity in the Winona (top) and Mayo (bottom) deep spots of Lake Waukewan. Dashed lines indicate a statistically significant increasing (worsening) trend. There are insufficient hypolimnion chloride data for a trend analysis.

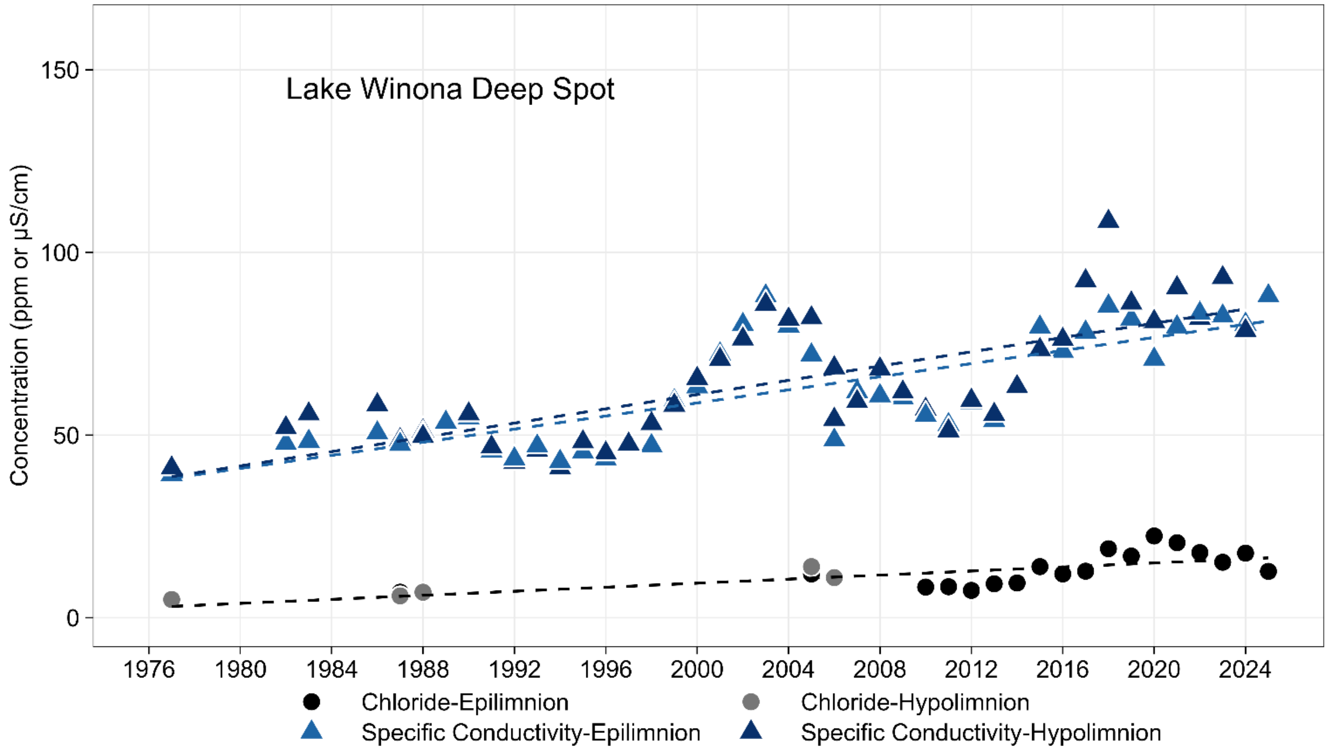

Figure 17. Yearly median of monthly medians for chloride and specific conductivity in the Lake Winona deep spot (WINNWHD). Dashed lines indicate a statistically significant increasing (worsening) trend. There are insufficient hypolimnion chloride data for a trend analysis.

pH

The pH of a water body describes how acidic or basic the water is, with 7 representing neutral. Lower values indicate more acidic conditions, while higher values indicate more basic conditions. The habitable range of pH for aquatic organisms is near neutral, with NHDES setting the standard for Class B waterbodies to have a pH between 6.5 and 8.0 to protect aquatic life (Figure 18).

Figure 18. Graphic of the pH scale, indicating the zone which supports aquatic life.

Median pH in the epilimnion at the two deep spots of Lake Waukewan (WAUMERWD; WAUMERMD) and the deep spot of Lake Winona is occasionally below a pH of 6.5, which is the lower (more acidic) end of the acceptable range set by NHDES (Figure 19). pH tends to be improving in New Hampshire lakes as they recover from the impacts of acid rain. New Hampshire lakes tend to have naturally low alkalinity, meaning there is little natural resilience to acid rain impacts.

Across the depth zones from 2016-2025, pH has generally been higher (less acidic) in the epilimnion than in the metalimnion or hypolimnion (Figure 19). This pattern is expected as photosynthesis in the photic zone consumes carbon dioxide and raises pH, while respiration at greater depths has the opposite effect resulting in acidifying conditions. The pH may be lowest in the hypolimnion due to organic matter settling and decomposing, increasing respiration and acidity. The hypolimnion has a median pH value below the NHDES guideline range for supporting aquatic life (Figure 19). Low pH can stress aquatic organisms, and extreme low pH can also mobilize iron and aluminum-bound phosphorus from lake sediments, degrading water quality.

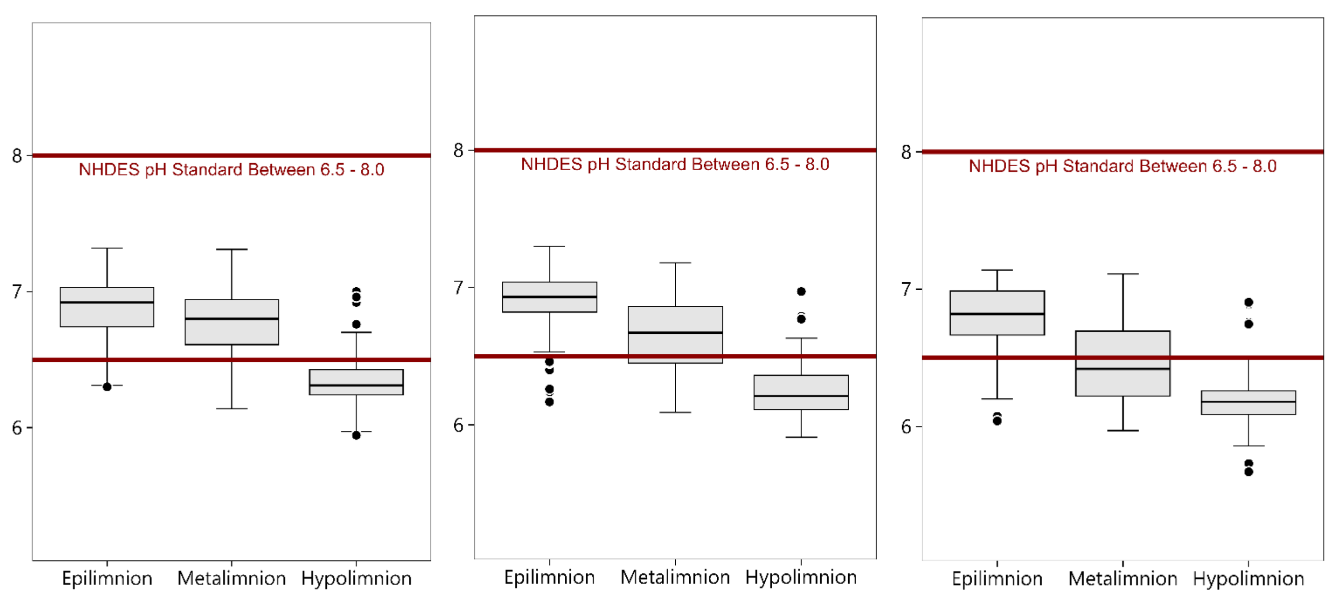

Figure 19. Boxplots showing the median pH in the epilimnion, metalimnion, and hypolimnion of the Winona Station deep spot (WAUMERWD) (left) and Mayo Station deep spot (WAUMERMD) (middle) of Lake Waukewan and the deep spot of Lake Winona (WINNWHD) (right) for the past 10 years, 2016-2025. Values were converted to the concentration of hydrogen ions before being summarized and logarithmically transformed to the pH scale.

ASSIMILATIVE CAPACITY

The assimilative capacity of a lake describes how much of a pollutant can be added without causing a violation of the Anti-degradation Tiers as listed in the NHDES Consolidated Assessment and Listing Methodology (NHDES, 2024e). The three tiers include: Tier 2, high quality waters where water quality is better than 10% of the difference between the best possible water quality (next lower trophic condition) and the criteria; Tier 1, where water quality is within 10% of the difference between the best possible water quality (next lower trophic condition) and the criteria; and Impaired, where water quality exceeds the criteria. Support determinations are based on the nutrient stressor (phosphorus) and response indicator (chlorophyll-*a*). When both parameters are available and the assessment differs between the two variables, chlorophyll-*a* dictates the assessment.

Water quality standards are specific to the lake's trophic classification. Lake Waukewan was assessed as an oligotrophic waterbody in the 1982 and 1994 trophic surveys. Lake Winona was classified as eutrophic in 1977, and as mesotrophic in 1987 and 2005. For a lake classified as oligotrophic, such as like Lake Waukewan, Tier 2 would be equal to or less than a median of 7.2 ppb of total phosphorus, and 3.0 ppb for chlorophyll-*a*. Tier 1 would be between 7.2 and 8.0 ppb for total phosphorus, and between 3.0 and 3.3 ppb for chlorophyll-*a*. Impaired would be greater than 8.0 ppb for total phosphorus, and 3.3 ppb for chlorophyll-*a*. For a lake classified as mesotrophic, such as like Lake Winona, Tier 2 would be equal to or less than a median of 11.6 ppb of total phosphorus, and 4.8 ppb for chlorophyll-*a*. Tier 1 would be between 11.6 and 12 ppb for total phosphorus, and between 4.8 and 5 ppb for chlorophyll-*a*. Impaired would be greater than 12 ppb for total phosphorus, and >5 ppb for chlorophyll-*a*.

Results of the assimilative capacity analysis show that Lake Waukewan is currently attaining the oligotrophic class designation, and Lake Winona is meeting the mesotrophic designation (Table 3, Table 4, Table 5). However, the median chlorophyll-*a* level in Lake Winona is only 0.1 ppb above the reserve capacity threshold. There is substantially less reserve capacity available for the response indicator (chlorophyll-*a*) than the nutrient stressor (phosphorus) for Lake Winona, suggesting that factors other than total phosphorus (such as nitrogen, micronutrients, light, and/or mixing) may have a larger influence on primary productivity in the lake.

Table 3. Assimilative capacity (AC) analysis results for Lake Waukewan using oligotrophic standards based on water quality data collected from the Winona Station South Deep Spot (WAUMERWD). Chlorophyll-*a* dictates the assessment results. ppb = parts per billion.

Parameter	CALM **Tier 2 Standard (ppb)**	CALM **Tier 1 Standard (ppb)**	CALM **Impaired Standard (ppb)**	Lake Waukewan **Existing Median WQ (ppb)***	Lake Waukewan **Remaining AC (ppb)**	Lake Waukewan **WQ Tier**	Lake Waukewan **Assessment Results**
Total Phosphorus	<7.2	7.2-8.0	>8.0	6.4	+0.8	Tier 2	Attaining Tier 2
Chlorophyll-*a*	<3.0	3.0-3.3	>3.3	1.9	+1.1	Tier 2	

** Existing water quality data truncated to May 24-Sept 15 in the previous 10 years (2016-2025) 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.*

Table 4. Assimilative capacity (AC) analysis results for Lake Waukewan using oligotrophic standards based on water quality data collected from the Mayo Station North Deep Spot (WAUMERMD). Chlorophyll-*a* dictates the assessment results. ppb = parts per billion.

Parameter	CALM **Tier 2 Standard (ppb)**	CALM **Tier 1 Standard (ppb)**	CALM **Impaired Standard (ppb)**	Lake Waukewan **Existing Median WQ (ppb)***	Lake Waukewan **Remaining AC (ppb)**	Lake Waukewan **WQ Tier**	Lake Waukewan **Assessment Results**
Total Phosphorus	<7.2	7.2-8.0	>8.0	5.7	+1.5	Tier 2	Attaining Tier 2
Chlorophyll-*a*	<3.0	3.0-3.3	>3.3	2.3	+0.7	Tier 2	

** Existing water quality data truncated to May 24-Sept 15 in the previous 10 years (2016-2025) 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.*

Table 5. Assimilative capacity (AC) analysis results for Lake Winona using mesotrophic standards based on water quality data collected from the deep spot (WINNWHD). Chlorophyll-*a* dictates the assessment results. ppb = parts per billion.

Parameter	CALM **Tier 2 Standard (ppb)**	CALM **Tier 1 Standard (ppb)**	CALM **Impaired Standard (ppb)**	Lake Winona **Existing Median WQ (ppb)***	Lake Winona **Remaining AC (ppb)**	Lake Winona **WQ Tier**	Lake Winona **Assessment Results**
Total Phosphorus	<11.6	11.6-12	>12	7.8	+3.8	Tier 2	Attaining Tier 2
Chlorophyll-*a*	<4.8	4.8-5	>5	4.7	+0.1	Tier 2	

** Existing water quality data truncated to May 24-Sept 15 in the previous 10 years (2016-2025) 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.*

MONITORING RECOMMENDATIONS

Given the available data summarized in this memorandum, the following recommendations are presented to enhance existing monitoring efforts as resources and funding allow. Recommendations are prioritized based on a combination of feasibility and importance.

Monitoring is essential to evaluate the effectiveness of the Watershed Restoration Plan update. At a minimum, VLAP should continue the current data collection at all long-term monitoring locations, including WAUMERWD, WAUMERMD, WINNWHD, and the tributaries feeding both lakes. The VLAP volunteers should continue to collaborate with VLAP to collect and submit all data to the NHDES for review and incorporation into the state Environmental Monitoring Database each year.

1. **Collect Additional Dissolved Oxygen and Temperature Profiles in Lake Winona**

   We recommend that profiles be collected at least monthly from May 15 to September 30 each year between the hours of 10am and 2pm. Additionally, a dissolved oxygen and temperature profile should be taken whenever grab samples are collected, which can serve as the monthly profile. If resources allow, profiles may be collected as frequently as biweekly during this period. All data should be submitted to VLAP.

2. **Expand Routine Monitoring for Total Phosphorus, Chlorophyll-*a*, Turbidity, pH, Specific Conductivity, and Chloride**

   Maintaining and expanding long-term datasets is a critical component of environmental assessments. We recommend continuing to conduct monthly sampling (June-September) for total phosphorus, chlorophyll-*a*, turbidity, pH, specific conductivity, and chloride at the two Lake Waukewan deep spots and Lake Winona deep spot. Additional parameters, such as total nitrogen and total iron, as recommended in (FBE, 2025), may be added as funding allows.

3. **Conduct flow monitoring at select stream sites.**

   Stream flow monitoring at select tributary sites can help characterize pollutant loading from streams under different weather conditions. We recommend flow monitoring at tributaries that are regularly sampled for total phosphorus, such as a low-gradient site close to the inlet to Lake Waukewan on the Snake River, and potentially EE Brook, Sayward Brook, or Mayo Farm Brook. Lake Winona sites such as the inlet from Hawkins Pond, the North Inlet, or Heights Brook Inlet are also viable candidate sites.

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