LAKE WAUKEWAN AND LAKE WINONA **WATER QUALITY GOAL**

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

This memo summarizes steps undertaken in determining a recommended water quality goal and objectives for Lake Waukewan and Lake Winona. The final water quality goal will be determined based on discussions among project partners and stakeholders at a Steering Committee meeting on May 5, 2026. The goal will be used to measure the success of future watershed management actions recommended in the Lake Waukewan and Lake Winona Watershed Restoration Plan Update.

INTRODUCTION

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. 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 sulfate algaecide in 1967 and 1968 to control algal blooms (NHDES, 2005).

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. 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.

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.

Figure 1 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 2 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.

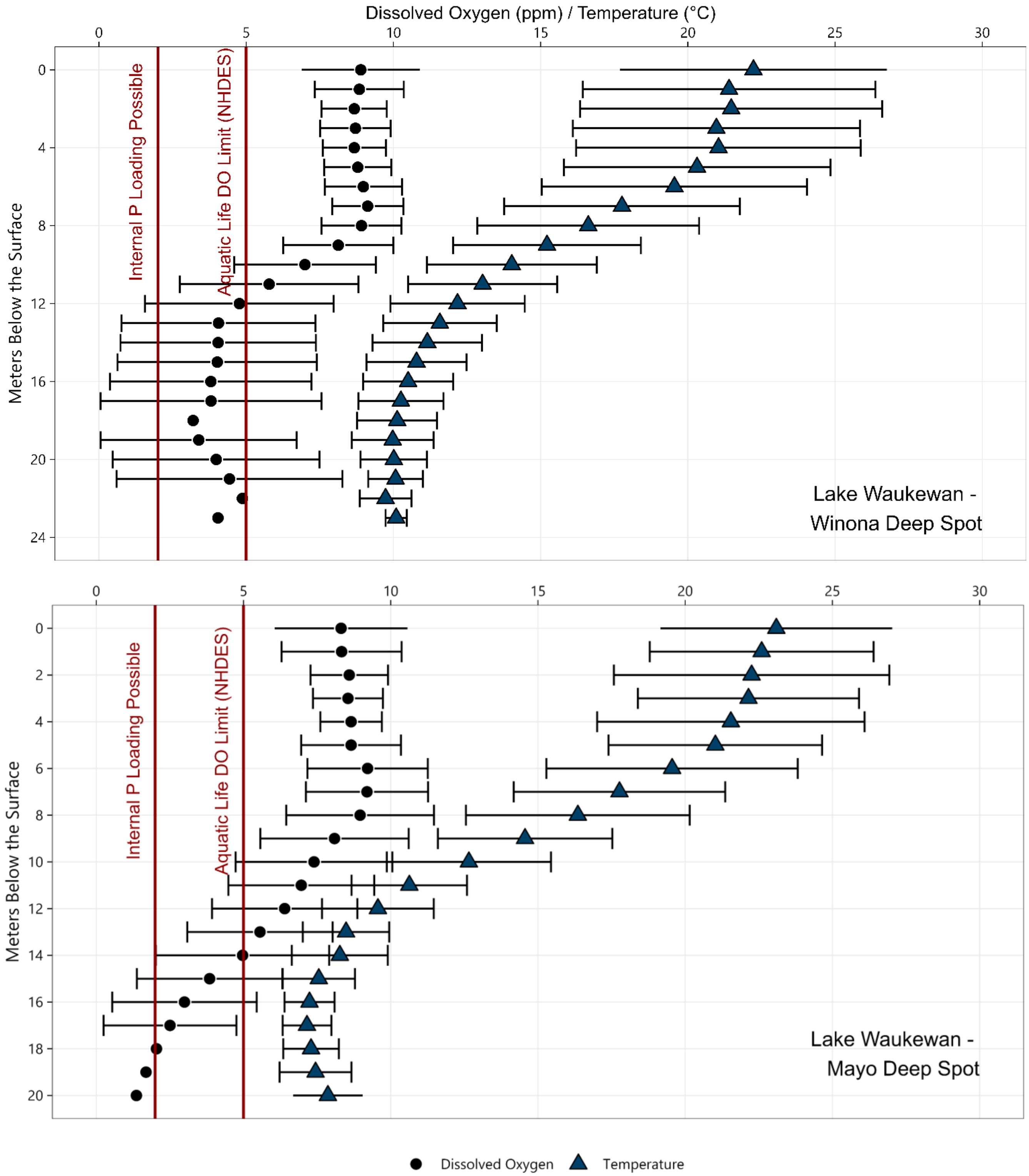

Figure 1. Dissolved oxygen and water temperature depth profiles for the Winona (top) and Mayo (bottom) deep spots of Lake Waukewan (WAUMERWD and WAUMERMD, respectively). Dots represent average values across sampling dates for each respective depth, rounded to the nearest meter. Error bars represent standard 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.

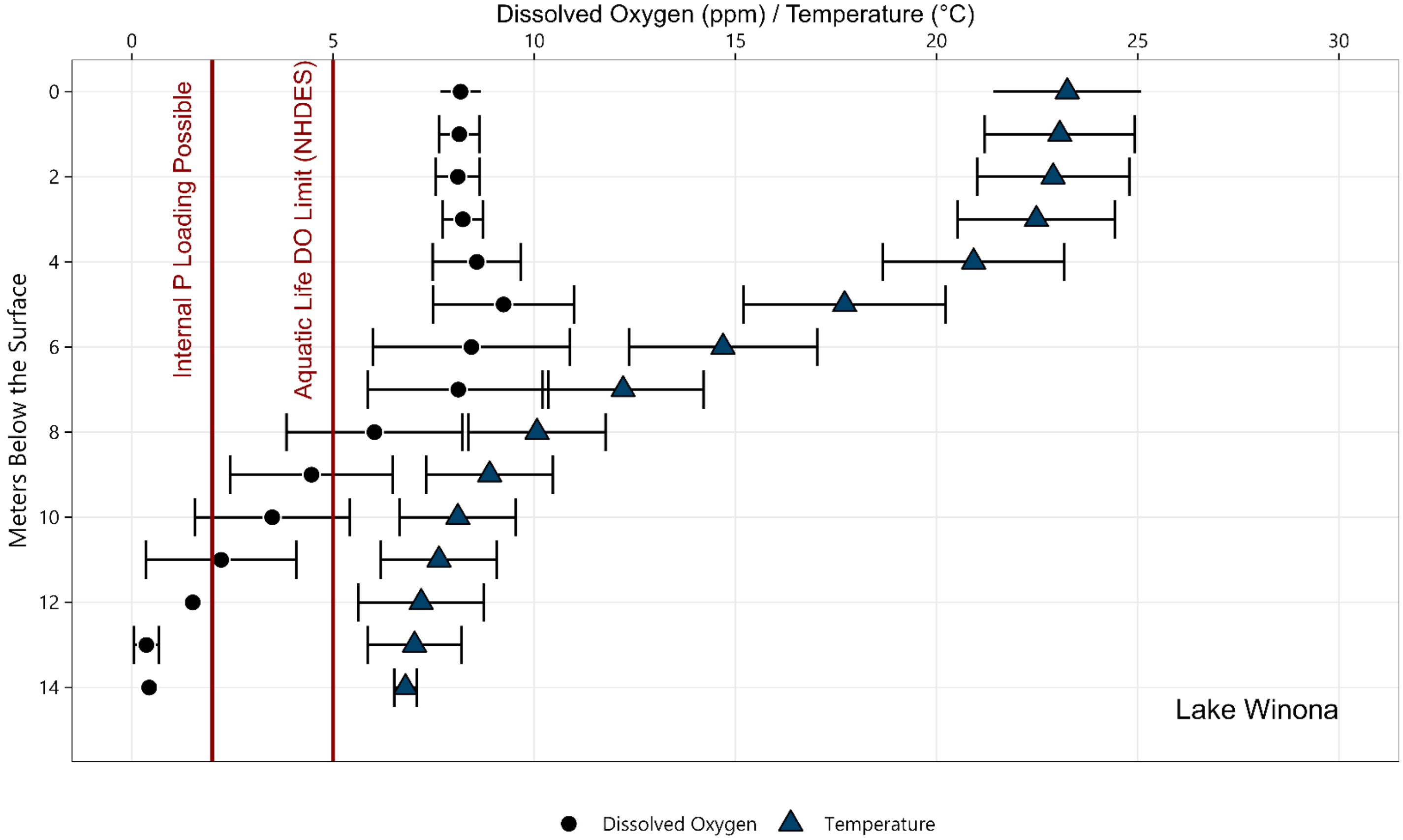

Figure 2. Dissolved oxygen and water temperature depth profiles for the Lake Winona deep spot (WINNWHD). Dots represent average values across sampling dates for each respective depth, rounded to the nearest meter. Error bars represent standard deviation. Data represents profiles collected from 1977-2024 (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 3). 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 4).

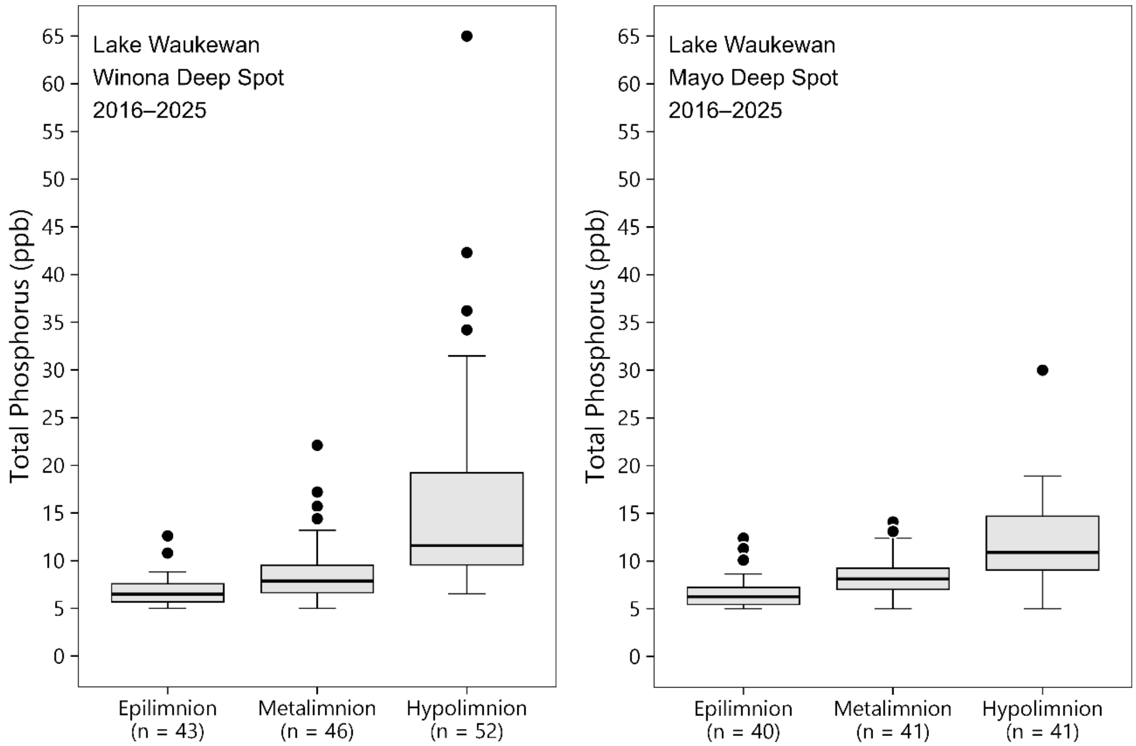

Figure 3. Boxplots showing median total phosphorus concentration in the epilimnion, metalimnion, and hypolimnion of the two Lake Waukewan deep spots from the recent data (2016-2025).

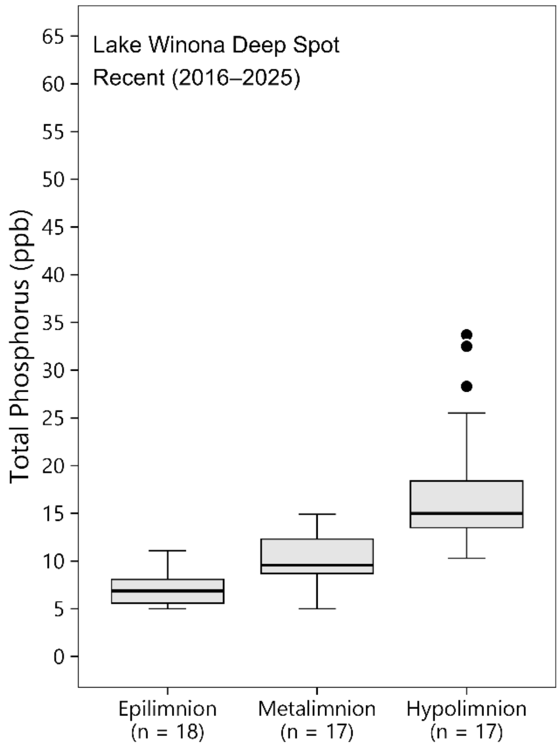

Figure 4. Boxplot showing median total phosphorus concentration in the epilimnion, metalimnion, and hypolimnion at the Lake Winona deep spot from the recent data (2016-2025).

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 5). 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 6). 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.

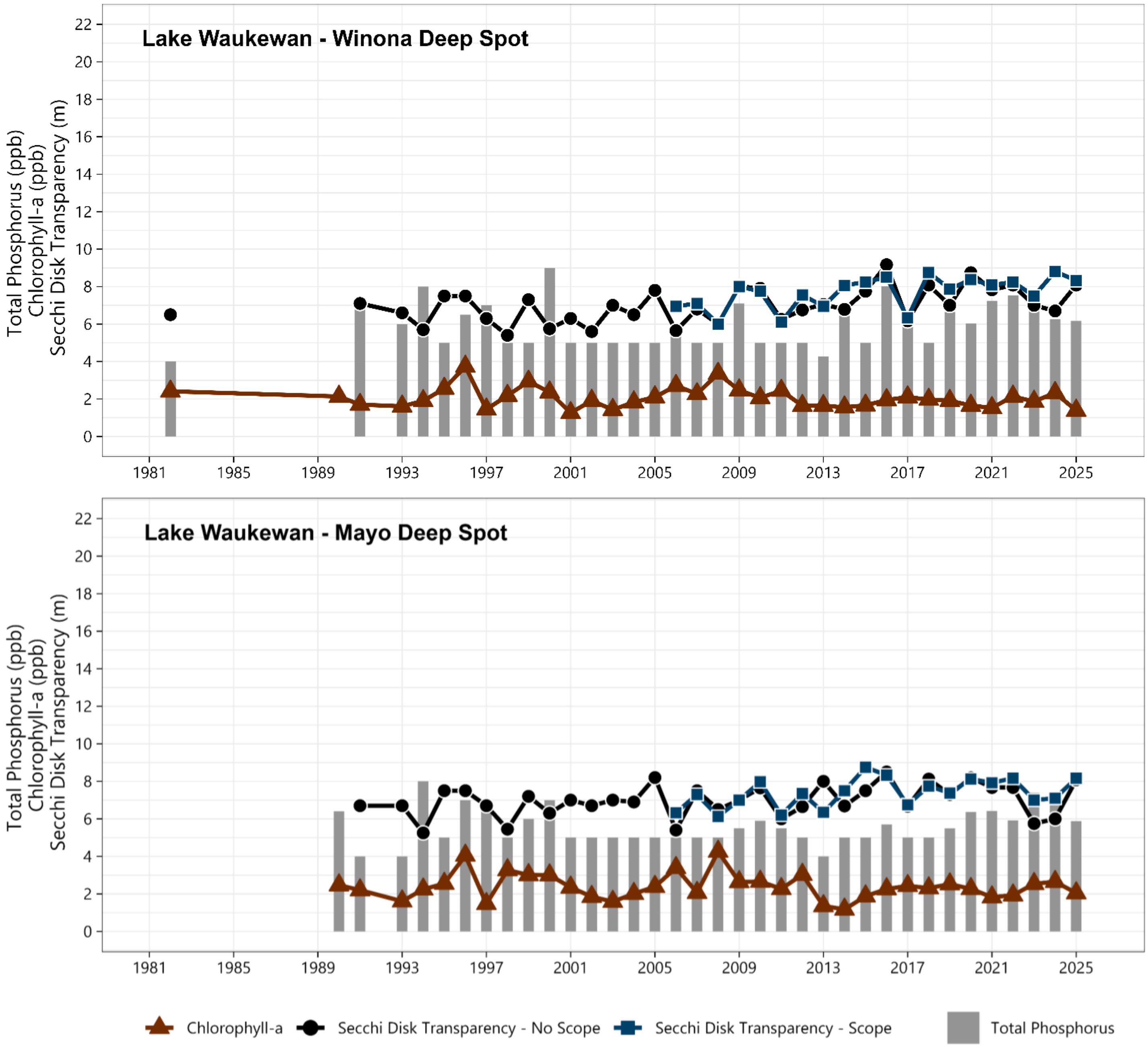

Figure 5. Median epilimnion total phosphorus, median epilimnion chlorophyll-a, and median water clarity (Secchi Disk depth for scope and no scope methods) measured at the Lake Waukewan Winona (top) and Mayo (bottom) deep spots largely in May-September from 1982-2025.

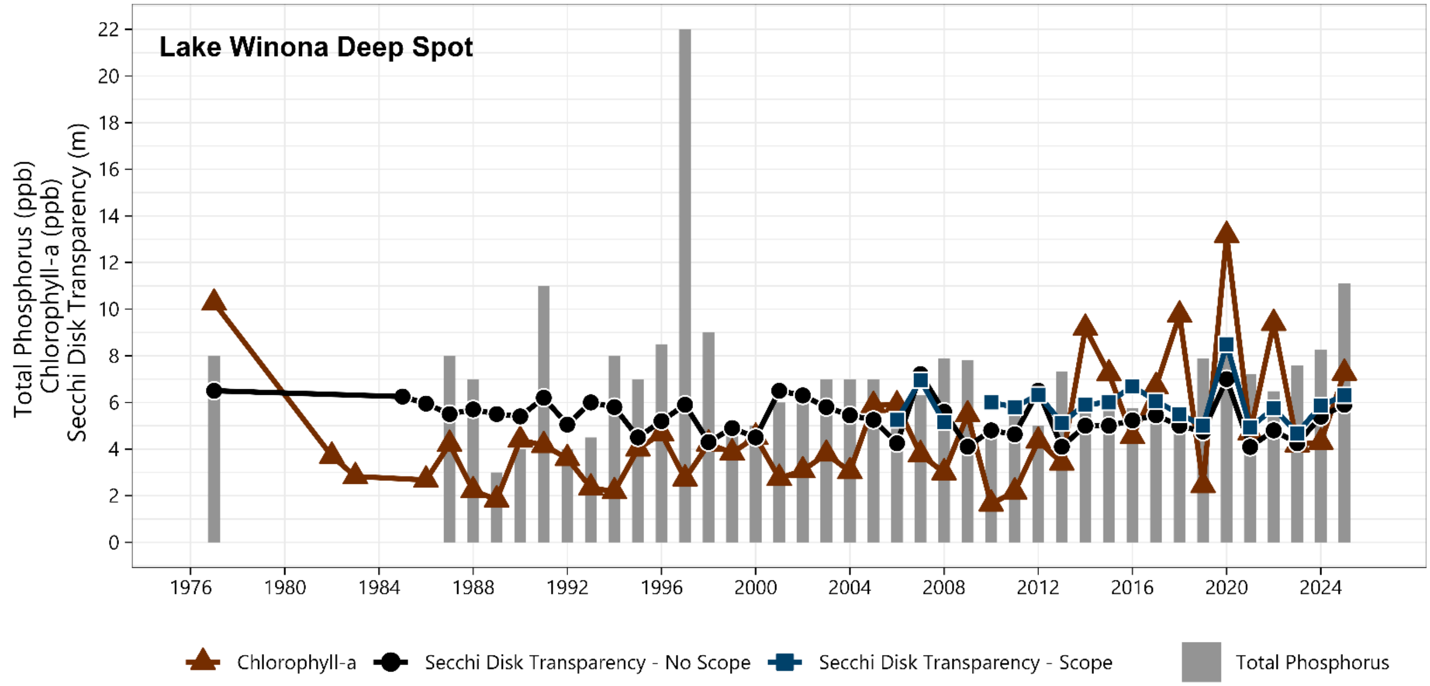

Figure 6. Median epilimnion total phosphorus, median epilimnion chlorophyll-a, and median water clarity (Secchi disk depth for scope and no scope methods) measured at the Lake Winona deep spot largely in June-September from 1977-2025.

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.

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, 2024). 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 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 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 2, Table **3**, Table **4**). 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 2. 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 3. 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 4. 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.*

LAKE LOADING RESPONSE MODEL RESULTS

A second analysis was used to link watershed loading conditions with in-lake total phosphorus and chlorophyll-*a* concentrations to predict past, current, and future water quality in Lake Waukewan and Lake Winona. An Excel-based model, known as the Lake Loading Response Model (LLRM), was used to develop a water and phosphorus loading budget for the lakes and their tributaries. Water and phosphorus loads (in the form of mass and concentration) are traced from sources in the watershed, through tributary basins, and into the lake. The model incorporates data about land cover, watershed boundaries, point sources, septic systems, waterfowl, rainfall, and an estimate of internal lake loading, combined with many coefficients and equations from scientific literature on lakes and nutrient cycles. Refer to the Lake Waukewan and Lake Winona Lake Loading Response Model Memorandum (FBE, 2026).

Overall, model predictions for Lake Waukewan and Lake Winona were in good agreement with observed data for total phosphorus (percent difference between model predictions and data for Lake Waukewan and Lake Winona, respectively: 0% and 1%), chlorophyll-*a* (10% and 21%), and Secchi disk transparency (30% and 21%) (Table 5). It is important to note that the LLRM does not explicitly account for all the biogeochemical processes occurring within a waterbody that contribute to overall water quality. As a result, the model is less accurate at predicting chlorophyll-*a* and Secchi disk transparency. For example, chlorophyll-*a* is estimated strictly from nutrient loading, but other factors strongly affect algae growth, including transport of phosphorus from the sediment-water interface to the water column by cyanobacteria, low light from suspended sediment, grazing by zooplankton, presence of heterotrophic algae, and flushing effects from high flows. There were insufficient data available to evaluate the influence of these other factors on observed chlorophyll-*a* concentrations and Secchi disk transparency readings.

Watershed runoff combined with baseflow was the largest phosphorus loading contribution across all sources to Lake Waukewan. The watershed load accounts for 70% of the total phosphorus load in Lake

Waukewan. This includes the watershed loads from both the direct Lake Winona (14%) and Lake Waukewan (56%) watersheds (Table 6). Atmospheric deposition (11%), septic systems (8%), waterfowl (6%), and internal loading (5%), were smaller sources. Lake Winona had a similar breakdown, with the watershed load making up 75% of the total phosphorus load. Septic systems (11%) were the second largest source of phosphorus to Lake Winona. Development in the watershed is most concentrated along the shorelines of each lake and near the Lake Waukewan outlet which has dense single-family homes and commercial land uses. Phosphorus loading can occur with dense shoreline development in unsewered areas where septic systems or holding tanks are located within a short distance to the water, leaving little horizontal (and sometimes vertical) space for proper filtration of wastewater effluent. Improper maintenance or siting of these systems can cause failures, which leach untreated, nutrient-rich wastewater effluent to the lake. Part of Lake Waukewan's southern shoreline is serviced by the municipal sewer system, which also represents a potential vulnerability if the sewer systems are old or damaged and leaking wastewater into groundwater near the lake. Note that septic systems are a relatively small source of phosphorus load to Lake Waukewan because 1) the estimate is only for those systems directly along the shoreline that are potentially short-circuiting minimally treated effluent to the lake, 2) part of the shoreline area is serviced by sewer which does not contribute any phosphorus loading in the model since the assumption is that the sewer lines are not leaking, and 3) shoreline septic systems for Lake Winona are included in that lake's watershed load (see Table 6 for a breakdown). The load from septic systems throughout the rest of the watershed is inherent to the coefficients used to generate the watershed load.

Internal loading is currently a relatively small source of phosphorus to Lake Waukewan and Lake Winona, though data from the 2025 *Lake Waukewan Source Water Assessment Report* (FBE, 2025) suggests that internal loading has been relatively stable over the past ten years, with the time around lake turnover being the only time of year when internal loading has worsened in the past ten years. The current model predicts zero bloom days annually for Lake Waukewan and 19 bloom days per year for Lake Winona (Table 5).

Normalizing for the size of a sub-watershed (i.e., accounting for the watershed annual discharge and direct drainage area) better highlights sub-watersheds with elevated pollutant export relative to their drainage area. The sub-watershed with the highest phosphorus mass exported per area was the Waukewan Street tributary with 0.26 kg/ha/yr. This sub-watershed and other sub-watersheds with moderate-to-high phosphorus mass exported by area in the range of 0.10 – 0.20 kg/ha/yr generally had more development. These drainages make up most of the Lake Waukewan direct sub-watershed, which includes much of the more densely developed shoreline and commercial areas. Lake Winona sub-watersheds had lower phosphorus mass export per area, though the Winona East Tributary had a higher export compared to other sub-watersheds in the Lake Winona direct drainage area.

Once the model is calibrated for current in-lake total phosphorus concentration, we can then manipulate land use and other factor loadings to estimate historical and future phosphorus loading (e.g., what in-lake total phosphorus concentration was prior to human development and what in-lake total phosphorus concentration will be following full buildout of the watershed under current zoning restrictions). A comparison of historical, current, and future water quality for Lake Waukewan and Lake Winona is shown in Table 5.

Pre-development loading estimation showed that total phosphorus loading to Lake Waukewan increased by 225%, from 118.2 kg/yr prior to European settlement to 384.6 kg/yr under current conditions (Table 6). For Lake Winona, total phosphorus loading increased from 42.2 kg/yr to 116.9 kg/yr (177%) across the two scenarios. These additional phosphorus sources under current conditions are coming from development in the watershed, septic systems, atmospheric dust, and internal loading (Table 6). Water quality prior to settlement was predicted to be excellent with extremely low phosphorus and chlorophyll-*a* concentrations and high water clarity (Table 5).

Future loading estimation showed that total phosphorus loading to Lake Waukewan may increase by 86.5%, from 384.6 kg/yr under current conditions to 717.1 kg/yr at full build-out (2130) under current zoning (Table 6). For Lake Winona, phosphorus loading may increase from 116.9 kg/yr to 342.9 kg/yr (193%). Additional phosphorus will be generated from more development in the watershed, greater atmospheric dust, more septic systems, and enhanced internal loading (Table 6). Some of the largest increases will come from sub-watersheds with the highest build-out potential, such as those in Center Harbor. These include the Hawkins Pond Direct, Bear Pond Direct, Winona East – Hawkins Tributary, EE Brook, Otter Pond Direct, Piper Hill Tributary, North Waukewan Tributary, and parts of the Lake Winona Direct, North Winona Tributary, Winona East Tributary, Snake River, East Waukewan Tributary, and Waukewan Direct sub-watersheds. The Lake Waukewan model predicted higher (worse) phosphorus concentration of 13.2 µg/L, higher (worse) chlorophyll-*a* concentration of 4.5 µg/L, lower (worse) water clarity of 3.2 m, and an increase from 0 to 30 cyanobacteria bloom days compared to current conditions for the lake (Table 5). Predicted future water quality was similarly poor for Lake Winona with a total phosphorus concentration of 25.3 µg/L, a chlorophyll-*a* concentration of 11.1 µg/L and 241 days of cyanobacteria blooms during the year (Table 5).

Table 5. In-lake water quality predictions for Lake Waukewan and Lake Winona. TP = total phosphorus. Chl-*a* = chlorophyll-*a*. SDT = Secchi disk transparency. Bloom Days represent average annual probability of chlorophyll-*a* exceeding 8 µg/L.

Waterbody	Model Scenario	Observed Median TP *(µg/L)*	Predicted Median TP *(µg/L)*	Observed Mean Chl-a *(µg/L)*	Predicted Mean Chl-a *(µg/L)*	Observed Mean SDT *(m)*	Predicted Mean SDT *(m)*	Predicted Bloom Days
Lake Waukewan	Pre-Development	no data	2.2	no data	0.2	no data	12.7	0
	Current (2025)	7.1	7.1	2.2	2.0	6.9	5.1	0
	Future (2130)	no data	13.2	no data	4.5	no data	3.2	30
Lake Winona	Pre-Development	no data	3.1	no data	1.5	no data	9.7	0
	Current (2025)	8.5	8.6	5.0	4.0	5.5	4.4	19
	Future (2130)	no data	25.3	no data	11.1	no data	1.9	241

Table 6. Total phosphorus (TP) and water loading summary by model and source for modeled waterbodies in the Lake Waukewan watershed. * Includes watershed load from Lake Winona.

Waterbody	Development State	Measurement (Units)	Atmospheric	Internal	Waterfowl	Septic System	Watershed Load	Total Load To Lake
Lake Waukewan	Pre-Development	TP (kg/yr)	27.2	0	23.3	0	67.8*	**118.2**
		TP (%)	23	0	20	0	57*	**100**
		Water (m^3/yr)	4,636,557	0	0	0	16,538,001*	**21,174,558**
	Current (2025)	TP (kg/yr)	42.7	21.2	23.3	29.2	268.2*	**384.6**
		TP (%)	11	5	6	8	70*	**100**
		Water (m^3/yr)	4,636,557	0	0	24,517	16,454,361*	**21,115,434**
	Future (2130)	TP (kg/yr)	97.0	39.5	23.3	34.8	522.4*	**717.1**
		TP (%)	14	6	3	5	73*	**100**
		Water (m^3/yr)	4,636,557	0	0	31,502	16,326,518*	**20,994,577**
Lake Winona	Pre-Development	TP (kg/yr)	4.5	0	3.9	0	33.9	**42.2**
		TP (%)	11	0	9	0	80	**100**
		Water (m^3/yr)	781,096	0	0	0	7,665,837	**8,446,933**
	Current (2025)	TP (kg/yr)	7.1	5.7	3.9	12.9	87.3	**116.9**
		TP (%)	6	5	3	11	75	**100**
		Water (m^3/yr)	781,096	0	0	10,762	7,654,278	**8,446,136**
	Future (2130)	TP (kg/yr)	16.0	16.7	3.9	16.6	289.7	**342.9**
		TP (%)	5	5	1	5	84	**100**
		Water (m^3/yr)	781,096	0	0	15,361	7,591,626	**8,388,083**

COMPARISON TO ORIGINAL GOAL

In the 2016 Lake Waukewan and Lake Winona Watershed Restoration Plan (LWA & FBE, 2016), the observed summer in-lake total phosphorus concentrations for Lake Waukewan and Lake Winona were 5.6 µg/L and 7.2 µg/L, respectively. For chlorophyll-*a*, the observed summer in-lake concentrations were 2.5 µg/L and 3.0 µg/L. Recent water quality data for Lake Waukewan and Lake Winona show summer total phosphorus concentrations of 6.1 µg/L and 7.8 µg/L and summer chlorophyll-*a* concentrations of 2.1 µg/L and 4.7 µg/L. Recent data suggest that total phosphorus concentrations have risen in both lakes, though chlorophyll-*a*, which is the response indicator to phosphorus, has only increased in Lake Winona. Numerous other factors such as light, nitrogen, micronutrients, and water temperature may impact chlorophyll-*a*.

The 2016 Lake Waukewan and Lake Winona Watershed Restoration Plan (LWA & FBE, 2016) set a water quality goal that reduced the in-lake total phosphorus concentration by 10% for both lakes, which would achieve 5.3 µg/L for Lake Waukewan and 6.5 µg/L for Lake Winona by 2025. Water quality data collected since the original WMP show that neither lake has met this goal, with Lake Waukewan and Lake Winona's predicted total phosphorus concentrations increasing by 1.5 µg/L or 27% and 1.3 µg/L or 18%, respectively, based on comparison of the original and updated lake models. Observed data collected from the lake epilimnions in the summer show that in-lake total phosphorus concentrations have increased by 0.5 or 9% and 0.6 or 8% for Lake Waukewan and Lake Winona, respectively. Despite some great work that has been accomplished since 2016 to address issues in the watershed, it appears that the addition of new sources of phosphorus from aging infrastructure and new development over the last decade has outpaced the reduction of existing sources of phosphorus in the watershed. However, model predictions indicate that the increase in phosphorus load and in-lake phosphorus concentration in both lakes could have been two to three times greater without local efforts.

WATER QUALITY GOAL AND OBJECTIVES

A water quality goal was updated based on the data and modeling above. The model results estimate changes in total phosphorus loading and in-lake total phosphorus concentrations over time from pre-development through future conditions, showing that the water quality of both Lake Waukewan and Lake Winona is already being affected by existing development in the watershed and will likely degrade further with continued growth. Results show that current in-lake concentrations have already more than doubled since pre-development and are projected to exceed the NHDES oligotrophic threshold if "business-as-usual" development continues, placing the long-term water quality of both lakes at risk. These results provide a foundation for informed management decisions and for establishing appropriate water quality goals for Lake Waukewan and Lake Winona.

Current in-lake total phosphorus and chlorophyll-*a* concentrations indicate that Lake Waukewan is currently oligotrophic and Lake Winona is currently mesotrophic. To improve water quality and move toward oligotrophic conditions, strong management objectives must be established to protect and improve the lakes' condition over the long term, especially given the recent cyanobacteria blooms, ongoing development pressures, and the use of Lake Waukewan as a public drinking water supply.

We recommend reducing the annual average total phosphorus concentration in Lake Waukewan from a predicted 6.1 ppb to 5.4 ppb. There are no additional total phosphorus thresholds set by NHDES below the 7.2 ppb oligotrophic + 10% reserve threshold. An in-lake total phosphorus reduction from 6.1 ppb to 5.4 ppb represents a 10% reduction (33 kg/yr) in total phosphorus loading to the lake, not counting the total phosphorus load from Lake Winona. Achieving this reduction would lower predicted chlorophyll-*a* concentrations to 1.8 ppb.

For Lake Winona, we recommend reducing the summer average total phosphorus from an observed 7.8 ppb to 7.2 ppb, to meet the oligotrophic 10% reserve threshold. This target represents a 7% reduction (8 kg/yr) in total phosphorus loading to the lake. Achieving this reduction would lower predicted chlorophyll-*a* concentrations to 4.4 ppb, a substantial improvement from current conditions.

It is important to note that meeting or surpassing an oligotrophic chlorophyll-*a* criterion may not be sufficient to prevent cyanobacteria blooms, as external factors such as heavy precipitation with droughts in between or rain-on-snow events, and a shorter period of ice cover can influence bloom dynamics. Additional data and continued evaluation of Lake Waukewan and Lake Winona's water quality response to environmental stressors are recommended to refine and, if necessary, adjust this water quality goal.

The goal of the Lake Waukewan and Lake Winona WRP update is to improve water quality such that both lakes meet state water quality standards for the protection of aquatic life integrity and primary contact recreation, while substantially reducing the likelihood of harmful cyanobacteria blooms. This goal will be achieved through the implementation of the following objectives. More detailed action items to achieve these objectives will be provided in the Action Plan of the updated WRP.

Objective 1

Reduce phosphorus loading from existing development by 10% (33 kg/yr) to Lake Waukewan and by 7% (8 kg/yr) to Lake Winona to improve the average in-lake summer or annual total phosphorus concentration to 5.4 ppb and 7.2 ppb, respectively, and annual chlorophyll-*a* concentration to 1.8 ppb and 4.4 ppb, respectively.

Objective 2

Mitigate (prevent or offset) phosphorus loading from future development by 31.7 kg/yr to Lake Waukewan and 20.7 kg/yr to Lake Winona to maintain average summer in-lake total phosphorus concentration in the next 10 years.

Reality Check

The watershed survey identified 77 sites impacting the lake. Remediating these sites could prevent up to 16.5 kg/yr of phosphorus from entering Lake Waukewan and 2.7 kg/yr from entering Lake Winona. Upgrading the 71 shoreline systems older than 25 years around Lake Waukewan and the 53 shorefront septic systems older than 25 years around Lake Winona is estimated to reduce the phosphorus load to Lake Winona and Lake Waukewan by 7.1 kg/yr and 5.3 kg/yr, respectively.

In sum, treating existing pollutant sources identified as coming from the external watershed load could reduce the phosphorus load to Lake Waukewan and Lake Winona by 23.6 kg/yr and 8.0 kg/yr, respectively, which meets 72% and 100% of Objective 1 for Lake Waukewan and Lake Winona, respectively. An updated shoreline survey was not conducted for Lake Waukewan and Lake Winona as part of this WRP update, though additional phosphorus load reductions can still be expected from improved shoreline conditions. The Lake Winnipesaukee Alliance (LWA) conducted an updated shoreline for Lake Waukewan outside of the WRP update effort on 7/23/2026. These results have not been thoroughly reviewed by FBE and thus will be used to represent an additional load reduction opportunity beyond those stated above. Data from Lake Winona's original 2014 shoreline survey suggest that treating shoreline sites could reduce the phosphorus load to Lake Winona by 0.9 kg/yr[1] from six low impact sites (disturbance score between 7-8). Data from LWA's updated shoreline survey of Lake Waukewan suggest that treating shoreline sites could reduce the phosphorus load to Lake Waukewan by 2.3 kg/yr[2] from two high impact sites (disturbance score 11+), 3.5 kg/yr[3] from twelve medium impact sites (disturbance score between 9-10), and 7.4 kg/yr from 51 low impact sites. **These additional load reduction opportunities bring the total external watershed load reduction opportunities to 36.8 kg/yr for Lake Waukewan and 8.9 kg/yr for Lake Winona, which meets 112% and 111% of Objective 1 for Lake Waukewan and Lake Winona, respectively.**

Non-structural best management practices (BMPs) such as educating homeowners about septic system maintenance, fertilizer use, and residential stormwater management may be effective at reducing phosphorus loading to Lake Waukewan and Lake Winona and meet the water quality goal by preventing septic system failures, reducing the amount of fertilizer used on residential lawns, and encouraging stormwater management at the property-scale.

Objective 2 can be met through ordinance revisions that implement low impact development strategies and encourage cluster development with open space protection and/or through conservation of key parcels of forested and/or open land.

The interim benchmarks for each water quality objective allow flexibility in reassessing objectives following more data collection and expected increases in phosphorus loading from future development in the watershed over the next ten or more years (Table 7). Comparing observed water quality changes to predicted water quality changes with no action can help guide adaptive changes to interim benchmarks (e.g., actions are meeting objectives or actions are falling short of objectives). If the benchmarks are not met due to lack of funding or other resources for implementation projects rather than due to increases in phosphorus loading from new development outpacing reductions in phosphorus loading from

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[1] *Based on PLET model bank stabilization estimate for fine sandy loams, using 50 feet (length) by 3 feet (height) and moderate lateral recession rate of 0.1 feet per year.*

[2] *Based on PLET model bank stabilization estimate for fine sandy loams, using 200 feet (length) by 3 feet (height) and moderate lateral recession rate of 0.1 feet per year.*

[3] *Based on PLET model bank stabilization estimate for fine sandy loams, using 100 feet (length) by 3 feet (height) and moderate lateral recession rate of 0.1 feet per year.*

improvements to existing development, then this creates different conditions from which to adjust interim benchmarks. For each interim benchmark year, stakeholders should review water quality data, then assess why benchmarks are or are not being met. Stakeholders can then decide how to adjust the interim benchmarks to better reflect water quality conditions and any practical limitations to implementation.

Table 7. Summary interim benchmarks for tracking progress towards achieving the water quality objectives for Lake Waukewan and Lake Winona. Interim goals/benchmarks are cumulative. kg/yr = kilograms per year. ppb = parts per billion.

Interim Goals / Benchmarks	Lake	2028	2030	2035
Objective 1 Reduce phosphorus loading from existing development by 10% (33 kg/yr) to Lake Waukewan and 7% (8 kg/yr) to Lake Winona to improve the average in-lake summer total phosphorus concentration to 5.4 ppb and 7.2 ppb, respectively.	***Waukewan***	Achieve **2%** (7 kg/yr) reduction in total phosphorus loading.	Achieve **5%** (17 kg/yr) reduction in total phosphorus loading; re-evaluate water quality and track progress.	Achieve **10%** (33 kg/yr) reduction in total phosphorus loading; re-evaluate water quality and track progress.
	Winona	Achieve **1%** (1 kg/yr) reduction in total phosphorus loading.	Achieve **4%** (4 kg/yr) reduction in total phosphorus loading; re-evaluate water quality and track progress.	Achieve **7%** (8 kg/yr) reduction in total phosphorus loading; re-evaluate water quality and track progress.
Objective 2 Mitigate (prevent or offset) phosphorus loading from future development by 31.7 kg/yr to Lake Waukewan and 20.7 kg/yr to Lake Winona to maintain average summer in-lake total phosphorus concentration in the next 10 years.	***Waukewan***	Prevent or offset **6 kg/yr** in total phosphorus loading from future development.	Prevent or offset **16 kg/yr** in total phosphorus loading from future development; re-evaluate water quality and track progress.	Prevent or offset **31.7 kg/yr** in total phosphorus loading from future development; re-evaluate water quality and track progress.
	Winona	Prevent or offset **4 kg/yr** in total phosphorus loading from future development.	Prevent or offset **10 kg/yr** in total phosphorus loading from future development; re-evaluate water quality and track progress.	Prevent or offset **20.7 kg/yr** in total phosphorus loading from future development; re-evaluate water quality and track progress.

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