AQUATIC ECOSYSTEM RESEARCH
A Freshwater Conservation Company

LAKE WONONSCOPOMUC

2017 Summary Water Quality Report

EXECUTIVE SUMMARY

Lake Wononscopomuc was assessed monthly from May through October in 2017 at two sites located in the deep basins of the lake. The lake was found to be thermally stratified during each site visit. Resultingly, oxygen was depleted and not replenished in regions of the water column near the bottom, thus creating the environment for internal loading of phosphorus and other ions. This was clearly evidenced by the seasonal increase in total phosphorus and specific conductance of the hypolimnion.

The upper reaches of the water column, where algae reside, were not influenced by the internal loading of nutrients. The greatest algal productivity occurred during the May and June site-visits. The dominant algal taxon in May and June was cyanobacteria and the most abundant genus was *Aphanizomenon sp*. This genus can regulate its buoyancy, and fix atmospheric nitrogen. Early season nitrogen levels were relatively low, which may have provided an advantage to the nitrogen fixing *Aphanizomenon*.

As the season progressed, Secchi transparency improved, algal cell concentrations generally decreased, nitrogen levels increased, and blue-green algae were replaced by green algae as the dominant taxon. In general, Lake Wononscopomuc exhibited early-mesotrophic to mesotrophic characteristics.

Alkalinity, pH, and specific conductance were generally high which is not surprising given the fact that the lake lies within the Marble Valley geological region of Connecticut.

A preliminary analysis of water quality trends was conducted using selected water quality variables assessed in 2017 and the readily available historical water quality data. Notable findings included:

- There is a positive (increasing) trend in alkalinity and specific conductance since the 1930s, which could promote higher incidences and dominance of blue-green algae populations over the long term.

- Trophic variables did not show notable positive or negative trends over the last 30 to 40 years.

    - Secchi transparency has not changed appreciably since the late 1980s / early 1990s.

    - Total phosphorus levels of the epilimnion exhibited a relatively stable state since at least the early 1970s.

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INTRODUCTION

Lake Wononscopomuc is a natural 348ac waterbody located in Salisbury, Connecticut. One of the deepest lakes in Connecticut, it has a maximum depth of 31m, a mean depth of 11m, and contains approximately $4.73x10^7$ gallons of water in two distinct basins. The lake's watershed is 1,621ac of sparse residential development. The resulting lake to watershed ratio is 4.65. Sucker Brook and one other small stream feed Lake Wononscopomuc; it flows out into Factory Brook, a tributary of Salmon Creek, which ultimately feeds to the Housatonic River. Furthermore, Lake Wononscopomuc is a marl-type lake, which is characterized by calcium rich water and high specific conductance, due to its proximity to the geological feature known as Connecticut's Marble Valley (Frink and Norvell 1984, Canavan and Siver 1995). This type of water chemistry results in unique features such as marl deposits and lake whitening events. Finally, this type of water chemistry supports specialized algae and plant communities.

In 2015, Aquatic Ecosystem Research (AER) was engaged to examine the summer season water quality features of Lake Wononscopomuc and to establish a high quality contemporary database of water quality information. The 2015 water quality assessment established a repeatable design and allowed for a general examination of current water quality for use in future water quality comparisons. One of AER's recommendations was to continue water quality monitoring on an annual or biennial basis. This report is a continuation of the process to develop a high quality, contemporary database.

In the 2015 report AER also recommended compiling historical data on the lake. In this report AER provides a preliminary examination of some of those historical data and makes additional recommendations for future lake management initiatives.

METHODS

Six monthly site visits took place at two sites on Lake Wononscopomuc between May through October, 2017, on the following dates: May 7^{th}, June 10^{th}, July 5^{th}, August 2^{nd}, September 4^{th}, and October 14^{th}. Site 1 and Site 2 (41°57'17.62"N / 73°26'50.65"W and 41°57'29.26"N / 73°26'34.72"W, respectively), were located within the deep basis in the lake (Fig. 1).

During each visit to both sites water samples and the following data were collected. A transparency measurement was taken using a standard 20cm Secchi disk. Temperature (°C), oxygen (mg/L), conductivity (µS/cm), specific conductance (µS/cm), and pH were measured just below the surface, at one meter (m), and at every meter to the bottom using a YSI® Professional meter. Water samples were collected at a depth of 1.0m from the surface and 0.5 to 1m from the bottom using a Van Dorn horizontal sampler for nutrient analyses. The Van Dorn sampling bottle was also used to collect a water sample at the depth of greatest oxygen concentration for an analysis of important algal taxa, including algal cell enumerations.

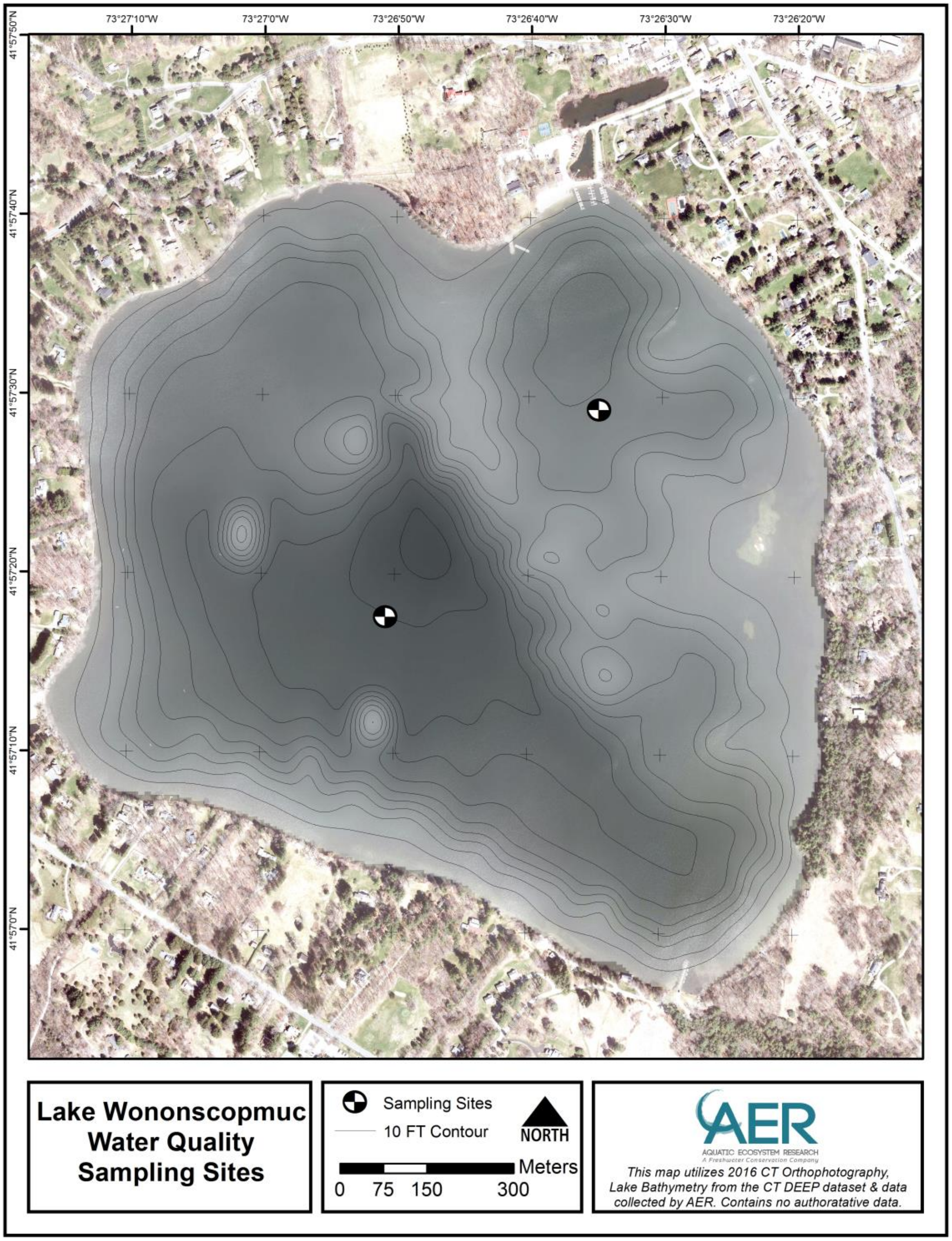

Figure 1. Water quality monitoring sites on Lake Wononscopomuc. Site 1 is located near the center of lake in 30 meters of water. Site 2 is located in the northeastern basin and in 17 meters of water. The lake's bathymetry has been layered into the map.

Chemical analyses were performed by a Connecticut State certified laboratory for alkalinity (mg/L), ammonia (mg/L), nitrite (mg/L), nitrate (mg/L), total Kjeldahl nitrogen (mg/L), and total phosphorus (µg/L). AER performed the algae analyses by first concentrating a known volume from the sample collected in the field to a smaller known volume with centrifugation and a vacuum pump / filtration flask system. A portion of that concentrate was pipetted into a counting chamber and genus-level algal cell enumerations were performed by counting cells in a subset of fields in the counting chamber using an inverted Nikon Diaphot research microscope. Those counts were then corrected to be representative of the whole sample.

Using those aforementioned data, algal community diversity and resistance to mixing within the water column were calculated. Algal community diversity was evaluated using Shannon's Diversity Index. This index was calculated using the following formula: $[-\Sigma (p_i * \ln(p_i)) – (S-1/2N)]$, where p_i is the fraction of the community each species is representative of, S is the total lake richness, and N is the total abundance at each point. Resistance to mixing, which is an assessment of the ability of two different water volumes – that differ in temperature – to mix, was calculated using the Relative Thermal Resistance to Mixing (RTRM) formula: $(D^1 – D^2) / (D' – D^o)$, where D^1 is the density of upper water volume, D^2 is the density of the lower water volume, D' is the density of water at 5°C, and D^o is the density of water at 4°C. The results of all of the aforementioned tests were stored in a database managed by AER.

RESULTS

Thermal Structure and Oxygen

The vertical structure of water temperature is influenced by the incident radiation of our sun hitting the surface of the lake and the diffusion of that energy through the vertical profile of the water volume. In short, the upper reaches of the lake are heated disproportionately faster compared to the lower reaches of the water body. The result is a warm surface water volume (i.e. epilimnion), a transitional area of rapid temperature decline with depth (i.e. metalimnion), and a cool bottom water volume (i.e. hypolimnion). Differences in temperature, and therefore density, between layers of water create resistance to mixing with the greatest resistance to mixing occurring where the density difference is the greatest (i.e. the thermocline).

As noted in the *Methods* section of the report, relative resistance to mixing (RTRM) is calculated between layers at 1-meter (m) intervals. Traditionally, RTRM values >30 are indicative of the metalimnion region of the water column. RTRM values >80 are indicative of strong resistance to mixing.

Concordant with the establishment of the thermal structure is a diminishment of oxygen in the hypolimnion. The reason for the decrease in oxygen is due to oxygen demand at the bottom and the inability of oxygen to diffuse to lower depths because of the resistance to mixing in the water column under thermally stratified conditions.

A good analogy for the separation of the epilimnion and hypolimnion in the water column is the manner in which oil and water do not mix. The result is minimal exchange of oxygen between layers and loss of oxygen near the sediment / water interface due to microbial aerobic activity. In short, oxygen does not diffuse to and replenish oxygen-depleted depths in the hypolimnion when the lake is stratified.

The water columns at both sites were found to be separated into epilimnion, metalimnion, and hypolimnion at the time of each visit (Figs. 2 and 3). Strong resistance to mixing was observed throughout the season at both sites with the exception of the June 10th visit when the greatest RTRM of 70 was observed between 6 and 7m depth at Site 1, and the greatest RTRM of 75 was recorded between 5 and 6m depth at Site 2. As the season progressed from July 5th to October 14th the thermocline gradually migrated downward due to increased mixing in the upper reaches of water column, and increased the size and volume of the epilimnion. By October 14th, stratification exhibited signs of breaking down as exemplified by less resistance to mixing throughout the water column at that date at both sites (Figs. 2 and 3).

Oxygen concentrations on May 7th and June 10th were well above the critical limit of 5mg/L throughout most of the water column. The exceptions were both from the June visit when a concentration of 4.0 was recorded at the very bottom (30m depth) at Site 1 and concentrations of 4.6 and 2.8mg/L were recorded at the last several meters above the bottom (16 and 17m depth) at Site 2. Oxygen concentrations below the thermocline were initially higher than those measured above the thermocline before decreasing to concentrations measured at the bottom.

On July 5th ample oxygen concentrations in the epilimnion increased at or below the thermocline, remained high well into the hypolimnion, then eventually decreased to <5mg/L near the bottoms of both sites. At Site 1, oxygen concentrations were <5mg/L but >1mg/L from 24m depth to the bottom. At Site 2, concentrations of <5mg/L but >1mg/L were observed from 14m depth to the bottom. Similar conditions were observed on August 2nd with the key difference being a greater volume of the water column being <5 and >1mg/L. At Site 1 in August, those depths ranged from 22m depth to the bottom, and at Site 2 those depths ranged from 12m depth to the bottom.

Similarly, on September 4th the depths where oxygen concentrations were <5 and >1mg/L continued to expand upward. At Site 1 those depths ranged from 18m to the bottom; at Site 2 those depths ranged from 11m depth to the bottom. By October 14th at Site 1 the range depths with oxygen levels <5 and >1mg/L was 13 to 20m depth. Below the 20m depth, oxygen concentrations were <1mg/L or anoxic. At Site 2 in October concentrations of <5 and >1mg/L were observed at 12 and 13m depth. From 14m depth to the bottom, concentrations were <1mg/L.

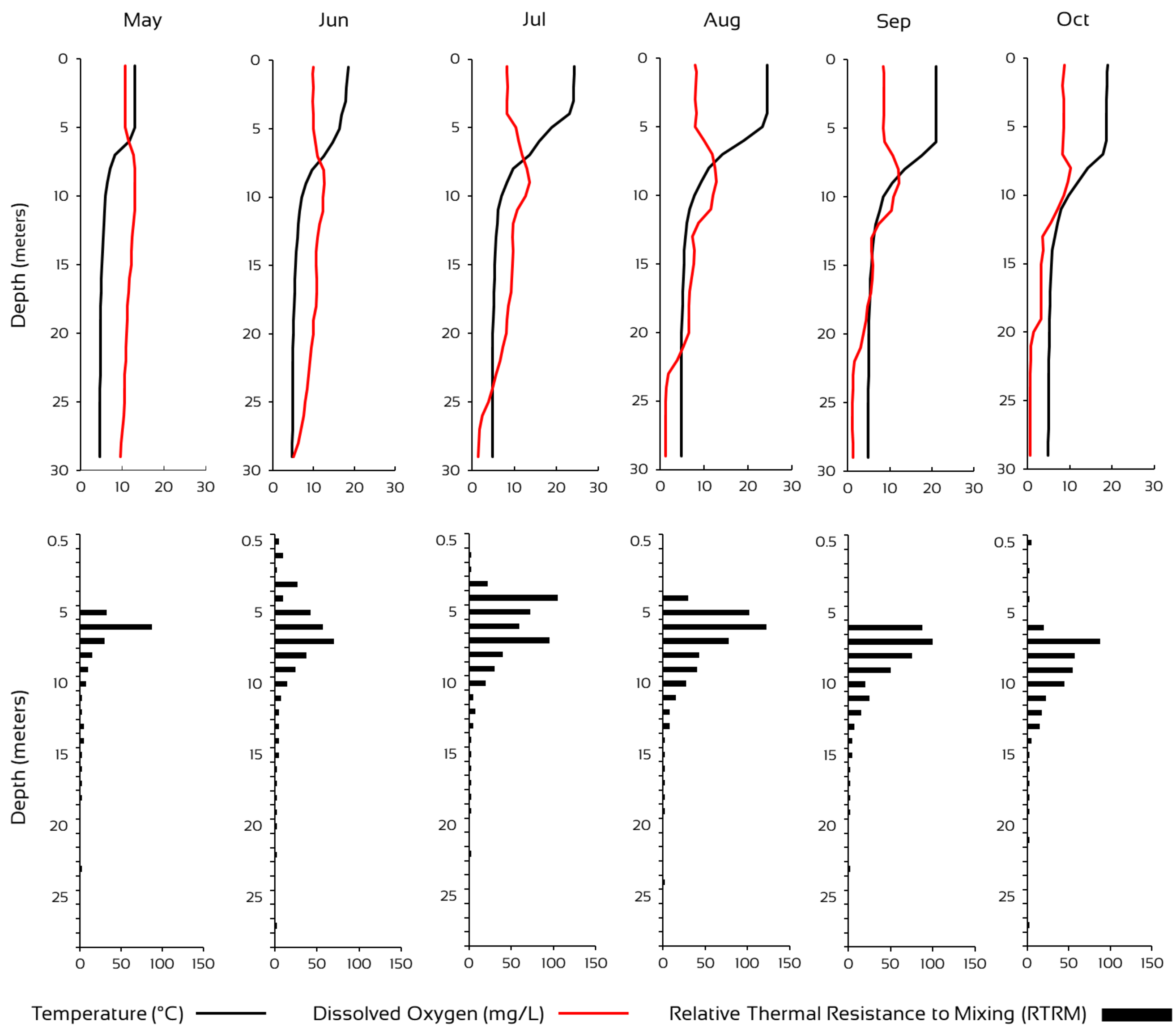

Figure 2. Temperature, dissolved oxygen and relative thermal resistance to mixing profiles at Site 1 in May through October.

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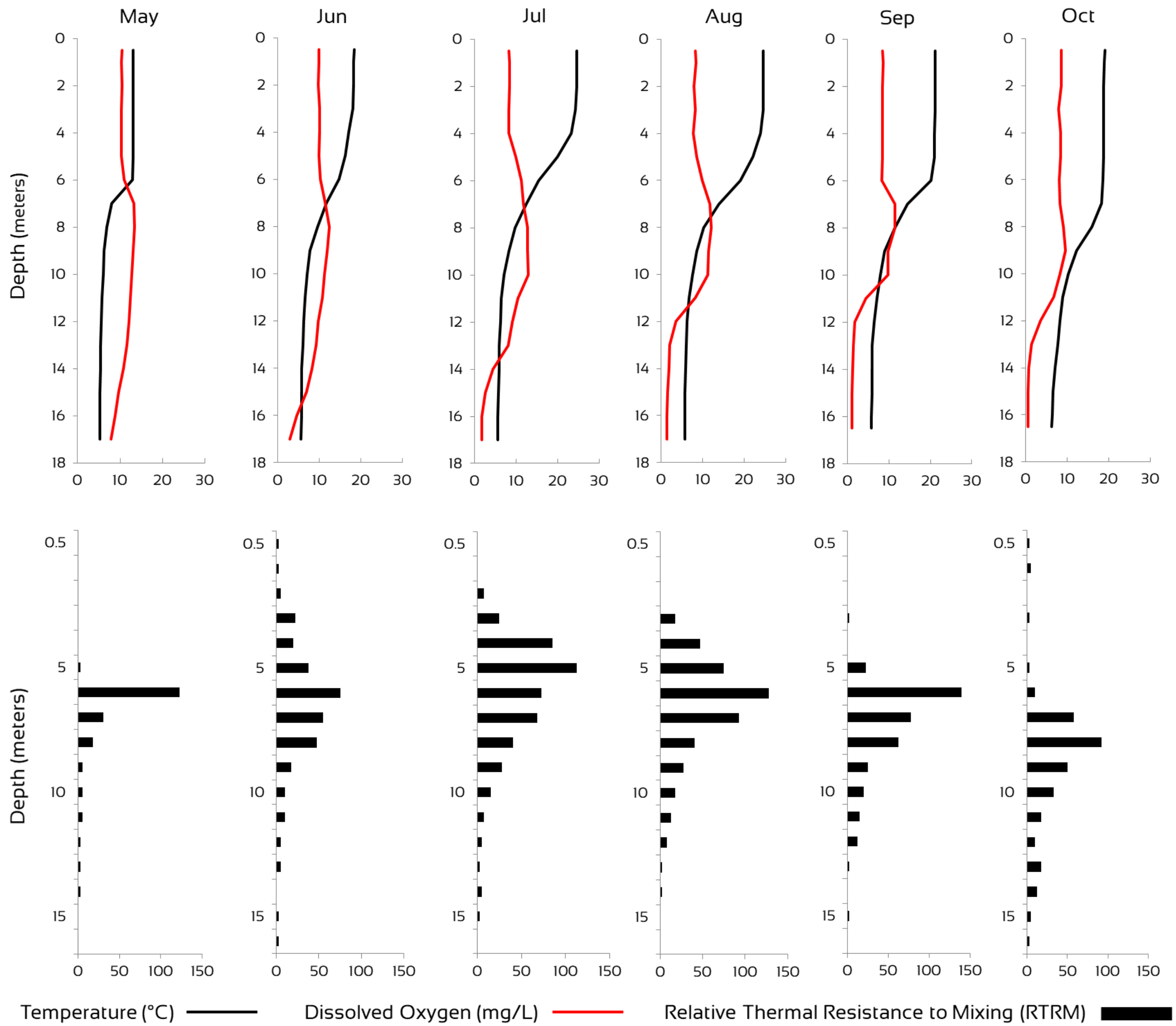


Figure 3. Temperature, dissolved oxygen and relative thermal resistance to mixing profiles at Site 2 from May through October.

Algal Community

The planktonic algal community was dominated by blue-green algae (cyanobacteria) in the first two months of the season (Figs. 4 and 5). The filamentous blue-green *Aphanizomenon sp*. comprised 90 and 85% of the algae cells at Site 1 and 2, respectively on May 7th and increased to 97 and 96% of all cells by June 10th. Cell concentrations ranged between 6,800 and 11,200cells/mL between both sites in the May and June samples. However, it must be noted that *Aphanizomenon* cells tend to be small with tens to hundreds of cells on a single filament.

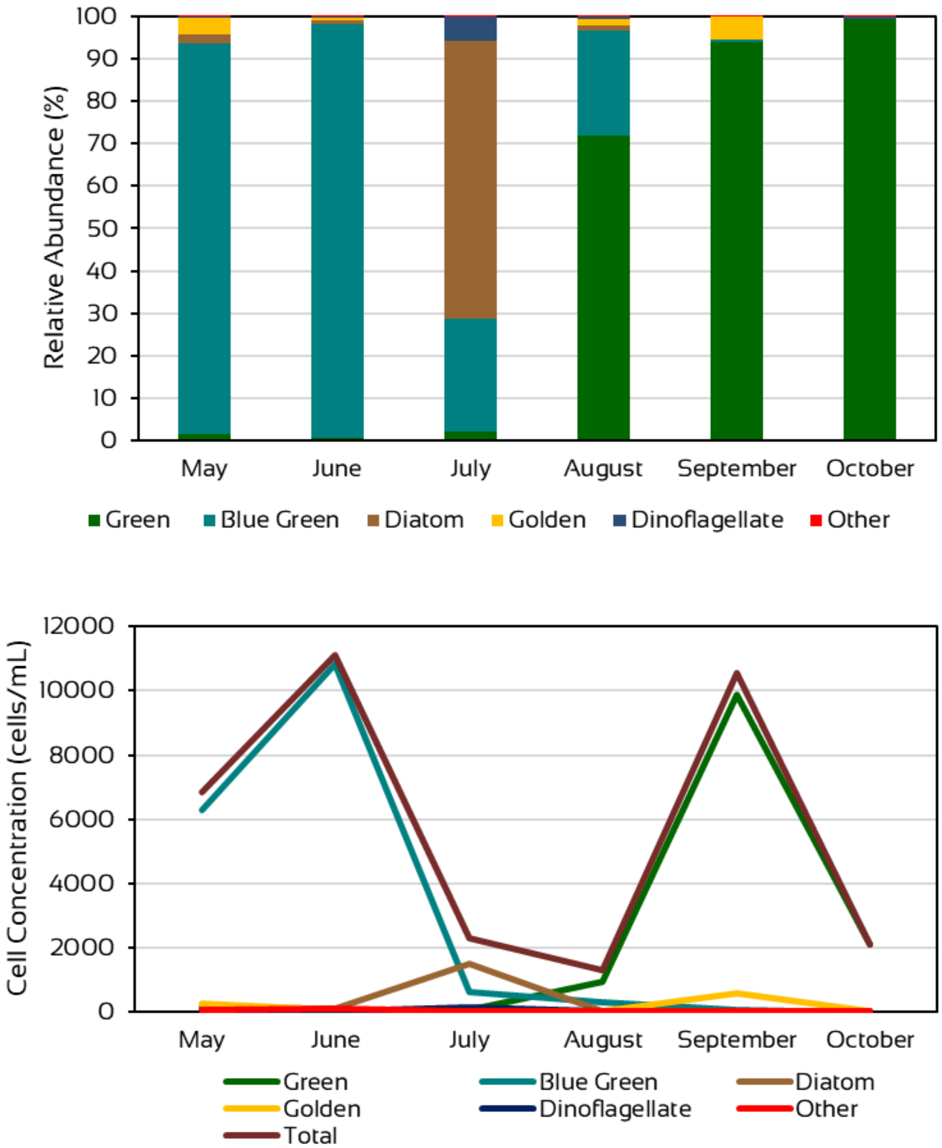
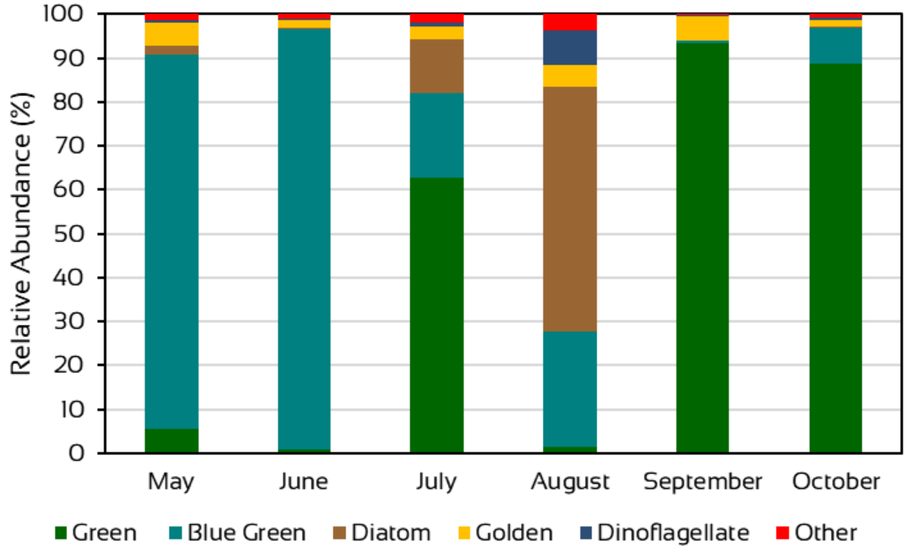


Figure 4. Relative abundance of major algal taxa (top) and cell concentrations each month at Site 1 from May through October.

By July 5th the algal community shifted to one dominated by diatoms at Site 1 and green algae at Site 2. *Fragilaria sp*. and *Synedra sp*. were the most abundant diatom genera at Site 1 while the green algae *Chlorella sp*. comprised 51% of the cells at Site 2. Cell concentrations in July were low with concordant high Secchi transparencies observed at both sites.



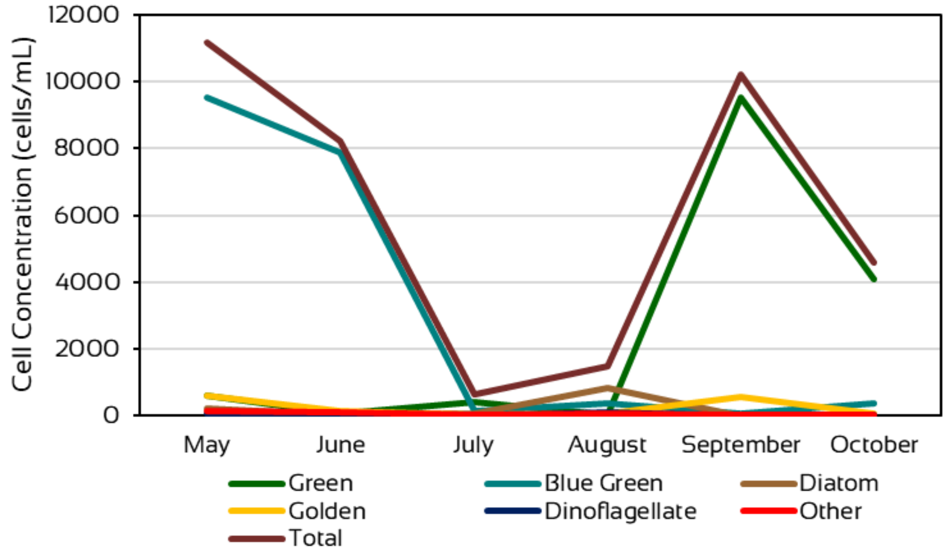


Figure 5. Relative abundance of major algal taxa (top) and cell concentrations (bottom) each month at Site 2 from May through October.

The green algae *Chlorella sp*. continued to be the most abundant at Site 1 at the time of the August site visit (Fig. 4). At Site 2, diatoms were the dominant taxa with *Fragilaria sp*. the most abundant genus (Fig. 5). Cell concentrations remained low in August and similar to those observed in July.

By September 4th, *Chlorella sp*. was the most abundant genus at both sites. *Scenedesmus sp*., another green alga, was also important. Cell concentrations exceeded 10,000cells/mL at both sites in September samples due largely to *Chlorella sp*. Concentrations in October 14th samples subsided to 2,183 and 4,597cells/mL at Sites 1 and 2, respectively.

Water Clarity

The lowest Secchi transparency at Site 1 was 2.64m measured in May (Fig. 6, Appendix 1). Clarity improved from the May assessment to 3.64m by June 10th and to 4.86m by July 5th. It then decreased to 3.80m by August 2nd, followed by an increase to 4.94m in September before attaining highest clarity in October of 5.63m. The average for Site 1 was 4.25m.

At Site 2 the lowest transparency of 2.53m was also recorded during the May site visit (Fig. 7, Appendix 1). Transparency increased to 3.55m by June 10th and to the season high of 6.58m in July. The August 2nd, September 4th and October 14th Secchi transparencies were 4.50, 5.14, and 4.57m, respectively. The average for the season at Site 2 was 4.48m. Averages for the two sites were not statistically different from each other ($p>0.05$).

Nutrients

Nitrogen can be present in a number of forms in lake water. Ammonia – a reduced form of nitrogen – is important because it can affect the productivity, diversity, and community dynamics of the algal and plant communities. Ammonia can be an indicator of internal nutrient loading since bacteria will utilize other forms of nitrogen (e.g. nitrite and nitrate) in lieu of oxygen under anoxic conditions, which results in ammonia enrichment of the hypolimnion.

Other forms of nitrogen in lake waters are nitrite and nitrate. These forms of nitrogen are often below detectable levels in natural systems because they are quickly cycled by bacteria and aquatic plants. Total Kjeldahl nitrogen (i.e. TKN) is a measure of the reduced forms of nitrogen (i.e. ammonia) and total organic proteins in the water column; therefore, it is useful in assessing the productivity of the lentic system because it accounts for biologically derived proteins in the water column. Total nitrogen is the sum of TKN, nitrate and nitrite; because the latter two are often below detectable limits, TKN levels are often the same as total nitrogen levels.

Ammonia was detected at Site 1 at a depth of 1m (epilimnetic samples) during each month and ranged from a low of 0.28mg/L measured from June 10th and July 5th samples to a high of 4.8mg/L from the October 14th sample. The Site 1 season average ammonia concentration was 1.4mg/L. At Site 2 in the epilimnion, ammonia was detected in samples collected on June 10th, July 5th, August 2nd, and October 14th. The range of concentrations and seasonal pattern at Site 2 was similar to that observed at Site 1 with the detectable low of 0.28mg/L measured in the July 5th sample and a high of 4.8mg/L measured in the October 14th sample. The mean at Site 2 was 1.08mg/L. In general, lower levels were measured in the epilimnion earlier in the season, and higher levels measured in the last three months of the season (Figs. 6 and 7).

Ammonia levels measured in hypolimnetic samples (29m depth at Site 1 and 17m depth at Site 2) were generally lower than those observed in the epilimnion. At Site 1, hypolimnetic ammonia was not detected on June 10th. The detectable low of 0.56mg/L was measured in samples collected on May 7th and September 4th; the high of 1.1mg/L was measured in the August 2nd sample. The hypolimnetic mean at Site 1 was 0.65mg/L. At Site 2, ammonia was detected in all hypolimnetic samples; this variable ranged from a low of 0.28mg/L measured in the July sample to a high of 1.4mg/L measured in samples collected on May 7th, June 10th, and October 14th. The season average at Site 2 was 0.98mg/L.

Nitrite was not detected in either epilimnetic or hypolimnetic samples collected from Lake Wononscopomuc. Nitrate was detected in some samples. At Site 1 in the epilimnion, nitrate was only detected in the sample collected on May 7th and the concentration was 0.25mg/L. At Site 2, nitrate was detected in the epilimnion on May 7th and June 10th with concentrations of 0.28 and 0.09mg/L, respectively. Hypolimnetic nitrate was detected in the first four months of the season at both sites. At Site 1, concentrations ranged from 0.13 and 0.33mg/L in samples collected on August 2nd and June 10th, respectively (Fig. 6). At Site 2, concentrations ranged from 0.07 to 0.40mg/L and were from the June 10th and July 5th samples, respectively (Fig. 7).

TKN levels in the epilimnion of Site 1 were reported to range from 3.4mg/L measured in the May sample to 10.1mg/L measured in the August sample. At Site 2 epilimnetic levels were reported at a low of 1.1mg/L from the July sample and a high of 5.0mg/L in the August sample. The season epilimnetic averages were 6.28 and 2.97mg/L for Site 1 and 2, respectively. Hypolimnetic TKN levels ranged from 1.7 to 10.1mg/L in samples collected during May and June, respectively at Site 1. At Site 2, a range of 1.7mg/L in the June sample to 7.3mg/L in the August sample was reported. Hypolimnetic TKN levels averaged 6.0 and 4.48mg/L for Sites 1 and 2, respectively.

Phosphorus is an important constituent of the overall nutrient cycle in aquatic systems. Its concentration can have important impacts on the state of the pelagic algal community, water clarity, and the overall health of a lentic ecosystem. In many cases elevated phosphorus levels cause algae blooms; importantly, those blooms are generally a result of dramatic increase in the blue-green algae populations. Furthermore, there are two sources of phosphorus: 1) watershed and 2) internal. Watershed sources are usually associated with anthropogenic activities (i.e. fertilizer use, water treatment systems, etc.) and internal sources are a result of chemical changes that occur in the lake sediments when oxygen becomes limited.

Total phosphorus concentrations in the epilimnion of Site 1 ranged from 9.3 (September 4th sample) to 31.3µg/L (May 7th sample) and averaged 15.0µg/L for the season. At Site 2, an epilimnetic range of 8.3µg/L (June 10th sample) to 26.1µg/L (May 7th sample) was reported and averaged 16.3µg/L for the season. In the hypolimnion of Site 1, total phosphorus concentrations ranged from 8.3µg/L (May 7th sample) to 63.2µg/L (October 14th sample); the season average was 33.7µg/L. At Site 2, the hypolimnetic total phosphorus concentrations ranged from 20.7 (June 10th sample) to 66.2µg/L (October 14 sample) and averaged 43.8µg/L for the season. In general, epilimnetic total phosphorus levels were highest in May and lower in the latter part of the season while in the hypolimnion, concentrations increased as the season progressed.

Alkalinity, pH, and Specific Conductance

Alkalinity regulates the ability of lake water to resist change in pH. It is expressed as mg/L of calcium carbonate ($CaCO_3$) and reflects the buffering capacity or acid neutralizing capacity of water. Lakes with low alkalinity are susceptible to changes in pH. Alkalinity of surface waters is largely influenced by the geology and other factors in the watershed. Calcium carbonate concentration at the bottom of a lake can also be generated internally from dissimilatory reduction reactions of sulfate by bacteria found in anoxic lake sediments (Siver et al. 2003).

Alkalinity levels were generally high and epilimnetic and hypolimnetic concentrations did not differ appreciably from each other (Fig. 6 and 7). At Site 1, epilimnetic concentrations ranged from 118 and 138mg/L. At Site 2, concentrations ranged from 116 to 154mg/L. Seasonal averages for Site 1 and 2 were 124 and 126mg/L, respectively. Higher epilimnetic concentrations were measured in samples collected in May and June while lower concentrations were found in samples collected in July through October (Figs. 6 and 7).

In the hypolimnion at Site 1, alkalinity concentrations ranged from 122 to 146mg/L and averaged 133mg/L. At Site 2, concentrations in the hypolimnion ranged from 114 to 154mg/L and averaged 133mg/L.

The pH of lake water is important for several reasons. Firstly, very low or very high pH levels will not support aquatic animal life. Algal communities are also influenced by pH due in part to the types of dissolved carbon in the water column at various pH levels. For example, at a pH greater than 8.3, bicarbonate is the dominant form of carbon available to the pelagic algal community. Blue-green algae have an adaptive advantage over other algal groups because they can utilize bicarbonate to fulfill carbon requirements while other groups are dependent upon carbon dioxide which becomes scarce as pH increases. Therefore, higher pH promotes the dominance of blue-green algae by putting other algal taxa at a disadvantage.

The high alkalinity at Lake Wononscopomuc resulted in high but stable pH levels. Epilimnetic pH levels on May 7th were 8.7 at both sites. The epilimnetic pH increased slightly as the season progressed up to September 4th when they were measured at 9.1 at both sites before decreasing by October to 8.8 and 8.1 at Sites 1 and 2, respectively. The averages for the season were 8.9 for Site 1 and 8.8 for Site 2.

The pH levels in the hypolimnion of Site 1 ranged from 6.4 to 8.0 and averaged 7.6 for the season. At Site 2, hypolimnetic pH ranged from 7.6 to 8.5 and averaged 7.9 for the season. One discrepancy among pH measurements was observed in the hypolimnetic on October 14th when the lowest hypolimnetic pH was measured at Site 1 while the highest hypolimnetic pH was measured at Site 2 (Figs. 6 and 7).

Specific conductance (hereafter conductivity) is a measure of lake water's ability to transmit electrical current at a specific temperature. Dissolved materials (i.e. nutrients and salts) have a distinct impact on conductivity measurements where higher concentrations of nutrients and salts result in higher conductivity readings. Because conductivity is also representative of the total concentration of ions in lake water, it can be used to identify sources of nutrient loading or pollutants. Differences in conductivity can also impact the algal community, e.g. hard water lakes with high conductivity tend to have more blue-green algae. Vertical differences can be observed in conductivity profiles, particularly during the periods of hypolimnetic anoxia when internal loading of nutrients and metals from the sediment enrich the lower depths of the lake.

Like alkalinity and pH, specific conductivity was high at Lake Wononscopomuc. Season averages at 1m depth at both sites were 317µS/cm. Modestly higher conductivity was measured in the epilimnion during the first three months of the season and ranged from 320 to 325µS/cm (Figs 6 and 7). In the latter half of the season, conductivity of the epilimnion ranged from 310 to 311µS/cm.

In the hypolimnion, conductivity exhibited a much wider range: 325 to 399µS/cm at Site 1; and 329 to 370µS/cm at Site 2. Lower hypolimnetic conductivity were measured in May and June. Levels increased through September and only subtly decreased by October 14th (Figs. 6 and 7).

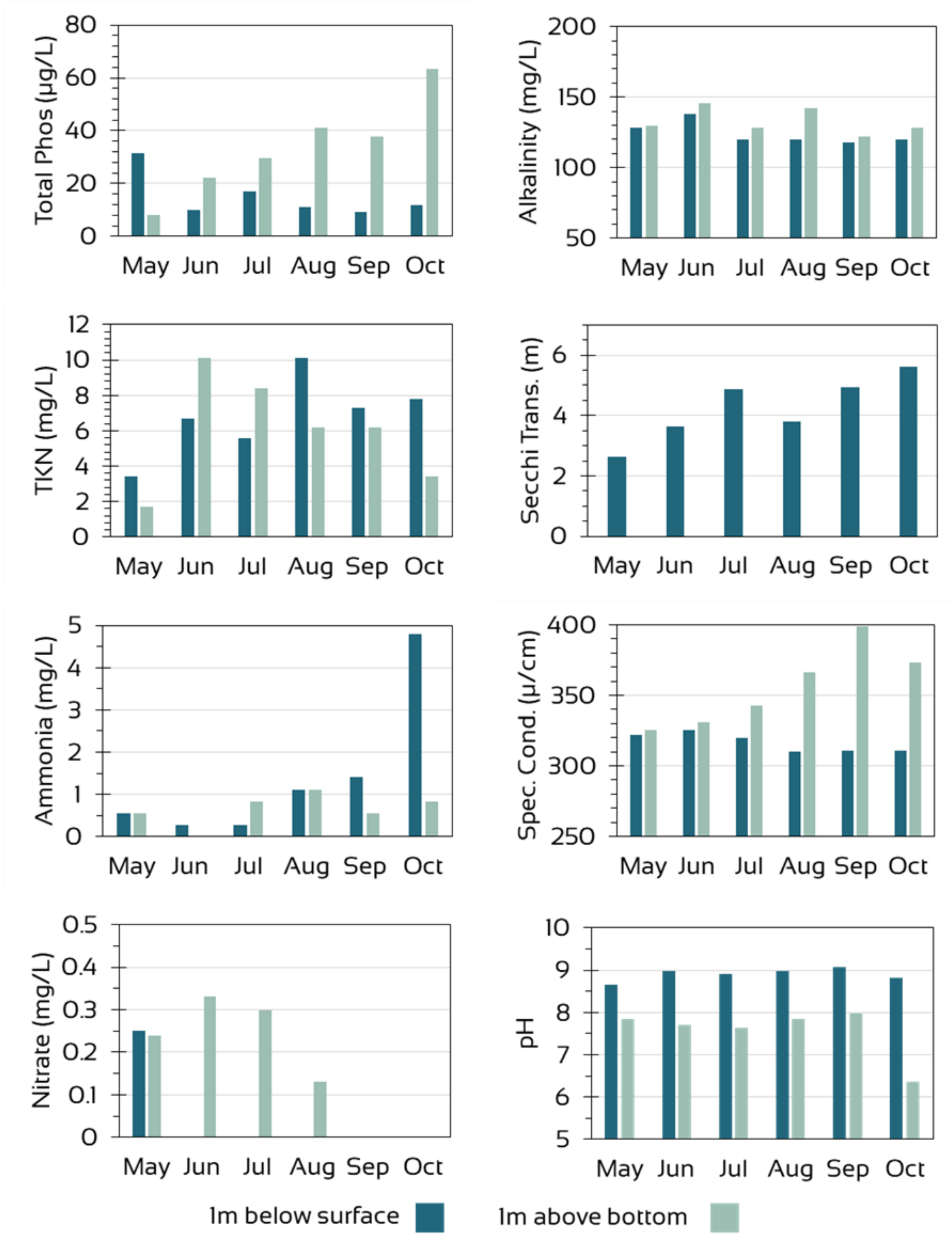


Figure 6. Epilimnetic (1m depth) and hypolimnetic (29 to 30m depth) measures of nutrients (total phosphorus, total Kjeldahl nitrogen (TKN), ammonia, and nitrate), Secchi transparency, alkalinity, specific conductance, and pH at Site 1.

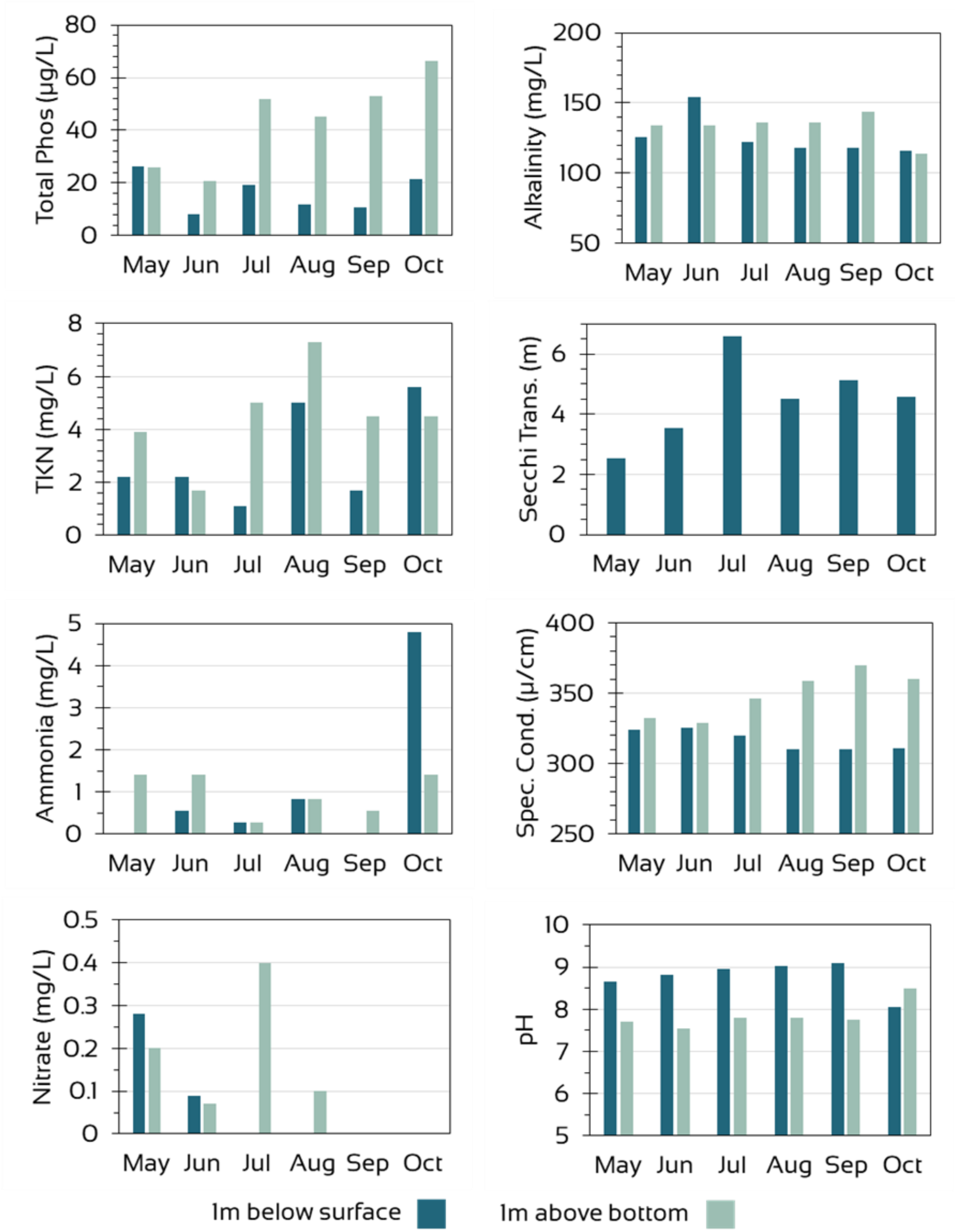


Figure 7. Epilimnetic (1m depth) and hypolimnetic (17m depth) measures of nutrients (total phosphorus, total Kjeldahl nitrogen (TKN), ammonia, and nitrate), Secchi transparency, alkalinity, specific conductance, and pH at Site 2.

2017 WATER QUALITY SUMMARY

Lake Wononscopomuc was stratified throughout the entire sampling protocol and exhibited strong resistance to mixing for much of the season. Consequently, oxygen was not replenished to the bottom of the lake. The low oxygen conditions of the bottom waters influenced a number of water quality characteristics near the bottom but did not appear to influence the epilimnetic waters (samples collected at 1m depth) most likely due to the strong resistance to mixing that kept the water masses separate. For example, total phosphorus concentrations in the hypolimnion of both sites increased as the season progressed. This was likely due to internal loading of phosphorus that occurred during periods of anoxia. Total phosphorus concentrations at 1m depth (epilimnion), however, did not increase; instead, the concentration of phosphorus modestly decreased as it was utilized by algae growth. A similar pattern was observed with specific conductance levels. In the hypolimnion conductivity levels increased and in the epilimnion modestly decreased over the course of the season (Figs. 6 and 7).

It is worth noting that a similar pattern was not observed with alkalinity concentrations in the epilimnion and hypolimnion. As noted above, deep water alkalinity can also be generated internally; however, this did not occur at Lake Wononscopomuc as epilimnetic and hypolimnetic levels were not statistically different at either site ($p>0.05$).

From the perspective of Secchi transparency and algal productivity, 2017 conditions were favorable. Secchi transparency averaged over 4m at Lake Wononscopomuc, which is generally regarded as desirable by Connecticut standards. Based on a classification system used in Connecticut, Wononscopomuc Secchi transparency falls within the early mesotrophic range (Table 1).

Table 1. Trophic classification criteria used by the Connecticut Experimental Agricultural Station (Frink and Norvell, 1984) and the CT DEP (1991) to assess the trophic status of Connecticut lakes. The categories range from oligotrophic or least productive to highly eutrophic or most productive.

Trophic Category	Total Phosphorus (µg / L)	Total Nitrogen (µg / L)	Summer Chlorophyll-*a* (µg / L)	Summer Secchi Disk Transparency (m)
Oligotrophic	0 - 10	0 - 200	0 - 2	>6
Early Mesotrophic	10 - 15	200 - 300	2 - 5	4 - 6
Mesotrophic	15 - 25	300 - 500	5 - 10	3 - 4
Late Mesotrophic	25 - 30	500 - 600	10 - 15	2 - 3
Eutrophic	30 - 50	600 - 1000	15 - 30	1 - 2
Highly Eutrophic	> 50	> 1000	> 30	0 - 1

A wide range of algal cell concentrations were observed over the course of the season. The May and June algal communities were dominated by cyanobacteria (blue-green algae), with *Aphanizomenon* being the most abundant genus. *Aphanizomenon* is one of a number of blue-green algae genera that can regulate its buoyance and therefore its position in the water column. In addition, *Aphanizomenon* is morphologically organized as rather small cells arranged in filaments. The combination of small cells and ability to regulate buoyancy may explain the lower Secchi transparency and higher cell concentrations in the early part of the season.

Nitrogen limitation can favor cyanobacteria over other more desirable taxa (diatoms, green and golden algae) particularly those cyanobacteria genera that are capable of nitrogen fixation. *Aphanizomenon* is a nitrogen fixer and the prevalence this species coincides with lower TKN and ammonia levels in the epilimnion.

The algal community shifted from a cyanobacteria dominated community to a green alga dominated community as the season progressed and epilimnetic nitrogen increased. With the exception of the cell concentrations in September that were dominated by the green algae *Chlorella sp.*, cell concentrations after June 10th were low.

Phosphorus concentrations in the epilimnion were within the early mesotrophic to mesotrophic range (Table 1) and higher in the early months of the season. This suggests that the most important factor influencing phosphorus concentrations in the epilimnion is watershed export. Early season concentrations result from the spring flushing of the watershed from snow melt and the higher levels of precipitation in the spring. Export of nutrients and other dissolved salts to the lake is also most likely influencing the modestly higher specific conductivity earlier in the season.

We do note that TKN levels reported here, and therefore total nitrogen levels, are quite high and not aligned with Secchi transparency and total phosphorus levels (Table 1). We believe this to be laboratory error but cannot be quite sure if it is an analytical or mathematical issue. Above we reported epilimnetic TKN averages of 6.28 and 2.97mg/L at Sites 1 and 2, respectively. By converting units of measure from mg/L to µg/L, the averages become 6,280 and 2,970µg/L which are characteristic of highly eutrophic conditions (Table 1). If these were mathematically off by one decimal place and adjusted accordingly, then the concentrations might be 628 and 297µg/L and closer to the trophic class that is suggested by the Secchi transparency and total phosphorus. They would also be closer to historic levels (Fig. 8). AER has already chosen a different Connecticut State Certified Laboratory to provide nutrient and chemical analyses in 2018.

HISTORIC TRENDS

To put the 2017 water quality conditions into context, AER has provided a comparison of some of variables measured this year to historical levels. These variable included

Secchi transparency, total phosphorus, total nitrogen, specific conductivity, and alkalinity (Fig. 8). Data used for this analysis prior to 2015 were compiled and taken from Canavan and Siver (1995) who used the research of Deevey (1940), Frink and Norvell (1984), CT DEP (1991), and Canavan and Siver (1994, 1995). The 2015 and 2017 data were from studies by AER and monthly lake averages (i.e. average of measurements from Site 1 and 2) were calculated and used in this analysis.

Historic Secchi transparency has decreased since the 1930s but has not appreciably shifted since the late 1980s / early 1990s. Total phosphorus levels in the epilimnion do not appear to have substantially shifted since the 1970s. These trends suggest that management efforts to mitigate nutrient enrichment of Lake Wononscopomuc have been successful. As noted earlier, recent total nitrogen levels are inconsistent with historical levels and AER believes these are due to laboratory error.

Two other trends examined here are specific conductance and alkalinity. Both are trending upward since at least the 1970s for conductivity and since the 1930s for alkalinity. As noted earlier, Lake Wononscopomuc is situated in the geological region of Connecticut known as the Marble Valley (Bell 1985). Bedrock in this region is rich in carbonate rock and more erodible than other Connecticut bedrock. Resultingly, lakes in this region have comparably higher conductivity and alkalinity than lakes in other geological regions of Connecticut (e.g. Western Uplands and Eastern Uplands).

But the historical shifts may also be influenced by stormwater runoff, particularly runoff carrying deicing agents used on roads. Kohli et al. (2017) noted a steady and significant increase in conductivity (dissolved salt levels) at Candlewood Lake, which is another Marble Valley lake. Those researchers believe the increase was likely due to enhanced use of road deicing treatments. These types of shifts, along with increasing pH, water temperature, and resistance to mix in the water column can all result in conditions more suitable for cyanobacteria and less suitable for those other taxa that might otherwise be competing for nutrients and light.

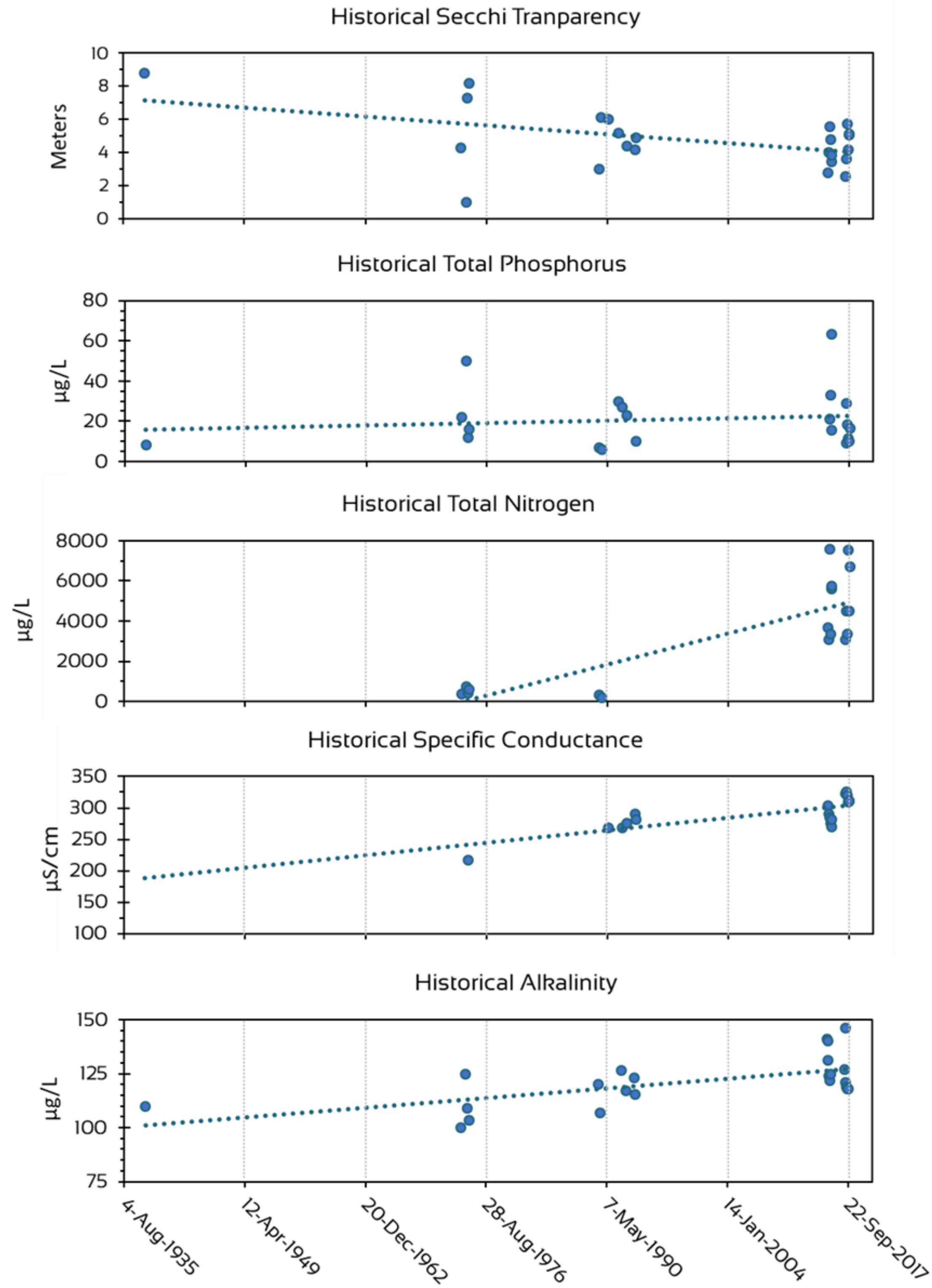


Figure 8. Comparisons of historic total phosphorus, Secchi transparency, total nitrogen, specific conductance, and alkalinity to current levels at Lake Wononscopomuc.

RECOMMENDATIONS

The following are recommendations for future water quality management initiatives:

1. Water Quality Monitoring
    a. Ideally, this should be conducted on a yearly basis to develop a comprehensive database for statistical modeling and real-time water quality management decision-making. This should always be conducted following the protocol outlined in this report.
        i. At minimum, this should be conducted every two years.
    b. Consider constructing a Quality Assurance Program Protocol to ensure the protocol is documented completely in case there is a change in the lake management entity.

2. EPA 9-Key Elements Watershed Study
    a. To establish the external nutrient and dissolved salt loading (e.g. deicing agents) and the relative influences of each part of the watershed, an EPA 9-Key Elements Watershed Study should be considered as part of your long-term lake management plan.
    b. These types of studies are expensive; therefore, you should consider applying for grant funding. A few grant initiatives that may help you obtain funding for this type of study are:
        i. EPA 319 Grant Program
        ii. Connecticut STEAP Grant

3. Historical Water Quality Data Analysis
    a. In this report AER provided a comparison of recent data to historic data of water quality monitoring for Lake Wononscopomuc. These historical data hold a wealth of information; therefore, all of these data should be compiled and analyzed using advanced statistical techniques.
        i. The major advantage to doing this is to determine what the long-term dynamics of Lake Wononscopomuc water quality have been. Furthermore, it will provide insight as to what the anthropogenic influences on the lake have been and to what degree these influences require remediation.

4. GIS Analysis of Current and Historic Land Use
    a. Geographic Information Systems (GIS) have become a powerful tool in lake and watershed management. Additionally, it is well known that changing land use within a watershed results in changes in water quality.

        i. An analysis of current land use conditions would be used and compared to historic land use and applied to nutrient export models to estimate nutrient loading from the watershed.

5. Examination of Water Quality Management Strategies
    a. Since there is a significant internal source of nutrients being produced in Lake Wononscopomuc in each summer season, the strategies for managing internal nutrient sources should be explored and quantified.
        i. This type of examination will allow for prudent fiscal planning should an internal water quality management strategy become necessary.
        ii. Types of nutrient management to be explored:
            1. Aeration
            2. Mixing
            3. Alum

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APPENDIX 1: 2017 WATER QUALITY DATA FROM SITES 1 AND 2 IN TABULAR FORMAT

Site 1: Surface Water Quality Parameters

	May	June	July	Aug	Sep	Oct
Alkalinity (mg/L)	128	138	120	120	118	120
Ammonia (mg/L)	0.56	0.28	0.28	1.1	1.4	4.8
Nitrate (mg/L)	0.25	0	0	0	0	0
Nitrite (mg/L)	0	0	0	0	0	0
TKN (mg/L)	3.4	6.7	5.6	10.1	7.3	7.8
Total P (µg/L)	31.3	9.8	17.1	11	9.3	11.7
N:P Ratio	117	684	327	918	785	667
Secchi (m)	2.64	3.64	4.86	3.80	4.94	5.63

Site 1: Bottom Water Quality Parameters

	May	June	July	Aug	Sep	Oct
Alkalinity (mg/L)	130	146	128	142	122	128
Ammonia (mg/L)	0.56	0.00	0.84	1.10	0.56	0.84
Nitrate (mg/L)	0.24	0.33	0.30	0.13	0	0
Nitrite (mg/L)	0	0	0	0	0	0
TKN (mg/L)	1.7	10.1	8.4	6.2	6.2	3.4
Total P (µg/L)	8.3	22.3	29.7	41.0	37.6	63.2

Site 2: Surface Water Quality Parameters

	May	June	July	Aug	Sep	Oct
Alkalinity (mg/L)	126	154	122	118	118	116
Ammonia (mg/L)	0.00	0.56	0.28	0.84	0.00	4.80
Nitrate (mg/L)	0.28	0.09	0	0	0	0
Nitrite (mg/L)	0	0	0	0	0	0
TKN (mg/L)	2.2	2.2	1.1	5.0	1.7	5.6
Total P (µg/L)	26.1	8.3	19.1	12.0	10.8	21.6
N:P Ratio	84	265	58	417	157	259
Secchi (m)	2.53	3.55	6.58	4.50	5.14	4.57

Site 2: Bottom Water Quality Parameters

	May	June	July	Aug	Sep	Oct
Alkalinity (mg/L)	134	134	136	136	144	114
Ammonia (mg/L)	1.40	1.40	0.28	0.84	0.56	1.40
Nitrate (mg/L)	0.20	0.07	0.40	0.10	0	0
Nitrite (mg/L)	0	0	0	0	0	0
TKN (mg/L)	3.9	1.7	5.0	7.3	4.5	4.5
Total P (µg/L)	25.9	20.7	52.0	45.0	53.1	66.2