Northeast Aquatic Research

Lake Pocotopaug

2018 Water Quality Report

Prepared for the Town of East Hampton

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Executive Summary

This report summarizes the results of water quality monitoring conducted in 2018 by Northeast Aquatic Research (NEAR). Lake testing was conducted approximately twice per month from May through October, and once in November. The lake was monitored at the two deep water sites, Markham and Oakwood, to track compliance with CT DEEP water quality standards. In 2006, CT DEEP listed Lake Pocotopaug as an impaired waterbody with respect to Recreational Use because human contact with the water was no longer considered safe due to prolific cyanobacteria blooms. In 2016, NEAR prepared a US EPA-approved Nine Elements Watershed Based Plan for Lake Pocotopaug that identified sources of nutrient loading in the watershed and suggested management measures necessary to improve water quality. The plan established that storm water retrofits are needed throughout the nearshore area to limit lake loading of phosphorus and nitrogen to acceptable levels. The Nine Elements Watershed Based Plan was used to apply for CT DEEP nonpoint source pollution grant funding to engineer and construct many projects in the watershed. By the end of 2018, the engineering process had begun on multiple selected sites and test pits were dug to determine infiltration capacity of local soils. In-lake and watershed data collected in 2018 shows the lake trophic status was more or less unchanged when compared to data collected from 2014 to 2017, meaning that Lake Pocotopaug is still impaired for Recreational Use. Yet, the Town is currently in the contract phase with CT DEEP to fully fund physical stormwater improvement construction projects in 2019. Stormwater monitoring in the watershed over the next several years will document improvements as construction projects are completed.

Monitoring is conducted at Lake Pocotopaug to track the water quality parameters related to cyanobacteria blooms:

1. Water Clarity
2. Water Temperature
3. Dissolved Oxygen
4. Phosphorus
5. Nitrogen
6. Cyanobacteria

Water Clarity = In 2018, water clarity was worse than 2 meters in April, and again from late July through the end of October. Clarity fell below 1 meter just once in 2018, at Markham station in early September. Water clarity was best from May through early July, and improved again in early November. All clarity readings less than 2 meters classify Pocotopaug as Eutrophic and indicate cyanobacteria bloom conditions.

Water Temperature = The lake was fully mixed, with equal water temperatures from the top to the bottom of the water column at the beginning and end of the sampling season. These periods are known as spring and fall 'turnover.' From May through September, the lake became thermally stratified, with warmer waters at the surface and colder dark deep waters below. Poor water clarity intensifies stratification and predisposes a lake to bottom-water oxygen loss.

Dissolved Oxygen = The bottom of the lake lost oxygen in May and remained anoxic until mid October. The anoxic boundary followed a pattern similar to that seen in the prior three years, reaching a maximum height of 4.78 meters at Markham station in early August, and 4.75 meters at Oakwood station in early September. Markham bay loses oxygen faster than does the Oakwood station and holds anoxic water later in the season than does Oakwood.

Phosphorus = Total phosphorus (TP) in the upper waters ranged from 7ppb to 27ppb for the duration of the season at both Markham and Oakwood stations, with the exception of a 37ppb concentration recorded at Oakwood station in May. The goal for water quality management in lakes is TP ≤10ppb. The upper tolerable level of TP is 30ppb, but at Pocotopaug just 20ppb TP in surface waters seems to trigger cyanobacteria blooms. Phosphorus in the bottom water was low at both stations in April but began to rise in May. The maximum bottom-water TP concentration of 129ppb at Markham station occurred in early September, and the maximum bottom-water TP concentration at Oakwood station of 506ppb occurred in late August.

Nitrogen = Total nitrogen (TN) in Pocotopaug was elevated for the entirety of the 2018 sampling season and followed a trend similar to those seen from 2015 through 2017. The goal in lake management is to have TN ≤ 200 ppb, with upper tolerable level of 600ppb. Each year between April and June, nitrogen concentrations in the surface water generally range from 300ppb to 500ppb. In late June to early July, TN increases dramatically to over 600ppb, remaining at that level until the end of the season. In the bottom water, TN reaches maximum concentrations of between 2,000ppb and 3,000ppb in August and September. In 2018, TN in the bottom water at Oakwood station was noticeably higher than in the prior three years, reaching a maximum concentration of 3,836ppb in late September. These extreme summer TN increases in bottom-water are in part driven by anoxic water allowing for the release of Ammonia nitrogen.

Cyanobacteria = Cyanobacteria samples were collected from open water at the Oakwood sampling station. Samples were a composite of the top three meters of water. All samples were enumerated for total cyanobacteria cells per milliliter by Northeast Aquatic Research personnel. These open-water cyanobacteria cells counts are separate from the cell counting done by Northeast Labs and Green Water Labs, which were solely based on beach samples collected by Chatham Health District. Beach sample cyanobacteria counts are not included in this report as they are available on the East Hampton Town website and shoreline samples are not indicative of overall open-water lake conditions. Oakwood station cyanobacteria cell counts increased dramatically from June through the beginning of September, with a maximum of approximately 525,000 cells/mL on September 4th. Cell counts then dropped steadily through the fall as full mixing resumed at the end of October. The November 7th open-water cyanobacteria sample contained roughly 24,000 cells/mL.

Introduction

Northeast Aquatic Research (NEAR) began monitoring the water quality of Lake Pocotopaug in the spring of 2014. Our involvement builds on the work of several other groups that have collected lake data over the years in response to serious algae blooms in 1988, 1989, and 1990.

NEAR sampling protocols are consistent with all prior study groups making the long-term data set comparable. The two established lake sampling stations are Markham Station, a deep-water basin of 30ft max depth to the northeast, and Oakwood Station, a deep-water basin of 36ft max depth to the northwest (**Figure 1**).

The goal of lake monitoring is to track the Trophic Status of the lake to track water quality changes that may be attributable to improvements made under the Nine Element Watershed Based Plan. Parameters used to evaluate lake trophic status and compliance with CT DEEP Water Quality Standards (**Table 1**) are: levels of the nutrients phosphorus and nitrogen, and associated changes in phytoplankton/cyanobacteria, water clarity decreases, and bottom water dissolved oxygen loss.

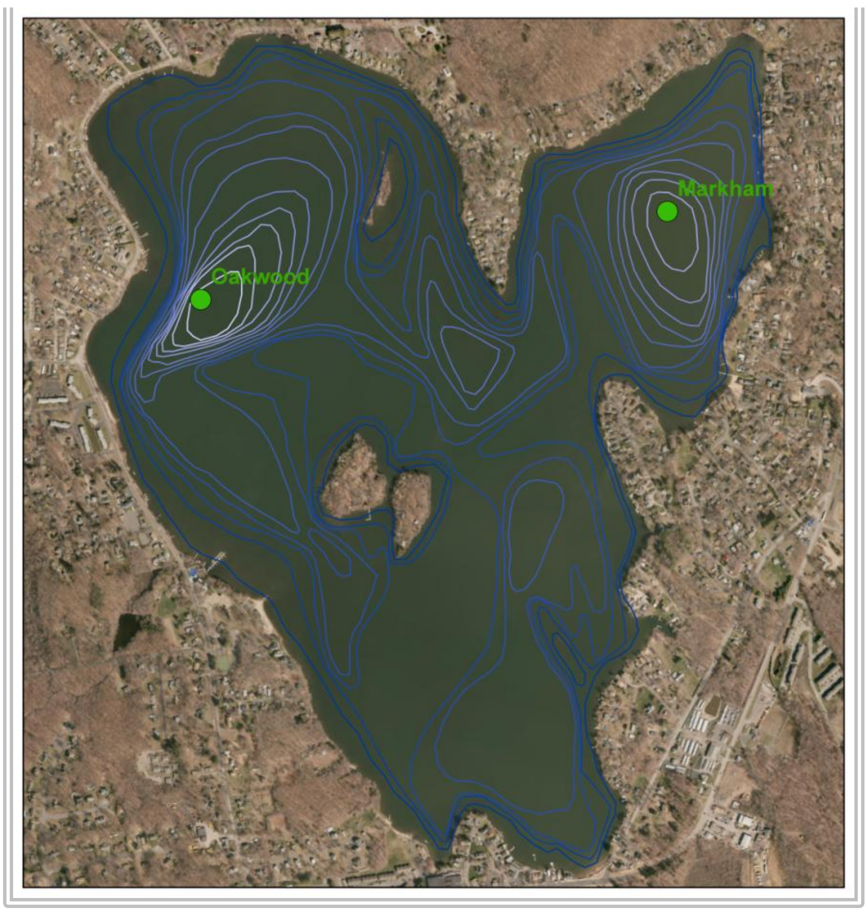


Figure 1: *Bathymetric map of Lake Pocotopaug, showing contour intervals in feet and location of the two in-lake sampling stations.*

Table 1: *Parameters and defining ranges for trophic states of lakes in Connecticut*[1]

Trophic state=>	Oligotophic	Mesotrophic	Eutrophic	Highly Eutrophic
TP -ppb	0 - 10	10 – 30	30 – 50	>50
TN -ppb	0 - 200	200 - 600	600 - 1000	>1000
Secchi -meters	>6	6 - 2	2 – 1	<1
Chlor.-*a* -ppb	0 - 2	2 – 15	15 – 30	>30

Methods

NEAR visited the two lake stations shown in **Figure 1** fourteen times in 2018 to measure seasonal changes in lake condition. This involves tracking water temperature, dissolved oxygen, cyanobacteria, zooplankton, water clarity, and nutrient concentrations over time and depth. The first two parameters were measured from top to bottom at 1-meter intervals using in situ probes. Cyanobacteria and zooplankton samples were collected by vertical compositing of the water column. Water samples for nutrient analysis were collected from discrete top, middle, and bottom depths with a horizontal sampler. The sample depths at Oakwood Station were 1 meter, 5 meters, and 9 meters; sample depths at Markham Station were 1 meter, 4, meters, and 8 meters. Water clarity was measured at each station using a Secchi disk and view scope.

Results

Water Clarity

Water clarity is the principal way that people aesthetically assess lakes. Clear water has less suspended phytoplankton and generally low nutrients. Lake Pocotopaug tends to have very poor water clarity, particularly in summer months during peak cyanobacteria bloom conditions. Cyanobacteria dominance is typically indicated by water clarity less than 2.0 meters, meaning that the goal of Lake Pocotopaug is for water clarity to be greater than 2 meters, shown by the red dashed line in **Figures 2 & 3**.

Water clarity in 2018 (**Figure 2)** followed a similar trend seen in the previous three years. Initially, in April, the water clarity was poor at approximately 1.2m but improved somewhat during May, June, and July, with a peak of 2.9m at Markham Station on June 20th, and a peak of 2.7m at Oakwood station on July 5th. These peaks in water clarity are not considered good in lakes overall, but these measurements are relatively good for Lake Pocotopaug. Yet, water clarity rapidly declined in late July & August to <1 meter on September 4th. Water clarity remained poor (<2m) until early November.

[1] Source: *Regulation on Connecticut Water Quality Standards R-39 Rev. 03/2012*

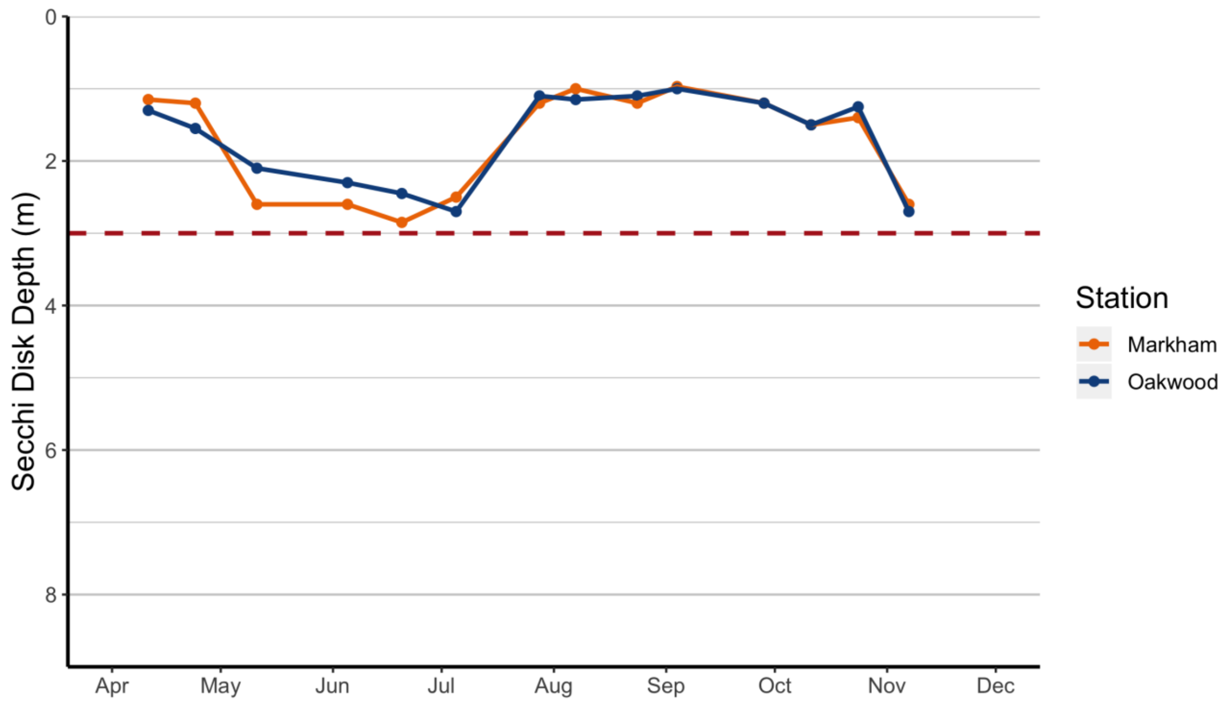


Figure 2: *Water Clarity tends for both stations in Lake Pocotopaug in 2018.*

The 2018 trend in water clarity was similar to patterns observed in the prior three years. Looking at the past four years together in **Figure 3** shows that the "Poor-Good-Poor" pattern occurs each year. Clarity was initially poor in April, improved in June and July followed by rapid deterioration--in a matter of weeks--to poor summer conditions that persisted until the end of each season. Note that the Secchi disk depth during the 'Good' phase in 2016 was exceptional at nearly 4 meters. The 2 meter clarity mark separates a cyanobacteria bloom 'Category' 2 from 3. Lakes with Secchi depths of greater than 2m are in Category 2 (Mesotrophic) or better Category 1 (Oligotrophic). Lakes with Secchi disk depths less than 2m are Eutrophic or worse Highly Eutrophic (**Table 1**). Lakes in Oligotrophic and Mesotrophic categories generally support recreational use, while lakes in Eutrophic and Highly Eutrophic categories do not. Eutrophic and Highly Eutrophic lakes are considered impaired by CT DEEP. The dividing line between good lakes and impaired lakes is shown by the red dashed line at the 2 meter mark, in **Figures 2 & 3**. Lake Pocotopaug water clarity declines below 2 meters between June 1 and August 1 every year and remains <2m until the last sampling visit in November.

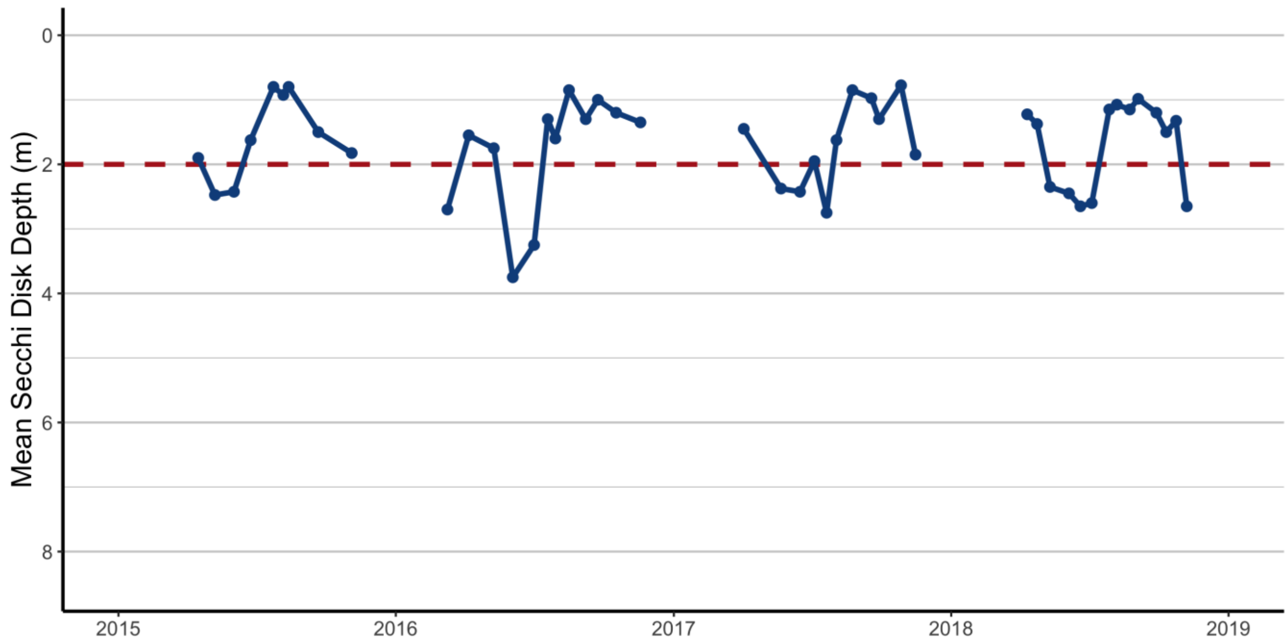


Figure 3: *Water clarity average of Markham and Oakwood stations between 2015 and 2018.*

Water Temperature

Water temperature of the lake was measured at each 1 meter depth from top to bottom, during each visit and at both stations between April and November. Water temperature profiles measured in 2018 are shown for Markham and Oakwood stations (**Figure 4**). For comparison, a typical temperature profile of a deep water lake is shown in **Figure 5**, where upper warm water floats over a middle layer where temperature decreases quickly with depth through the thermocline, and a bottom layer of homogeneously coldest water. Lake Pocotopaug develops only an upper layer of equally warm water between 0 and 3-4 meters, and a middle temperature changing layer where water gets colder with depth to the bottom. No true hypolimnion forms in Lake Pocotopaug.

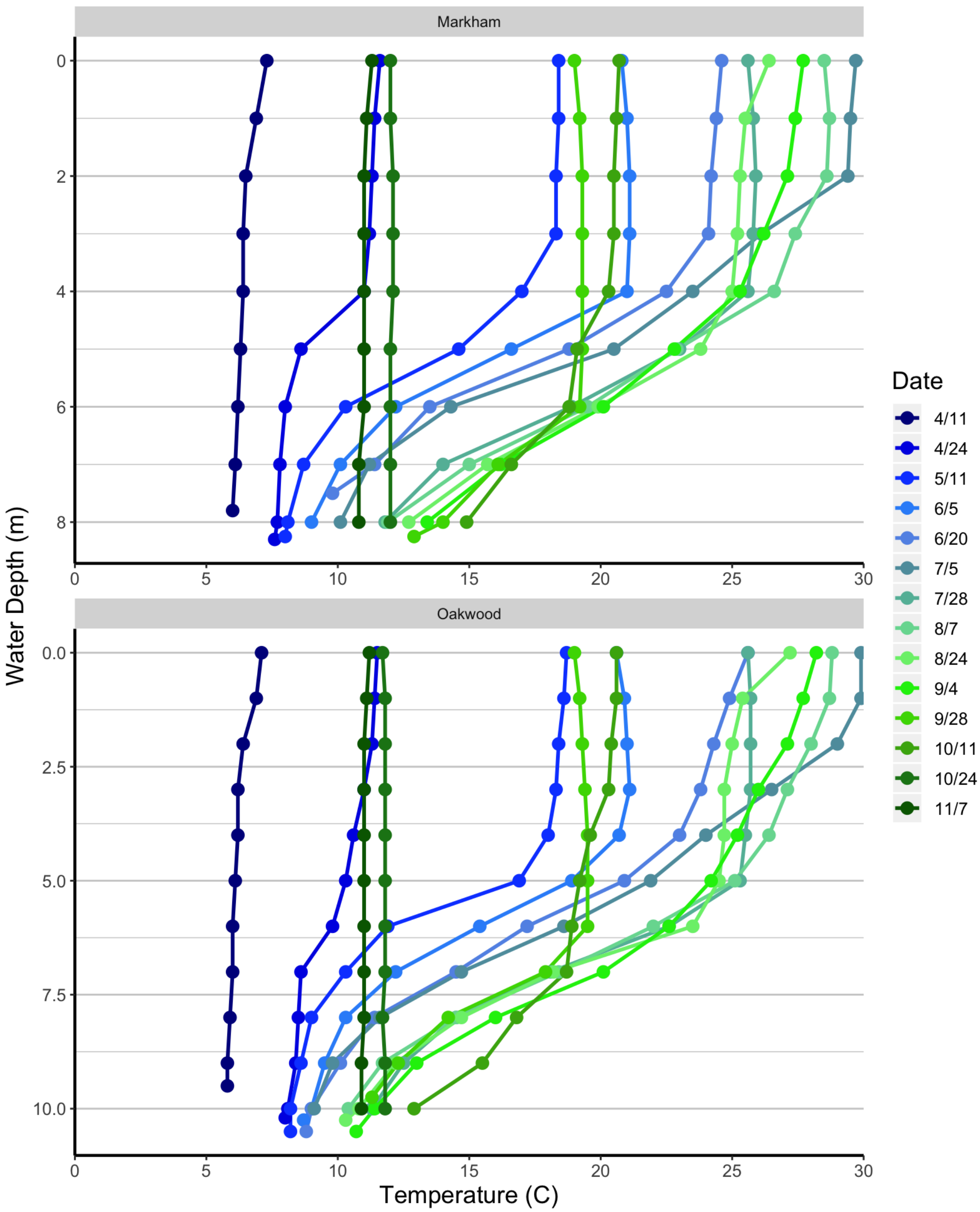


Figure 4*: Water temperature with depth at Markham and Oakwood stations in 2018.*

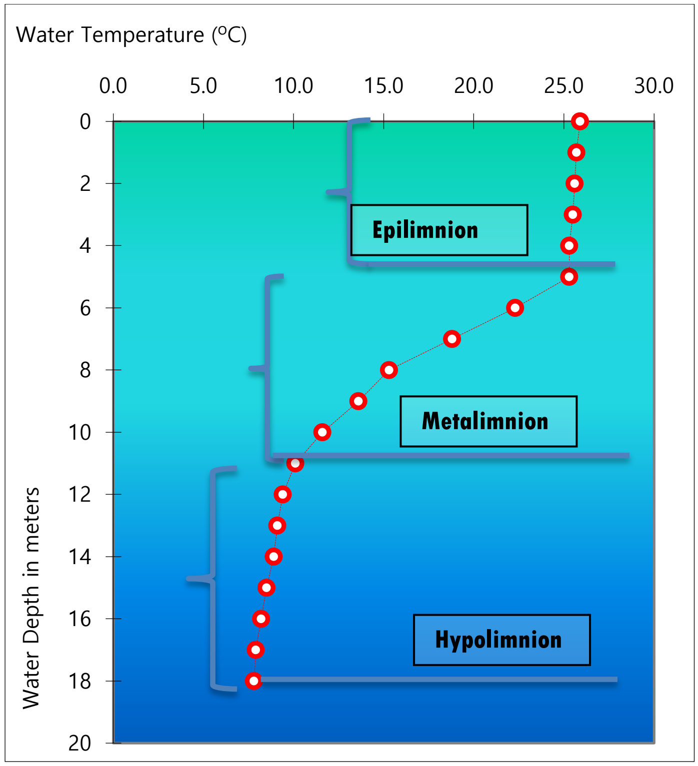


Figure 5: *Classical stratification of a deep water lake showing upper warm water or Epilimnion, a middle temperature changing layer called the Metalimnion (thermocline), and deep cold layer called the Hypolimnion.*

The water temperature profiles show the lake to be fully mixed on three dates; April 11th, Oct. 24th, and Nov. 7th. On all other dates the lake showed temperature differences between top and bottom indicating stratified or semi-stratified conditions. Lake stratification began in late April with the formation of an upper layer of warmer water, and a layer of cooler water below. The upper layer of warmest lake water is the Epilimnion, where temperatures are identical or very similar from the top of the layer to the bottom. This report will also refer to the Epilimnion as the Upper Waters.

Lake stratification was fairly strong below the Epilimnion as shown by the horizontal bars in **Figures 6** *&* **7.** The bars show the amount of energy required to mix two adjacent waters of different temperatures or densities. Longer bars indicate progressively more energy required to mix the two waters. For example, the strongest stratification for the lake in 2018 occurred at Oakwood station on August 24th, when the RTRM was 141 at 7 meters.

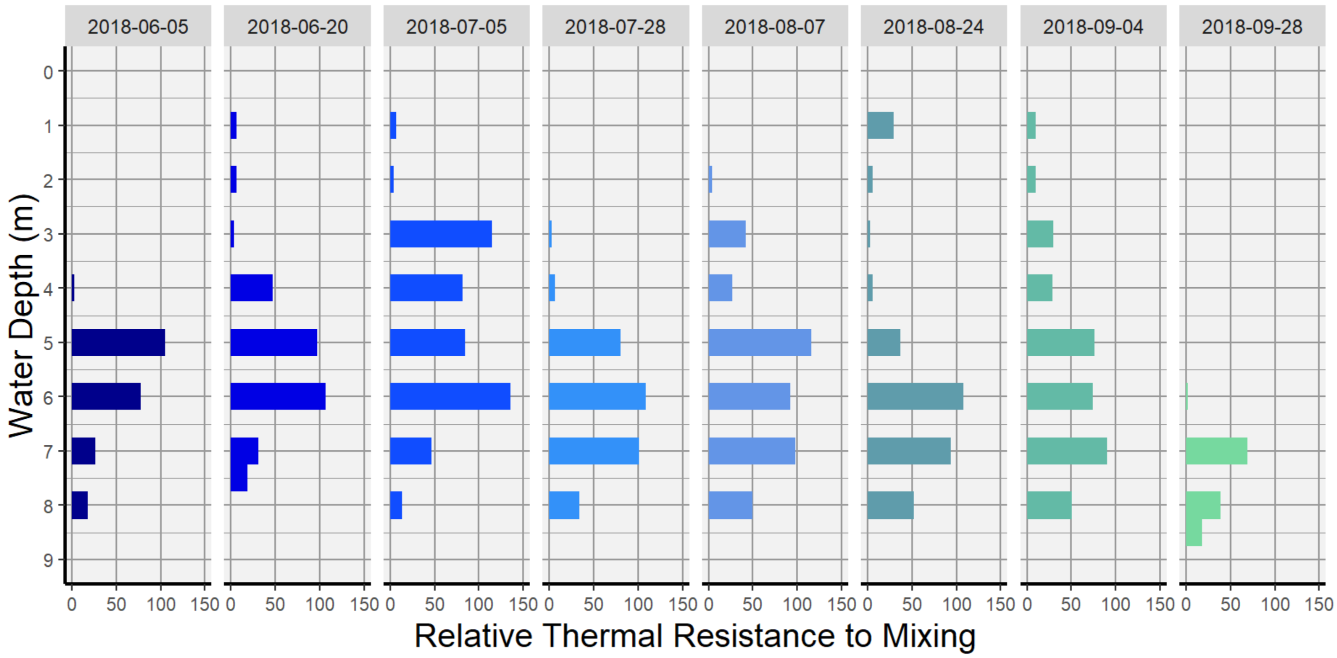


Figure 6*: Thermal resistance to mixing in the water column at Markham station in 2018.*

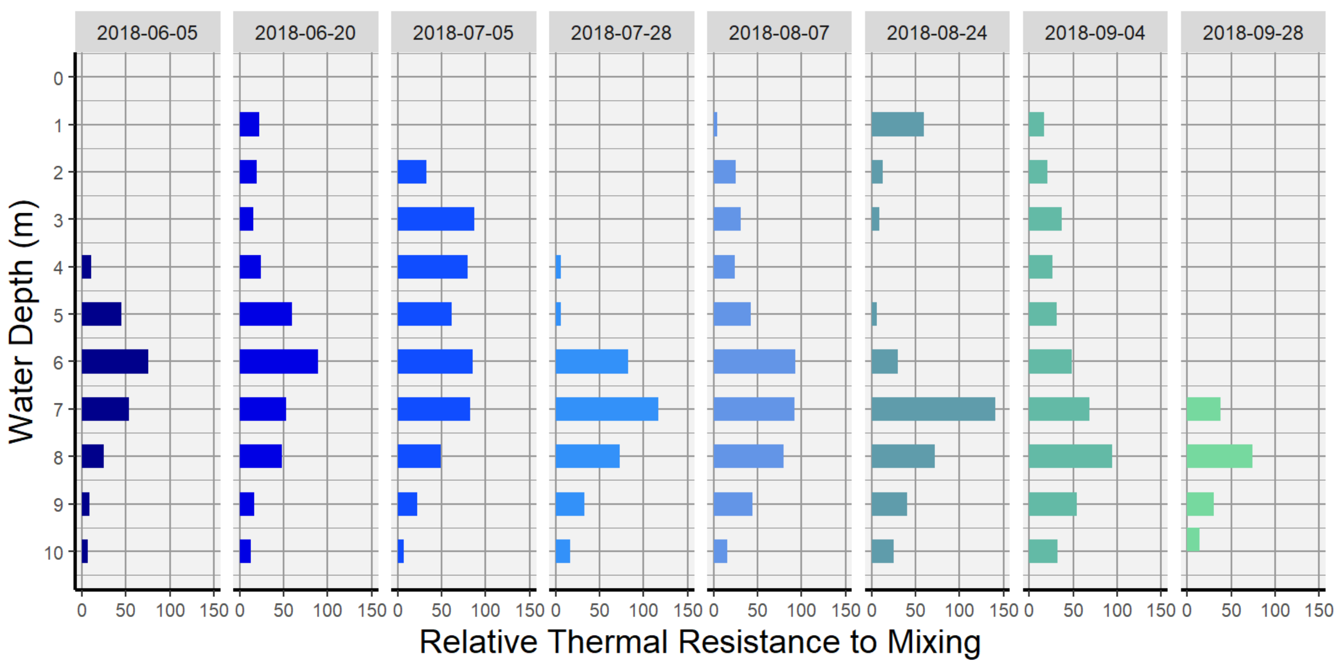


Figure 7: *Thermal resistance to mixing in the water column at Oakwood station in 2018.*

These results suggest that there is enough temperature difference between top and bottom to allow stagnation from the atmosphere to cause oxygen loss in deep waters, but there is not enough resistance to mixing to form a stable boundary in the middle depths to prevent diffusion of nutrients from bottom waters to upper waters for the entire summer. The way the waters below 3 meters are constantly changing with depth in time suggests that mixing of bottom water with upper waters may be significant.

To reiterate a point made in the 2017 report, the Markham sampling station has less fetch from north, east and south winds, which results in greater water column stagnation. The Oakwood station is located in the north central area of the lake so is exposed to maximum fetch from the south, which allows for greater water column mixing at this station.

Dissolved Oxygen

The dissolved oxygen (DO) in the lake was measured at each meter depth from top to bottom. The 2018 dissolved oxygen profiles for Lake Pocotopaug is provided in **Figure 8.** The figures show that the lake was fully mixed – from top to bottom – during April, October, and November, as indicated by straight lines of dissolved oxygen with depth. DO was fully saturated at all depths to the bottom in April and late October-November.

The deepest water, just over the bottom sediments at each station, became anoxic by May 11th, with the boundary ascending rapidly to 5 meters by early July. This rate of deep-water oxygen loss appears to be increasing. Waters below 6m were anoxic for more than three months in 2018, from early June to early September (**Figure 9)**. When the anoxic boundary is at 6 meters, approximately 70 acres of bottom sediments are overlain by anoxic water; at 5 meters there are 111 acres overlain with anoxic water (**Figure 10**). This acreage is important because it defines the potential area of internal release of nutrients stored in bottom muck.

The bottom water at Oakwood station became anoxic at the earliest date on record in 2018, which also suggests that the lake oxygen loss is worsening. Maximum anoxia occurred in August, consistent with the months that had the strongest RTRM values in **Figures 6** & **7**. Markham generally loses DO faster in the spring than does Oakwood, and holds anoxic water longer into the fall than does Oakwood. The persistence of anoxic water in Markham is likely due to the reduced wind fetch into the Markham bay, as opposed to Oakwood which is susceptible to the full southerly wind fetch.

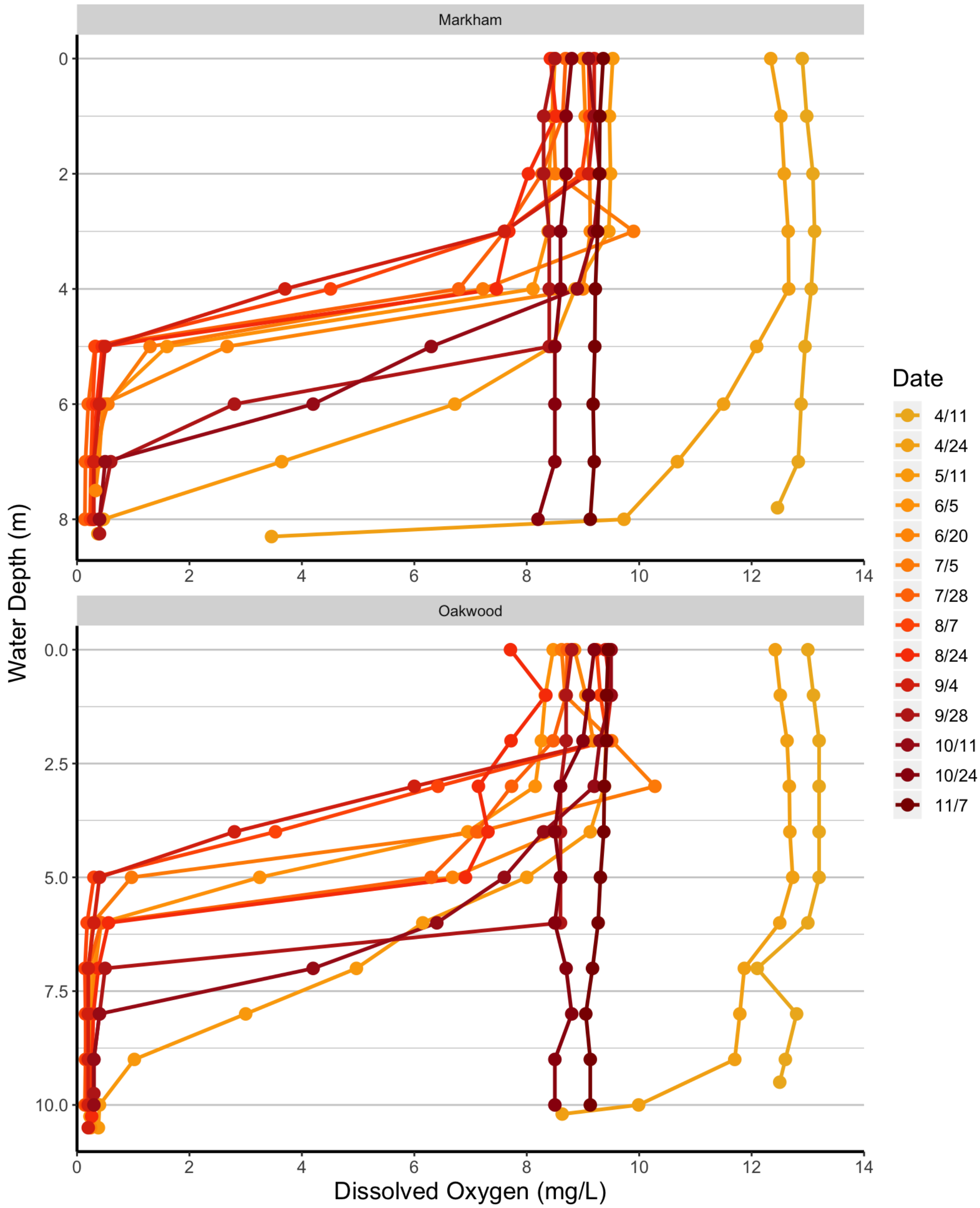


Figure 8*: Dissolved oxygen profile at Markham station during 2018, dashed line shows 1mg/L dissolved oxygen*

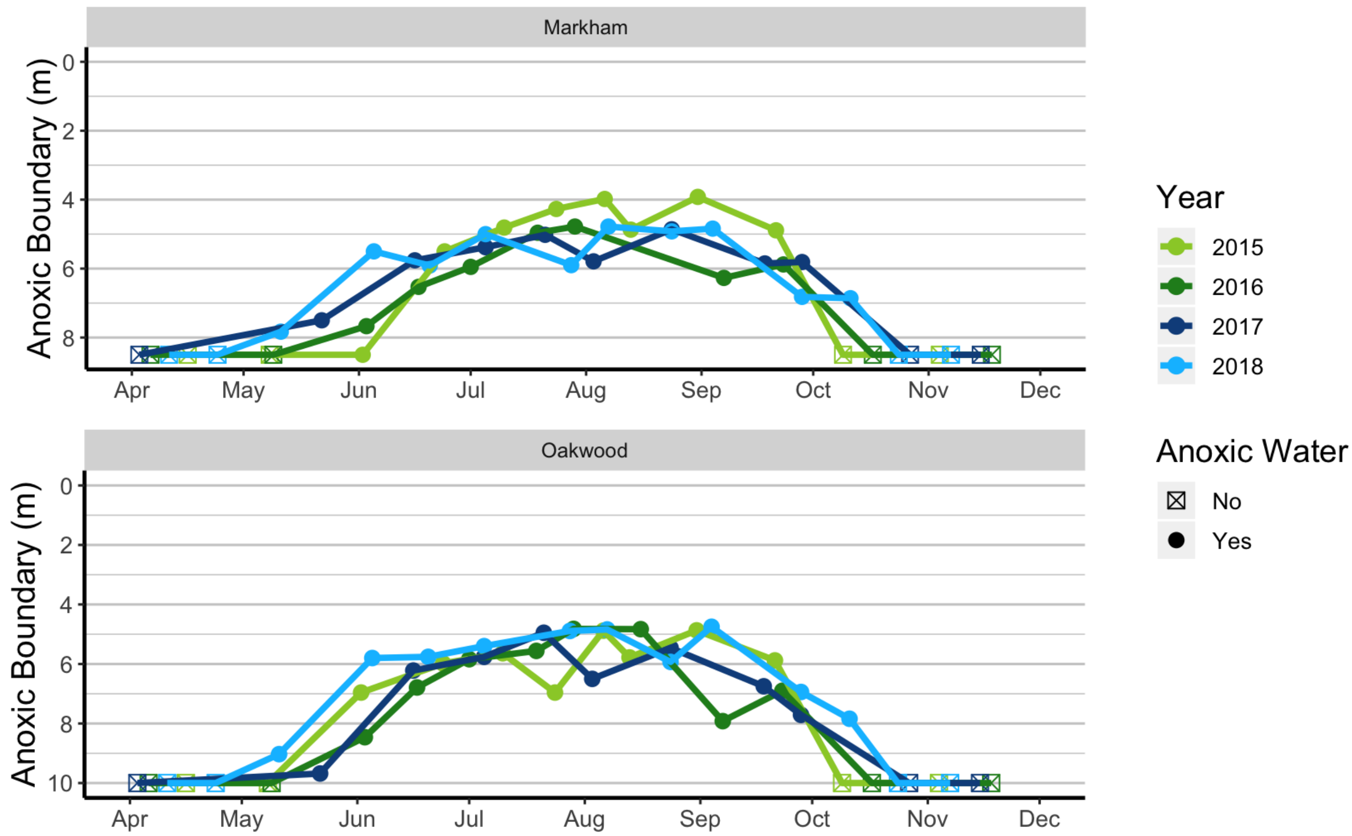


Figure 9: *Anoxic boundary depths at Markham and Oakwood stations, 2015-2018*

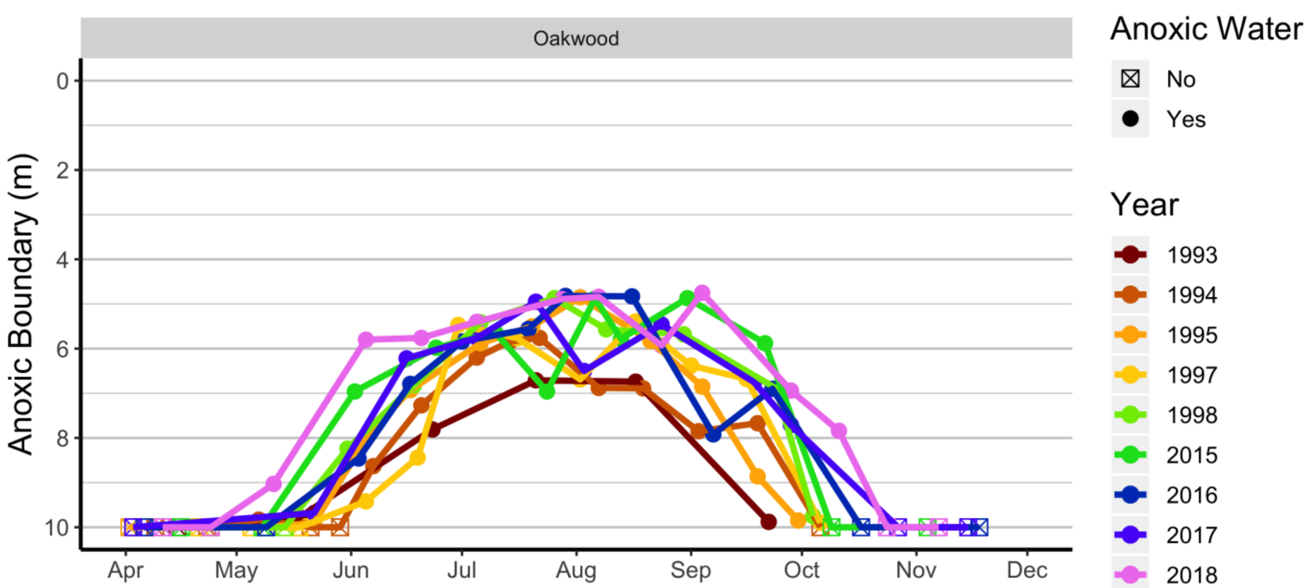


Figure 10: *Anoxic boundary depths at Oakwood station, 2015-2018*

Phosphorus

Background

Phosphorus is an important element for all living things and the limiting nutrient for phytoplankton, especially cyanobacteria, in freshwater lakes. Phosphorus is released from the watershed by the development of the drainage basin. Phosphorus that washes into a lake becomes incorporated into plants and animals, and is attached ionically to sediments. Eventually, the phosphorus in plants and animals becomes part of the sediments as organisms die. Analytically, all forms are measured together in one test called Total Phosphorus (TP).

As explained in the 2017 report, an empirical study of CT lakes conducted in the 1970s by the CT Agricultural Experiment Station[2] found that lakes could be separated into 4 categories based on phosphorus content as presented in **Table 1**. The TP/Water Clarity relationship from the Frink and Norvell survey is shown in **Figure 11** as red circles. The CT DEEP trophic categories are superimposed as boxes that bracket respective values in **Table 1**. The graph shows that lakes with very low phosphorus <10ppb, can have water clarities better than 6meters. Once phosphorus increases above 10ppb, however, water clarities better than 6 meters are rare. When phosphorus exceeds 25ppb water clarities above 4 meters are no longer possible, and when phosphorus reaches 30ppb water clarity above 2 meters is unlikely.

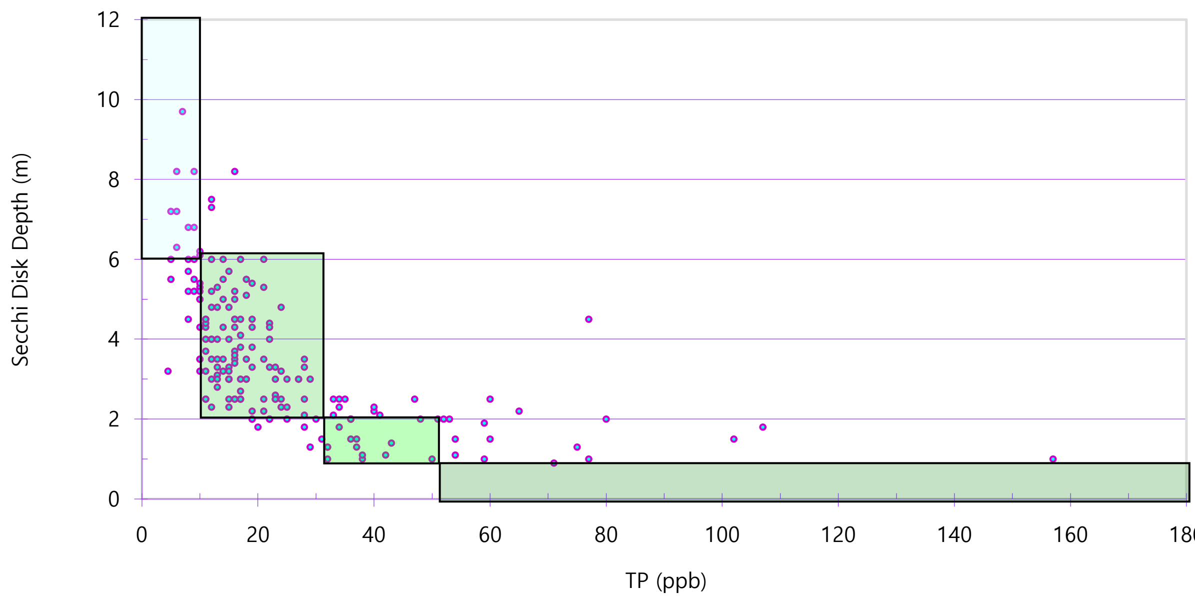


Figure 11: *Graphical representation of changes in water clarity with increasing phosphorus levels. Boxes conform to ranges of phosphorus and clarity given in Table 2 are data points from Frink and Norvell 1984.*

[2] Frink C.R. and W.A. Norvell. 1984. Chemical and Physical Properties of Connecticut Lakes. CAES bulletin 817. April 1984 New Haven.

The ranges in **Table 1,** and shown graphically in **Figure 11,** give two thresholds for phosphorus concentration in lakes when managing for cyanobacteria blooms, 10ppb, and 30ppb. Above 10ppb water clarity can no longer be excellent, above 30ppb water clarity is no longer good and waters often do not support recreational use.

Upper waters

The goal for Lake Pocotopaug is to have TP concentrations at or below 10ppb in upper waters. The upper threshold is 30ppb. Bottom waters will be treated separately. The Nine Element Watershed Based plan used 25ppb as an improvement goal for lake phosphorous concentration in upper waters, which should at least decrease cyanobacteria bloom prevalence.

The trend of TP in upper waters of Lake Pocotopaug in 2018 is shown in **Figure 12**, representing the top and middle water sampling depths at both stations. Trends over the last three years are shown in **Figure 13**. The majority of the TP concentrations at 1 meter fall between 10 and 20 ppb, while 5 meter values fall between 15 and 25 ppb. Concentrations at both 1 and 5 meter depths increased to over 30 ppb at least once each year. The data also show that at least once a year the TP decreases to near 10ppb, meaning that 10ppb goal is still realistic for Pocotopaug.

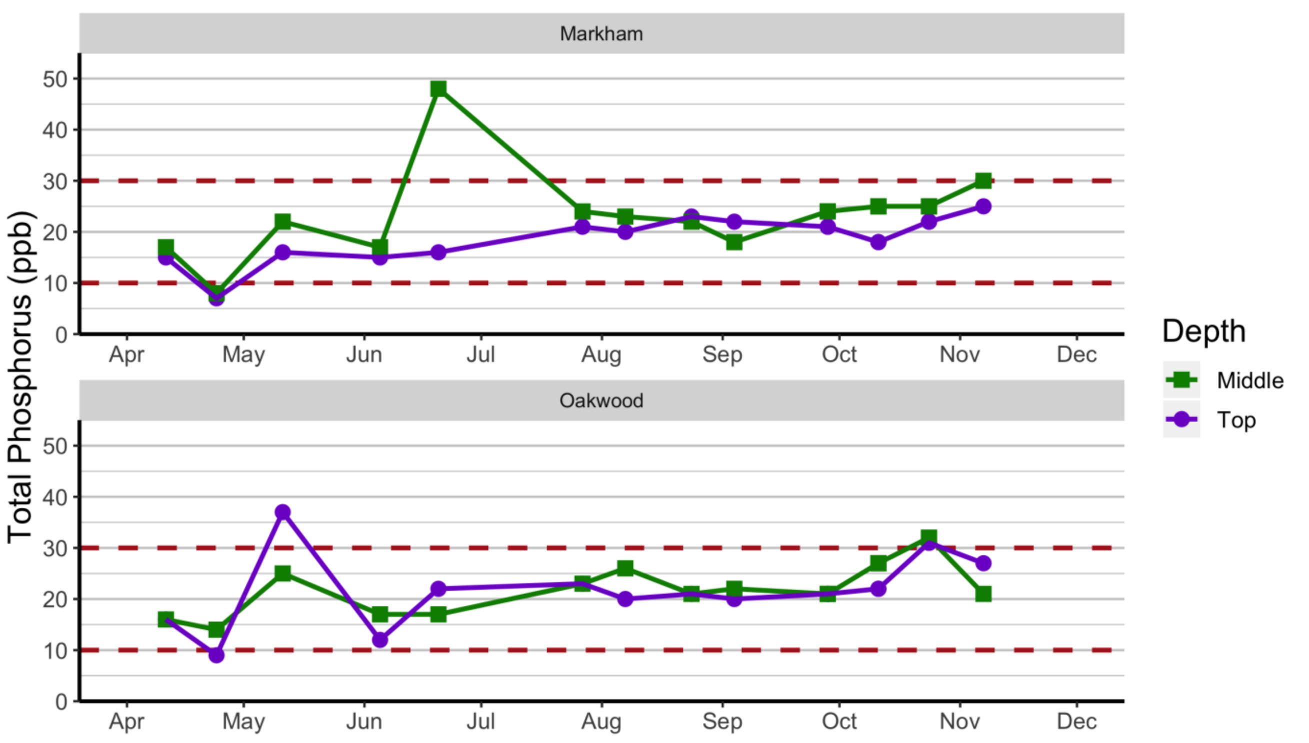


Figure 12: *Total phosphorus concentrations (ppb) at 1 and 5 meters at Markham and Oakwood stations in 2018*

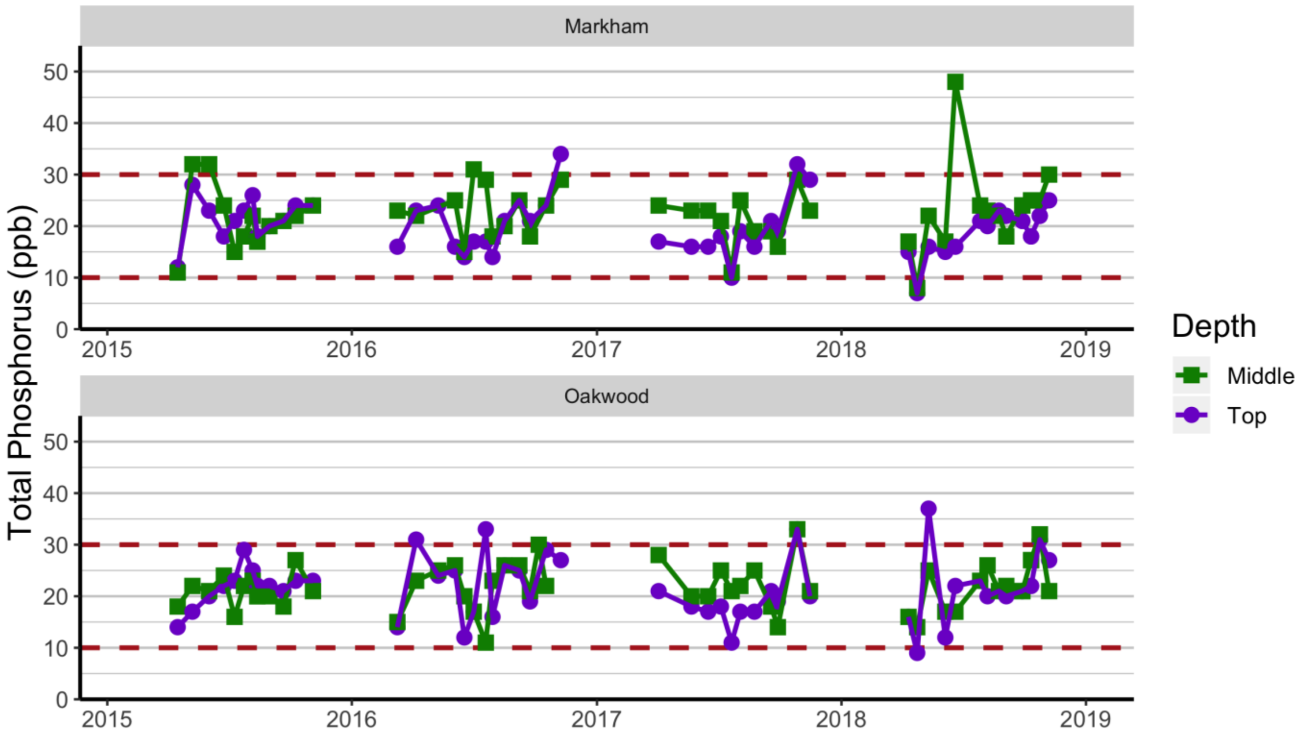


Figure 13: *Total phosphorus concentrations (ppb) at 1 and 5 meters at Markham and Oakwood stations in 2015-2018*

The graphs in **Figure 14** show that the concentrations of phosphorus in the top and middle layers are frequently unequal indicating a phosphorus concentration gradient with depth, even when the thermal and dissolved oxygen gradients indicate that the whole lake was mixing; during early spring, and late summer/early fall. When the lake has equal temperatures along the entire water column, yet the phosphorus concentration differs between depths, this implies that phosphorus is being actively supplied to one specific layer of the lake. As stated in the 2017 report, examination of differences between top and middle depth phosphorus concentrations in recent years shows that the lake appears to shift each year from a period early in the season when the phosphorus concentration at 5 meters is higher than at 1 meter, to a period later in the season when phosphorus at 1 meter is higher than at 5 meters. When concentrations at 5 meters are higher, internal loading is implied, when 1 meter is higher, surface drainage basin loading is implicated. However, internal loading doesn't start until at least mid-summer, too late to influence higher concentrations in the spring. When internal loading does occur in August and September, the top layer has higher concentrations than at 5 meters, reverse of what would be expected.

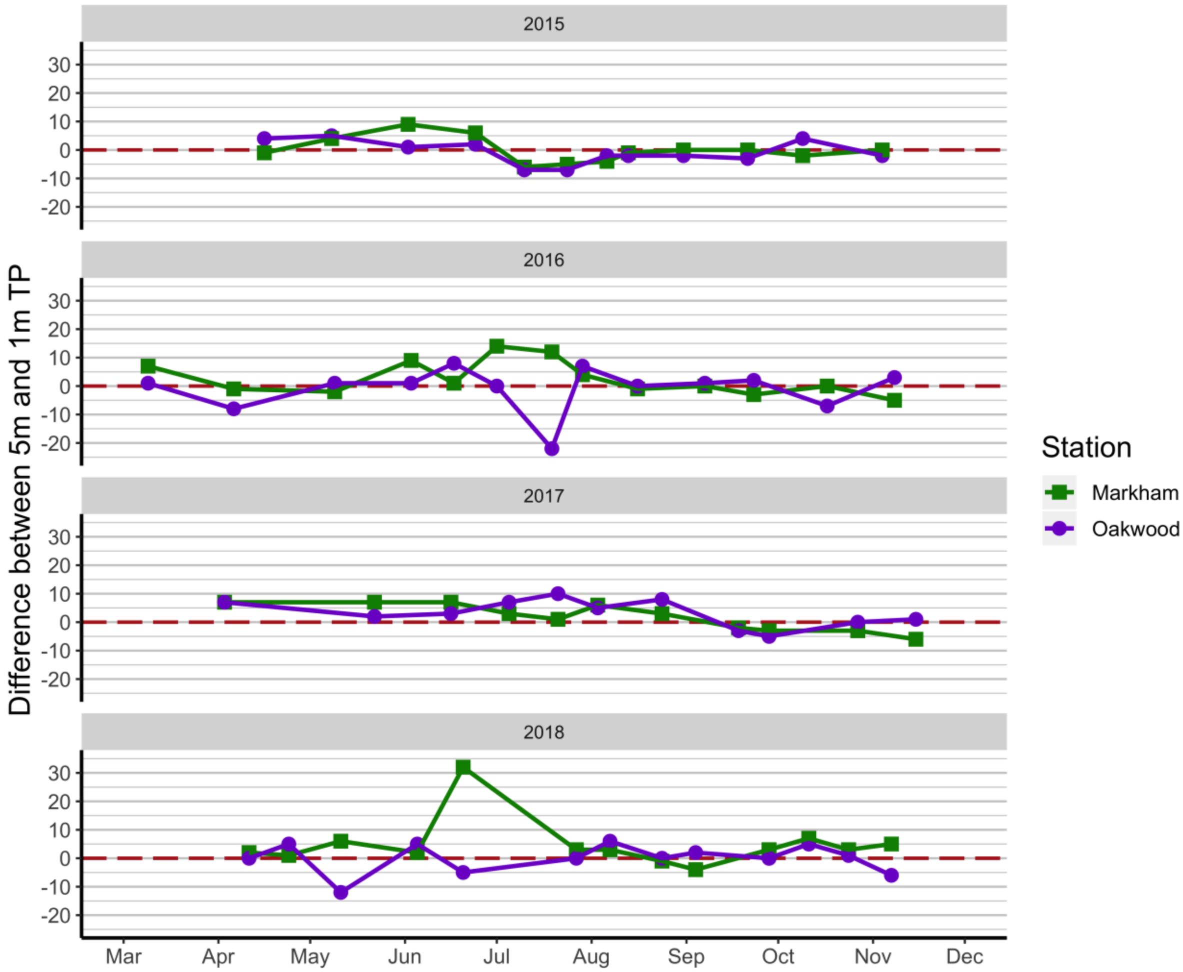


Figure 14: *Difference between 1 and 5 meter phosphorus concentrations (ppb) at the bottom of Markham and Oakwood stations, 2015-20178 Positive numbers mean 5m TP was higher than 1 meter TP. Negative numbers mean 1 meter TP was higher than 5m.*

The bottom water phosphorus concentrations for each station in 2015-2018 are shown in **Figure 15** as a seasonal composite of the three years. The composite graph superimposes the three seasonal trends on one year to show similarities of trends and timing of increases and peak concentrations.

Bottom waters

Bottom waters are represented by the water sample collected from 7 or 8 meters at Markham station, and 9 or 10 meters at Oakwood station. Trends in bottom water total phosphorus are shown in two charts below. The seasonal trends for the four years are shown as a composite in **Figure 15**. The bottom water phosphorus concentration trends over time are shown in **Figure 16**.

Generally, bottom water phosphorus is low in the spring and then begins to increase in the early summer as stratification intensifies. Peak bottom-water phosphorus concentrations are reached around late August before beginning to decrease again in late September or early October (**Figure 15**). Phosphorus in the bottom water reaches higher concentrations at Oakwood station, indicative of worsened internal loading.

Bottom water total phosphorus concentrations at Oakwood station were particularly high in 2018, reaching a maximum concentration of just over 500ppb in August and remaining near or above 300ppb through the end of October. This is the highest concentration recorded in Pocotopaug since NEAR began nutrient testing in 2015. This increase in phosphorus may have been caused by the record early-season oxygen loss and early-season elevated anoxic boundary also experienced in 2018.

It appears that the elevated phosphorus in the bottom water remains mostly contained in the bottom, as the phosphorus concentrations at the top and middle of the water column were not irregularly elevated in 2018.

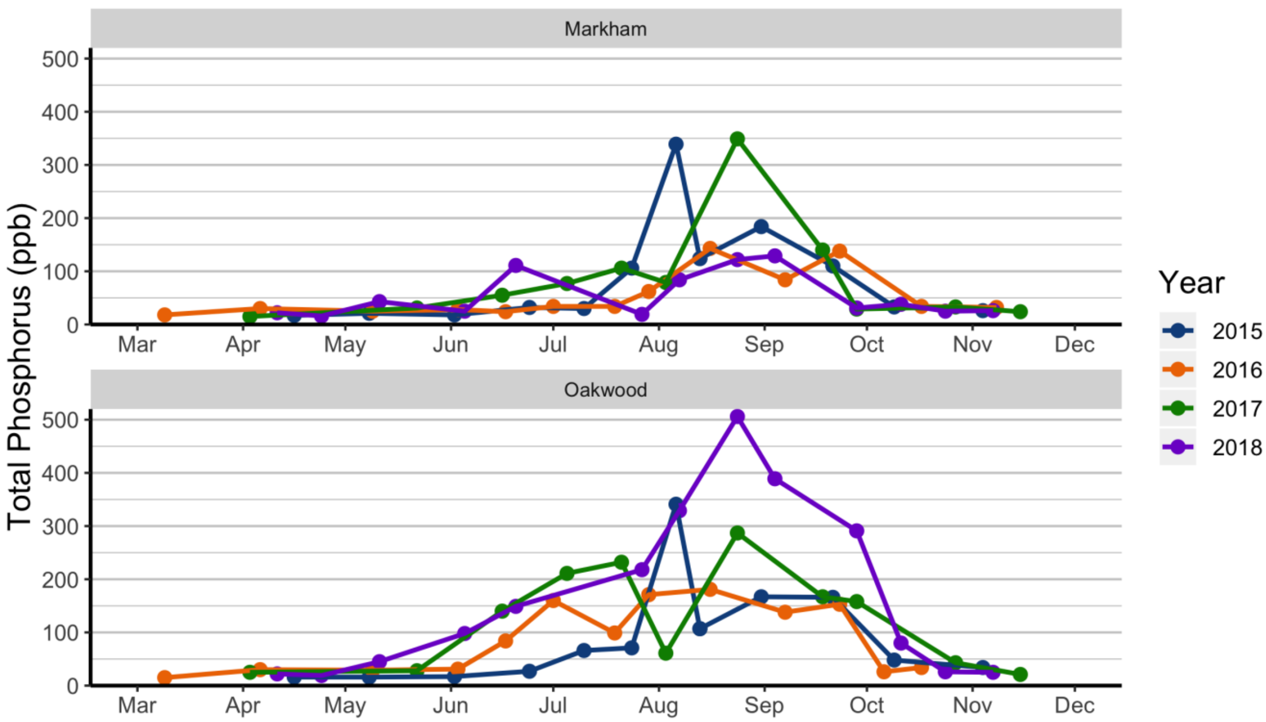


Figure 15: *Total phosphorus concentrations (ppb) at the bottom of Markham and Oakwood stations, 2015-2018*

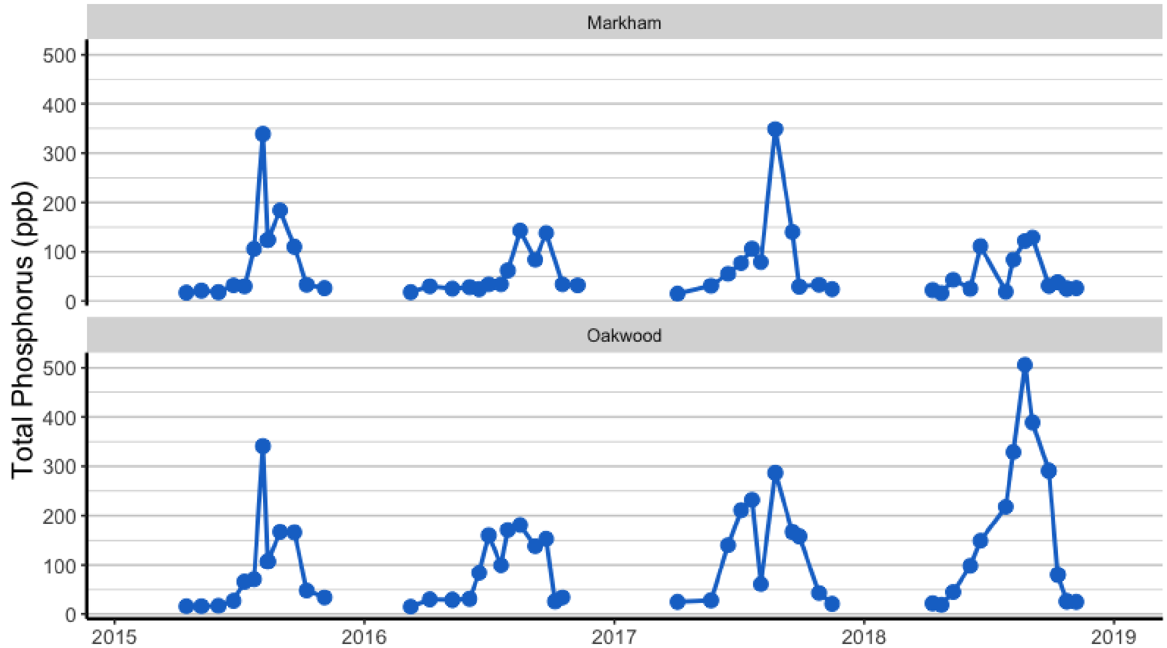


Figure 16: *Total phosphorus concentrations (ppb) at the bottom of Markham and Oakwood stations, 2015-2018*

Nitrogen

Total Nitrogen

Nitrogen is the second of the two primary growth nutrients for phytoplankton. Tracking nitrogen concentrations follows the thresholds given in **Table 1**. The goal of Lake Pocotopaug is TN <200 ppb, with upper allowable level of 600ppb.

Trends in total nitrogen for the four years in Lake Pocotopaug are shown in **Figure 17** for both stations. Trend lines for each year are very similar, showing essentially the same pattern each year, slightly offset by timing. The chart in **Figure 17** shows that each season the total nitrogen is moderately high in the early spring and then decreases to seasonal low levels around June of each year. However, as noted in the 2017 report, this initial decrease is then followed by a rapid increase in total nitrogen at a rate of about 500ppb in a 45 day period. The red dashed line shows the upper tolerable limit of total nitrogen concentration – 600ppb. In past years, this threshold was exceeded between July and mid-August and persisted until the end of the season. However, in the 2018 season, total nitrogen at the surface remained below the 600ppb threshold for the duration of the season at Oakwood station, and only rose slightly above the threshold at Markham station in late August and early September.

Bottom water nitrogen (**Figure 18**) shows only minor increases between April and July with no apparent changes in nitrogen at 1m and 5meters during that same time. Bottom water nitrogen begins to increase in

August and doubles or triples in concentration by late September, again seemingly uncoupled with changes at 1 and 5 meters (**Figure 19**). In 2018, bottom water TN at Oakwood station in August, September and October rose to the highest concentrations recorded in the past four years.

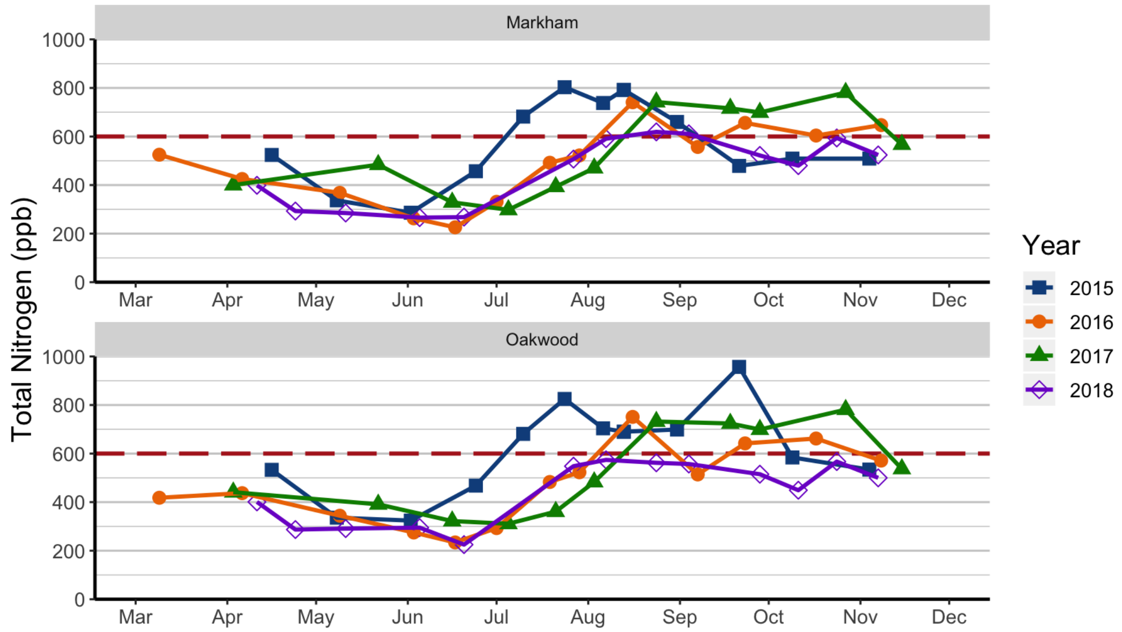


Figure 17: *Total nitrogen concentrations (ppb) in the upper water (1m) of Markham and Oakwood stations, 2015-2018.*

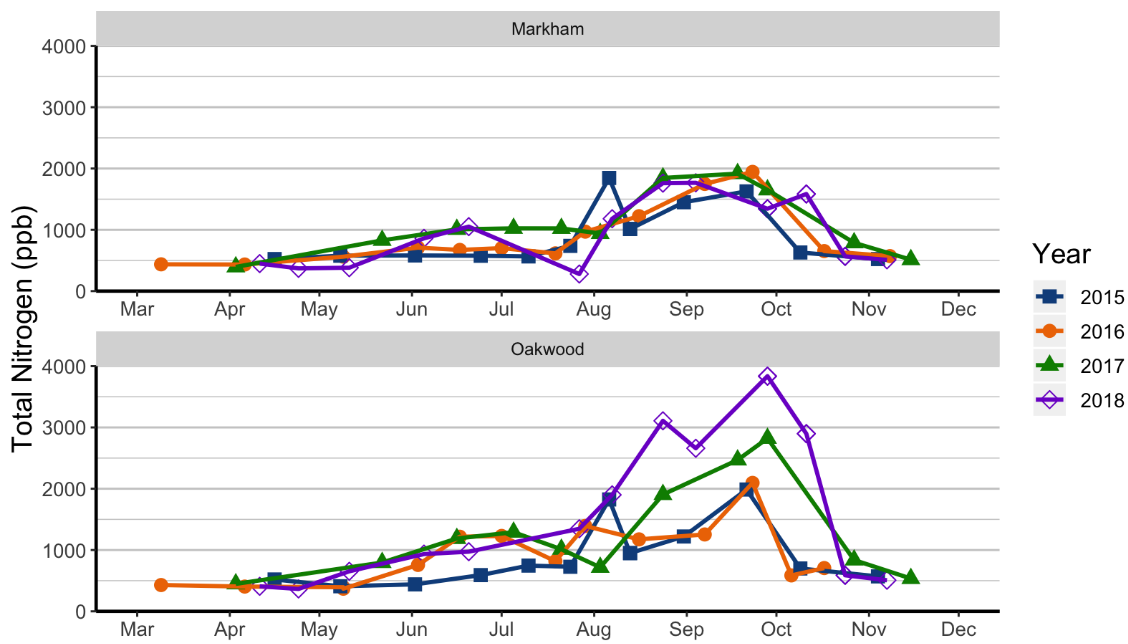


Figure 18: *Total nitrogen concentrations (ppb) at the bottom of Markham and Oakwood stations, 2015-2018.*

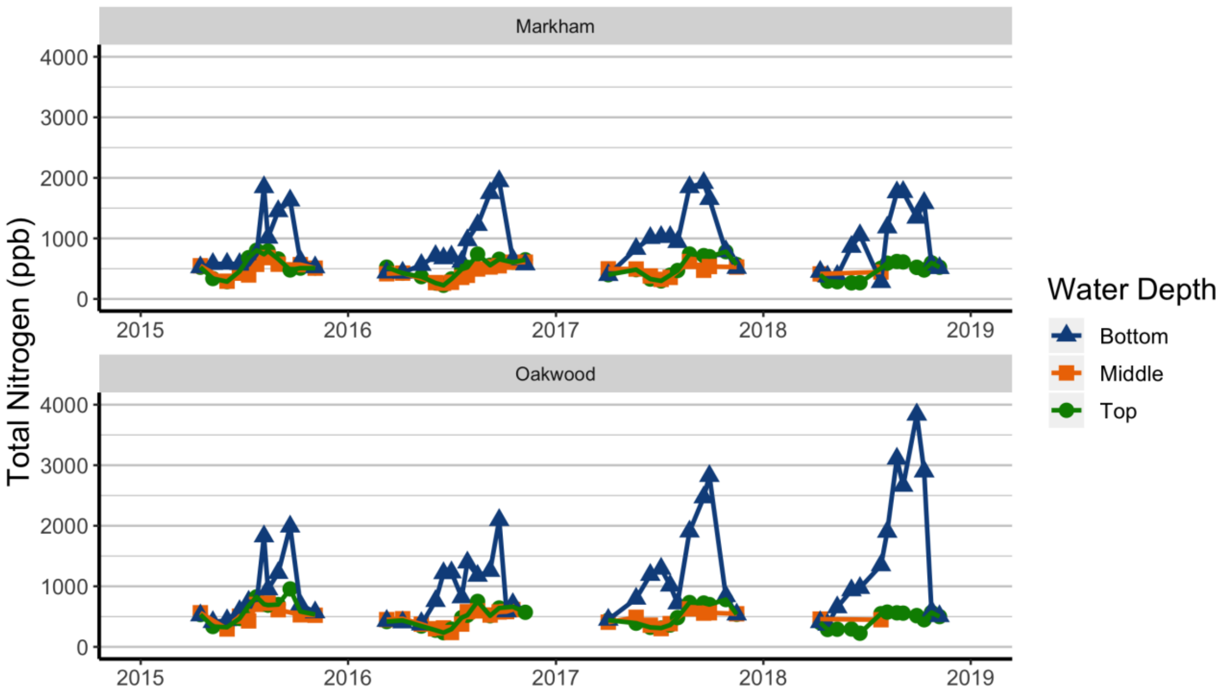


Figure 19: *Total nitrogen concentrations (ppb) at the top, middle and bottom of Markham and Oakwood stations, 2015-2018.*

Water Clarity and Total Nitrogen

1-meter total nitrogen concentration and water clarity are closely correlated in Lake Pocotopaug (**Figure 20**). This is unusual and suggests that nitrogen plays a larger-than-usual role in phytoplankton growth at Lake Pocotopaug. Highest total nitrogen concentrations occur during poorest water clarity. At TN concentrations less than approximately 500 ppb, there are a wide range of clarity readings, ranging from approximately 1.25 meters to approximately 4 meters. When TN is over approximately 500 ppb, the water clarity and TN concentration become closely correlated, with no Secchi readings better than 2 meters recorded.

Correlation does not necessarily imply that one variable causes change in the second variable. However, it is widely accepted that high concentrations of nutrients such as total nitrogen do lead to increased cyanobacteria in the water, which in turn causes reduced water clarity. Adding in the 2018 total nitrogen and water clarity data to this trend slightly reduced the correlation coefficient using an exponential trend line from $r^2 = 0.82$ to $r^2 = 0.67$, meaning that water clarity was less potentially less dependent on total nitrogen concentrations in 2018 than in the past years of monitoring.

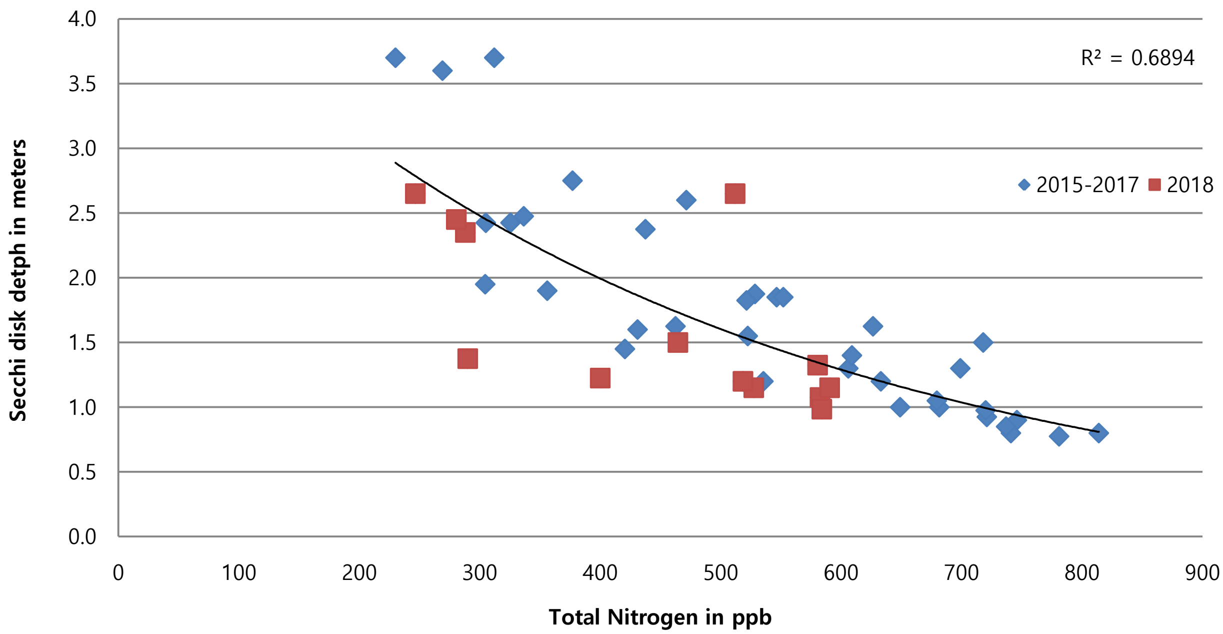


Figure 20: *Average water clarity and average 1-meter total nitrogen at Markham and Oakwood stations, 2015-2018*

Ammonia

Ammonia is an inorganic form of nitrogen that is formed by breakdown of organic matter. It is not stable in the presence of dissolved oxygen, as DO will quickly oxidize ammonia to nitrate. Ammonia is also the preferred form of nitrogen by phytoplankton so is rapidly depleted in the surface waters of lakes by algae.

Ammonia was present at low concentration (less than or close to 25ppb) in surface waters of Lake Pocotopaug at both Markham and Oakwood stations between April and early September. By late September, ammonia had begun to rise at both stations, and reached maximum concentrations in early November at the time of fall turnover (**Figure 21**). These are the highest concentrations recorded in the surface water in the past four years. However, ammonia in the surface water makes up only a small percent of total nitrogen described above in surface waters, indicating that the large increases in total nitrogen in surface water overall was due to organic nitrogen forms.

Figure 22 shows bottom-water ammonia data. In the 2018 season, ammonia concentrations were higher than those recorded in the prior three years. At Markham station, ammonia exceeded 100ppb in May and had exceeded 1,000ppb by late August. In late October and early November, Ammonia concentrations had decreased from mid-summer levels, but were still elevated. Ammonia concentrations at Oakwood station were higher than Markham, rising to nearly 400ppb by May and nearly 2,000ppb by early August. Ammonia at Oakwood station reached a maximum concentration of 3,930ppb in early September. The rapid decrease in bottom ammonia at the end of the season indicates that fall turnover mixed ammonia into the surface, and also that ammonia was mostly oxidized to other forms of nitrogen in early November.

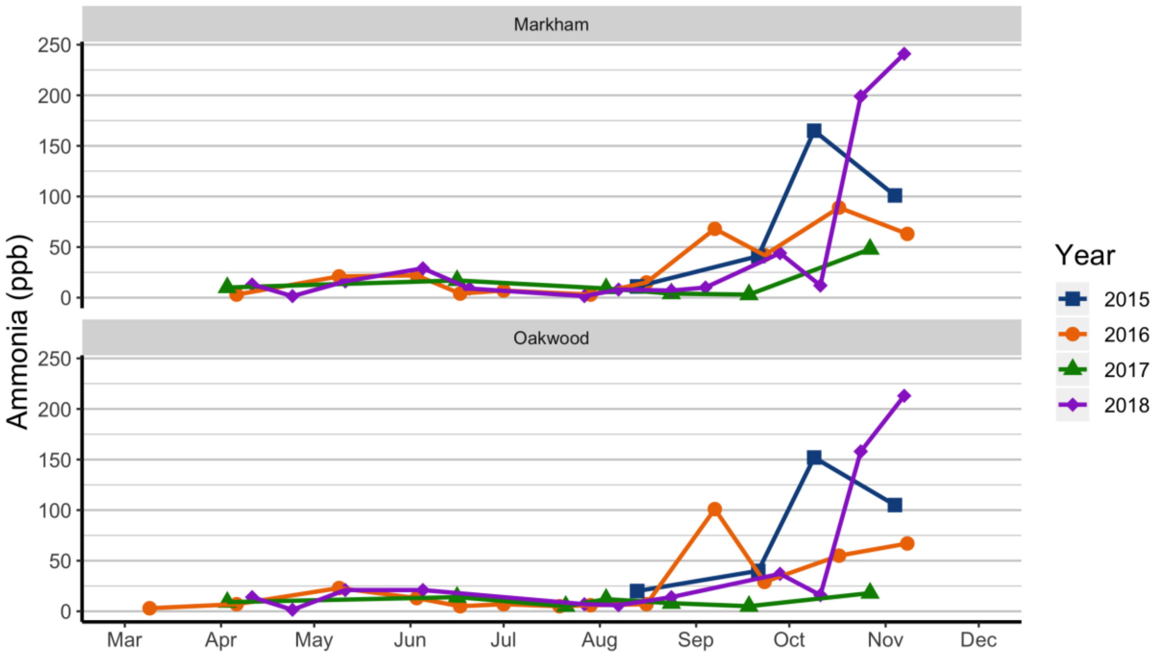


Figure 21: *Ammonia-nitrogen concentrations (ppb) at 1-meter at Markham and Oakwood stations, 2015-2018.*

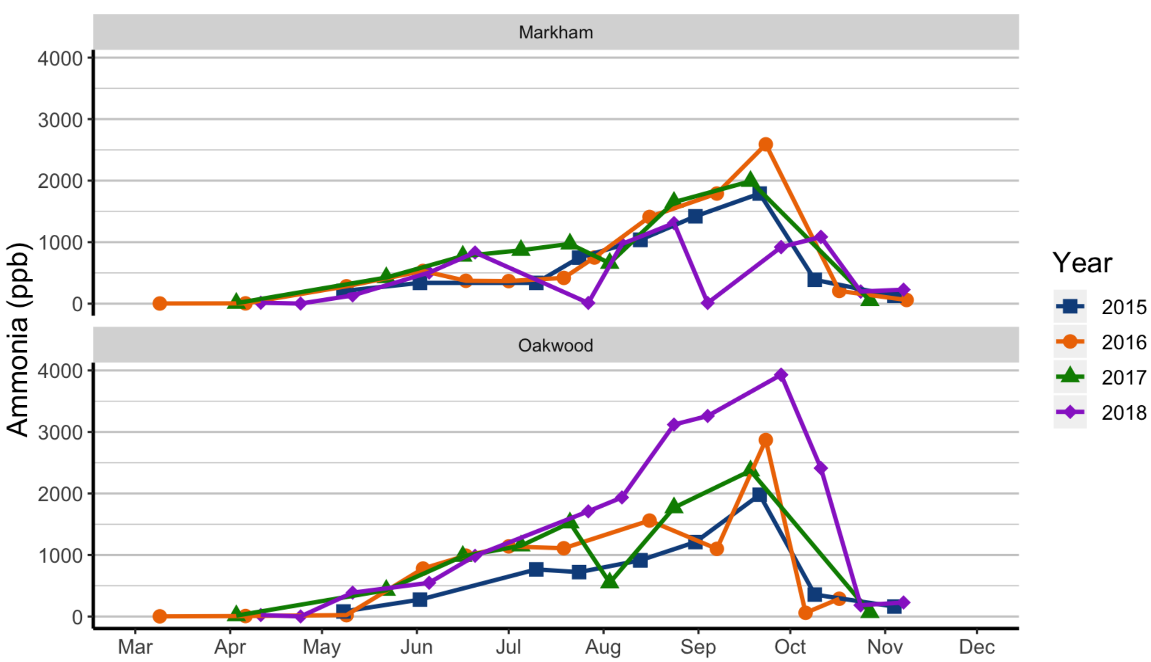


Figure 22: *Ammonia-nitrogen concentrations (ppb) in bottom waters at Markham and Oakwood stations, 2015-2018.*

Nitrate

Nitrate is a second inorganic form of nitrogen formed by Nitrification where ammonia is oxidized to nitrate. It is very stable in the presence of dissolved oxygen but is also very soluble in water, including ground water. Nitrate was present in Lake Pocotopaug waters in fall and early spring months (F**igure 23**), which is essentially when water temperature and light are too low to stimulate plant uptake. In the winter and spring of 2017-2018, nitrate was lower than in 2015-2016, reaching a maximum concentration of just 20ppb in early April. However, Nitrate at the end of the 2018 season was somewhat elevated, reaching nearly 100ppb at both stations in early November.

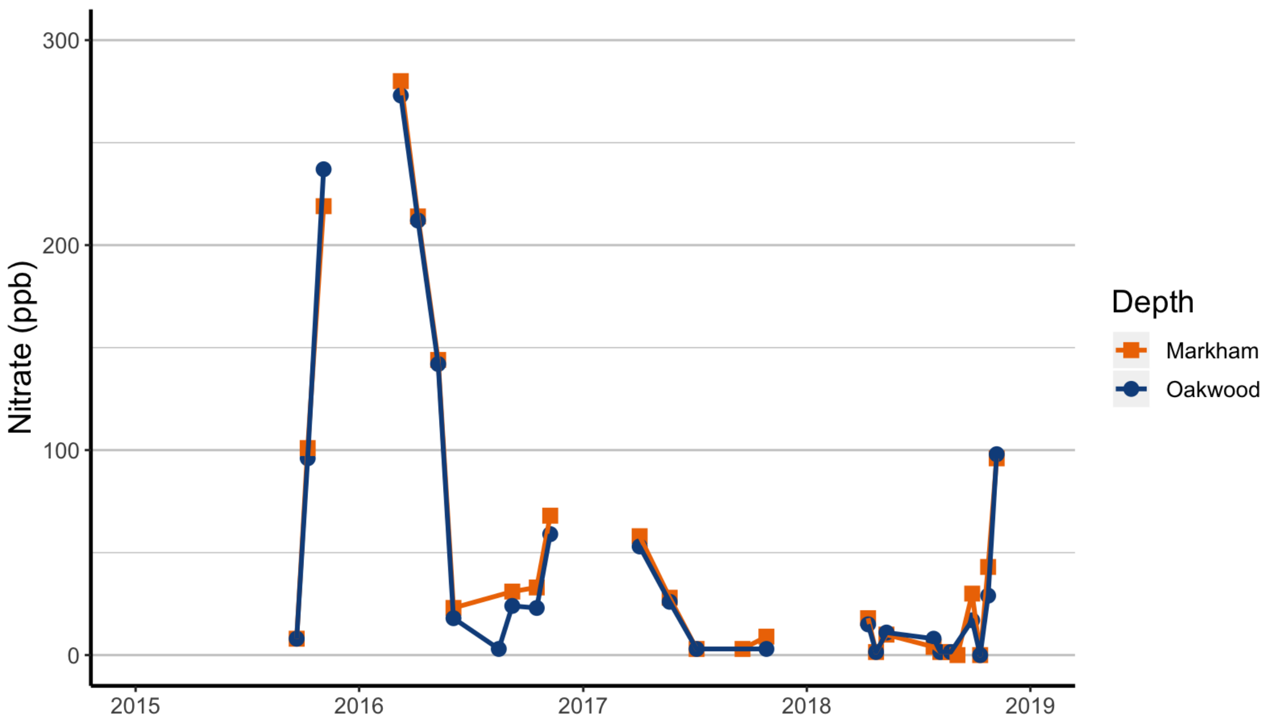


Figure 23: *Nitrate-nitrogen (ppb) at 1 meter depth at Markham and Oakwood stations, 2015-2018.*

Cyanobacteria

The principal goal of the lake monitoring at Pocotopaug is to track the growth of cyanobacteria in the lake. The lake had very few to no cyanobacteria between April and June. Plankton during that time is typically dominated by Diatom and Green algae types. Cyanobacteria numbers increase sharply in July as lake thermal stratification begins. The 2018 cyanobacteria counts were much higher than in the previous years (**Figure 24**). This is in part due to the change in cyanobacteria genera that is dominant in the lake. In previous years, the lake has been dominated by *Aphanizomenon*, but in 2018 the dominant cyanobacteria genera was *Planktolygnbya*.

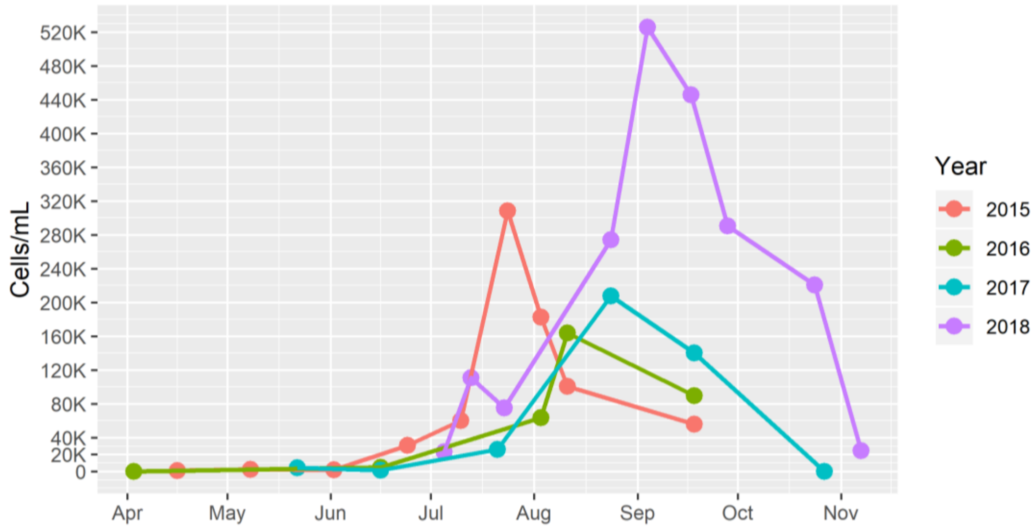


Figure 24: *Cyanobacteria numbers at Oakwood station 2015 - 2018*

Zooplankton

Zooplankton are tiny aquatic animals that live suspended in the water column. Some are grazers of phytoplankton, others are predatory on small zooplankton. The principal algae grazers are the Cladoceran zooplankton. In 2017 Cladocerans were present at high abundance in June and July and may have been in part responsible for the period of good water clarity during that time. **Figure 25**, however, shows the results of three major categories of zooplankton throughout the 2018 season. The 2018 Cladoceran peak does not appear to coincide with increased water clarity, meaning that the relationship may not have been present in 2017 either. Rotifer counts were highest at the end of the season at fall turnover, occurring in 2017 and 2018.

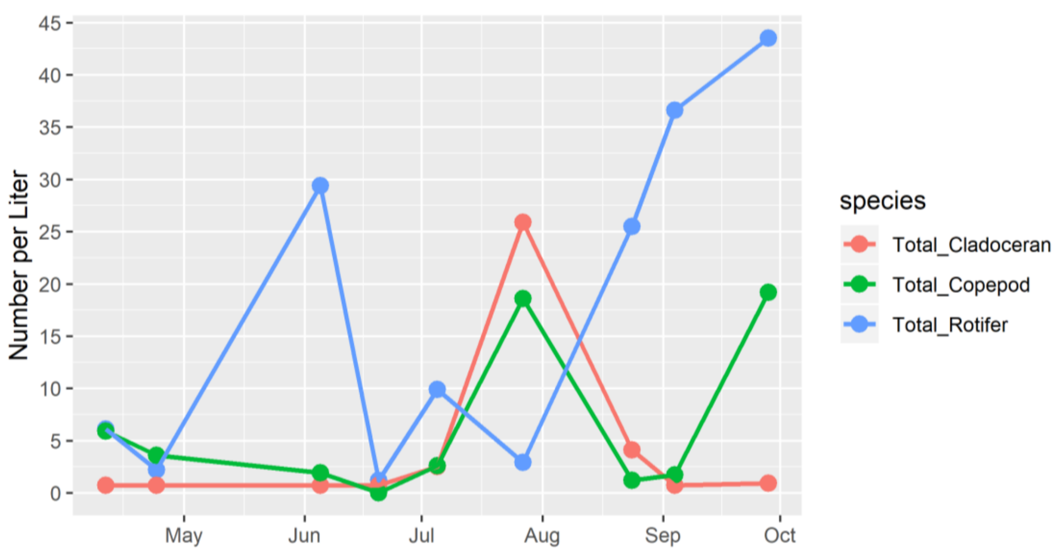


Figure 25: *Zooplankton numbers at Oakwood station during 2018*

Drainage Basin Sampling

No inlets were sampled in 2018 due to budget constraints. However, as in 2017, there were multiple storm events that led to severe erosion and high nutrient loading from the watershed. The major documented erosion event in 2017 took place at Christopher Brook, a result of upstream construction from the Skyline development. The 2018 major erosion events took place on the eastern side of the lake at the site of the new Town Hall construction. At least two major erosion events were documented in 2018 at this site. Erosion from the Town Hall construction site flows under Route 66 to an underground culvert marked as waypoint 350 in the stormwater culvert GPS file.

Christopher Brook at Happy Paddler, August 3, 2017

Outfall of Culvert #350 flowing from Town Hall construction

Additionally, there were two major breaks in the sewer line at Old Marlborough Road in November 2018. Town WPCA and the Local Health Department were on scene to investigate and fix the burst sanitary sewer pipe. NEAR inspected this area only after the leak had been fixed and noted a severe saturation of dirty brown water in the wetland, on the side of the road opposite the lake. The wetland appeared to have suffered the worst sewage loading, which is unfortunate, but also may have slightly lessened the direct impact of the leak to the lake itself. Nevertheless, a ruptured sewage line is a large watershed nutrient pollution. This sewage breach is particularly concerning because the gravity fed pipes may have multiple other minute fractures that will go undetected throughout the watershed. During an inspection for a stormwater retrofit on the western side of the lake in 2018, we also witnessed a suspect connection of sanitary and storm sewers. These sewer leaks should not be overlooked and we recommend that the Town WPCA ensures that there are no further leakages, however small or large, to groundwater, as this presents an ongoing potential nutrient source to the lake.

Photo taken November 20, 2018: Aftermath of sewer pipe rupture.
Lake on left side of the road at Day's Brook.

General Conclusions

In early years of monitoring, between 1990 & 2000, the maximum clarity was about 4 (13ft) meters during the "clear" water period the lake experiences around mid to late June. In recent years, however, that period with increased clarity has declined, with clarity measurements of around 2.5 meters. Poor water clarity prior to the clear water period is due non-Cyanobacteria type algae called Diatoms. Diatom algae in April is caused by watershed loading over the prior winter. Water clarity in April shows a decreasing trend since 2000 (**Figure 26**). The "Average" data points indicate the averages between Markham and Oakwood station clarity readings, as taken by resident volunteers during that time period.

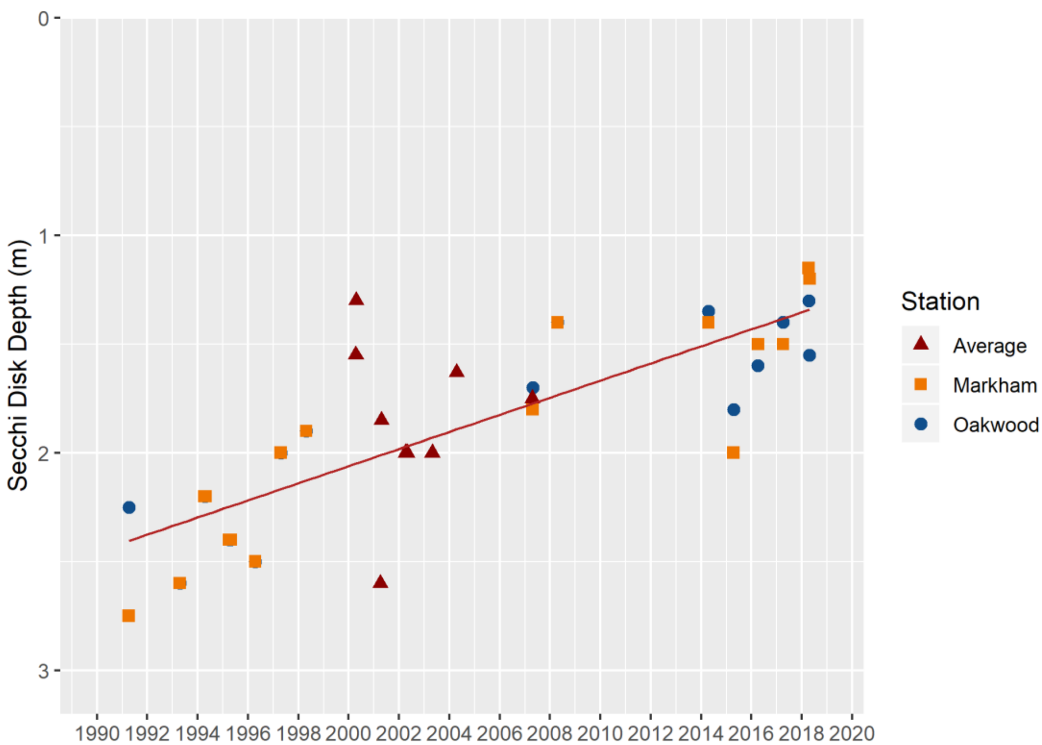


Figure 26 Spring Water Clarity Trend 1991-2018

Values from the last four years of spring water clarity monitoring are lower than all prior years, indicating that watershed loading to the lake is still increasing over the years. The Nine Element Plan watershed fixes may first be reflected by changes in spring clarity to stop this upwards trend shown in **Figure 26**.

Overall, the 2018 season saw many challenging watershed conditions, with multiple large rain storm events and watershed erosion events, as well as two ruptures to near-shore sanitary sewage pipes. Yet there was also great progress made in the watershed improvement projects list. The Friends of Lake Pocotopaug successfully funded the engineering and construction of a biorention area to capture the large quantities of stormwater from the Edgemere Condo complex. The Friends of Lake Pocotopaug have also begun their efforts to engage the Nine Elements Plan by beginning the engineering planning phase of constructing a similar stormwater retrofit to capture stormwater runoff from Angelico's restaurant and parking lot, which is an important part of the local community.

Similarly, the Town took initial steps to use the recommendations and stormwater checklist from the Nine Elements Watershed Based Plan to begin the soil infiltration testing and Low Impact Development (LID) engineering of stormwater retrofits for Clark Hill and Old Clark Hill Road, Mohigan Drive, West Street, Candlewood Road, Barbara Drive, Ola Avenue, and Boulder Road. The Town will continue to work with the DEEP nonpoint source pollution program office, who plans to dispose funds for the construction phase of selected projects in 2019. The next round of soil infiltration testing will also be conducted at a number of additional selected sites in 2019.

In-lake water quality monitoring in 2019 will replicate the 2018 monitoring program. Future monitoring will also include stormwater sampling in the watershed to track water quality improvements at sites of completed stormwater retrofits. The 2019 cyanobacteria beach sampling program will resume with continued guidance from Chatham Health and the CT DEEP.

Appendix

Secchi disk depths (m) at Markham and Oakwood stations, 2018.

	4/11	4/24	5/11	6/5	6/20	7/5	7/28	8/7	8/24	9/4	9/28	10/11	10/24	11/7
Markham	1.15	1.2	2.6	2.6	2.85	2.5	1.2	1	1.2	0.97	1.2	1.5	1.4	2.6
Oakwood	1.3	1.55	2.1	2.3	2.45	2.7	1.1	1.15	1.1	1	1.2	1.5	1.25	2.7

Anoxic boundary depths at Markham and Oakwood stations, 2018.

	4/11	4/24	5/11	6/5	6/20	7/5	7/28	8/7	8/24	9/4	9/28	10/11	10/24	11/7
Markham	NA	NA	7.83	5.5	5.91	5	5.9	4.78	4.92	4.84	6.82	6.86	NA	NA
Oakwood	NA	NA	9.03	5.8	5.76	5.4	4.89	4.84	5.93	4.75	6.94	7.84	NA	NA

Total phosphorus concentrations at Markham and Oakwood stations in 2018.

Markham	4/11	4/24	5/11	6/5	6/20	7/28	8/7	8/24	9/4	9/28	10/11	10/24	11/7
Top	15	7	16	15	16	21	20	23	22	21	18	22	25
Middle	17	8	22	17	48	24	23	22	18	24	25	25	30
Bottom	22	16	43	25	111	19	84	122	129	31	38	25	26

Oakwood	4/11	4/24	5/11	6/5	6/20	7/28	8/7	8/24	9/4	9/28	10/11	10/24	11/7
Top	16	9	37	12	22	23	20	21	20	21	22	31	27
Middle	16	14	25	17	17	23	26	21	22	21	27	32	21
Bottom	22	19	45	98	149	218	329	506	389	291	80	26	25

Long-term and 2018 average total phosphorus concentrations.

Station	Markham		Oakwood	
Water Depth	**Top**	**Bottom**	**Top**	**Bottom**
2015-2018 Avg.	20	70	21	116
2018 Avg.	19	53	22	169

Total nitrogen concentrations at Markham and Oakwood stations in 2018.

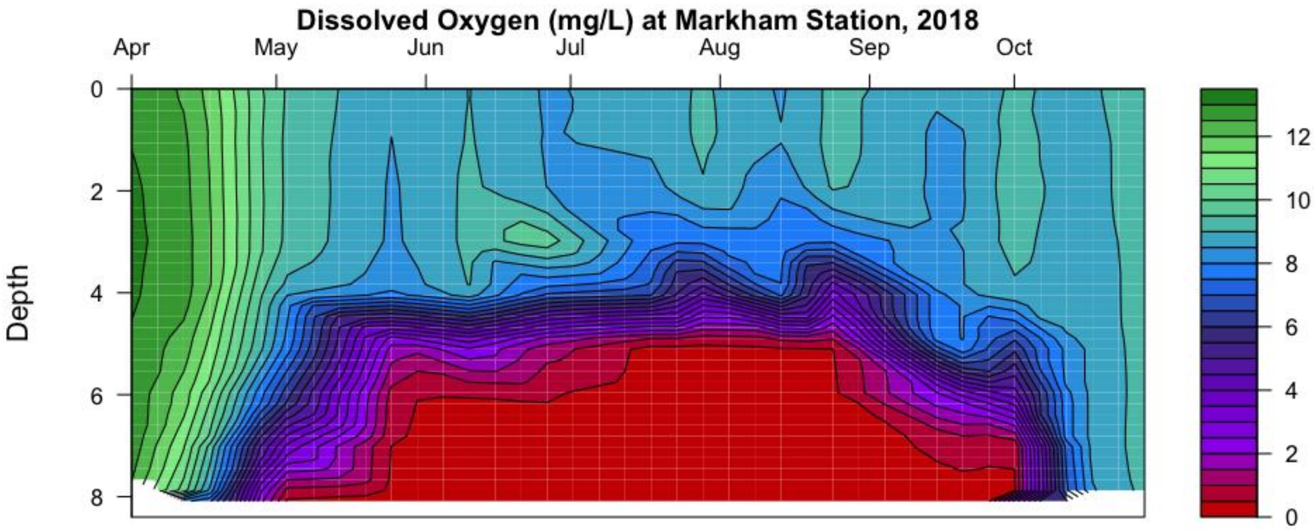
Markham	4/11	4/24	5/11	6/5	6/20	7/28	8/7	8/24	9/4	9/28	10/11	10/24	11/7
Top	399	293	285	266	268	507	591	619	611	522	480	594	524
Bottom	449	371	382	861	1052	279	1181	1761	1767	1344	1584	567	510

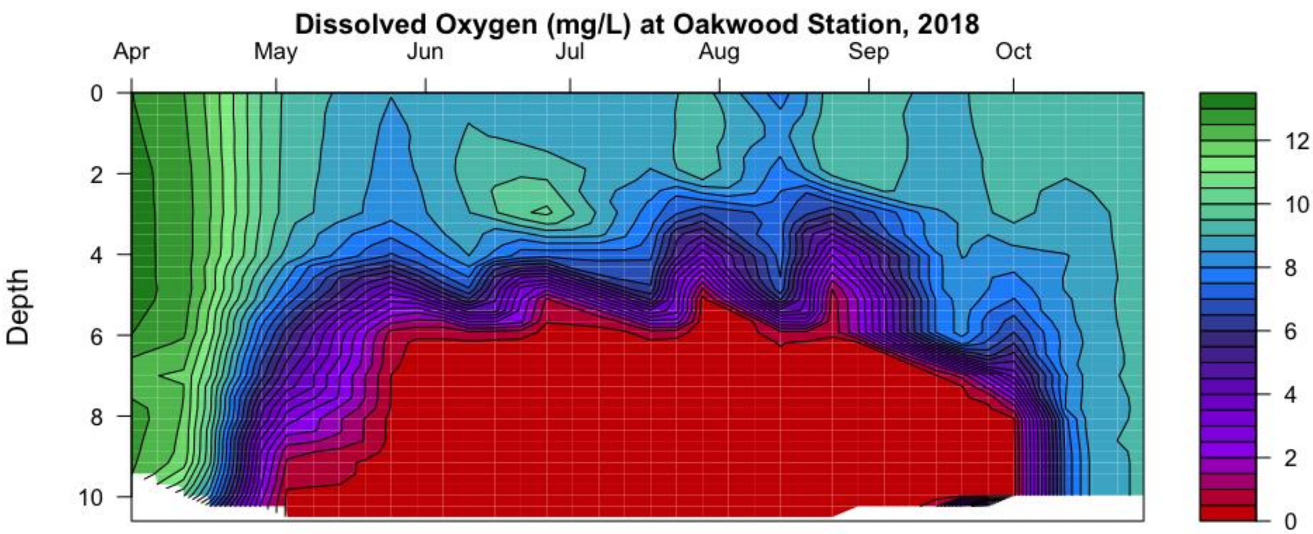
Oakwood	4/11	4/24	5/11	6/5	6/20	7/28	8/7	8/24	9/4	9/28	10/11	10/24	11/7
Top	401	287	291	295	225	548	574	562	557	515	449	567	500
Bottom	408	365	653	934	973	1347	1900	3108	2660	3836	2898	588	507

Long-term and 2018 average total nitrogen concentrations.

Station	Markham		Oakwood	
Water Depth	**Top**	**Bottom**	**Top**	**Bottom**
2015-2018 Avg.	515	939	515	1150
2018 Avg.	458	931	444	1552

Isopleths of Dissolved Oxygen at each station in 2018.





Isopleths of water temperature at each station in 2018