Northeast Aquatic Research

Roaring Brook Lake Water Quality and Aquatic Plant Monitoring Report

2019

Prepared for the Town of Putnam Valley, NY,

Supervisor Sam Oliverio, August 2020

Northeast Aquatic Research, LLC ⁙ 74 Higgins Highway, Mansfield, CT 06250 ⁙ 860-456-3179

Contents

Figures

Tables

Executive Summary

In 2019, Northeast Aquatic Research, LLC (NEAR) began a water quality monitoring program for Roaring Brook Lake, Putnam County, NY. Earlier monitoring by volunteers had been done since 2009 through the Citizens Statewide Lake Assessment Program (CSLAP).

NEAR's monitoring consisted of visiting the lake once per month from April through October 2019 to collect water quality data as outlined below. In addition, we conducted one full-lake aquatic plant survey. Key monitoring findings are as follows:

- Water clarity was better during the beginning of the season, with clarity declining in September and October.
- There was a period of brief lake stratification beginning in late May and ending at the end of September.
- The corresponding stratification leads to a loss of dissolved oxygen at the lake bottom, with the worst conditions present in late July.
- The loss of dissolved oxygen on the lake bottom resulted in the release of phosphorus and nitrogen from the sediments. The sediment release of phosphorus was at a concentration 10 X greater than surface concentrations.
- The algal community was dominated by blue-green cyanobacteria for the entire season, with the highest counts coming from the end of July.
- There were many large-bodied zooplankton, particularly *Daphnia sp*., which can aid in filtering water and increasing clarity.
- Inlet nutrients varied throughout the season, with the highest phosphorus and nitrogen values present in May at inlets 5 and 6.
- Inlet 1 had the highest fecal coliform readings in June and July, which could indicate pollution from onsite wastewater.

Recommendations for Roaring Brook Lake represent a mixture of increased monitoring and direct, actionable items to be undertaken by the Town of Putnam Valley. Recommendations are as follows:

- Continue in-lake and watershed monitoring to further understand sources of nutrients, particularly the internally loaded phosphorus. Orient monitoring toward identifying whether adding an aeration/circulation system, or utilizing a phosphorus locking treatment would benefit in-lake nutrient conditions in a cost-effective manner.

- Adjust the present law requiring RBL District septic pump-out every 5 years to require pump-out every 3 years. This would conform with DEC and other general recommendations for water body protection (eg Chesapeake Bay, NYC watershed, impaired NYS lakes) and also be consistent with the Town's present requirements for Lake Oscawana.
- We recommend the institution of a RBL District Tax supported septic system cost deferment grant program. This would allow the community to offset the individual property owner's cost of septic system maintenance, repair, and/or replacement. If adopted, it could result in improved compliance at no additional cost to the individual or the Town, and with decreased enforcement

costs. Prioritization of funded projects could be based on various factors, but should be equitable.

- Start work on outlined stormwater management projects in various parts of the Roaring Brook Lake Watershed laid out in the watershed loading section (p.35). These can be a combined effort from the Town of Putnam Valley and volunteers from the Roaring Brook Lake community.
- Continue to monitor the aquatic plant population in anticipation of a rebound in abundance as carp continue to die off and drawdown effectiveness becomes increasingly unpredictable.

Description of Water Quality Monitoring Components

Water Clarity

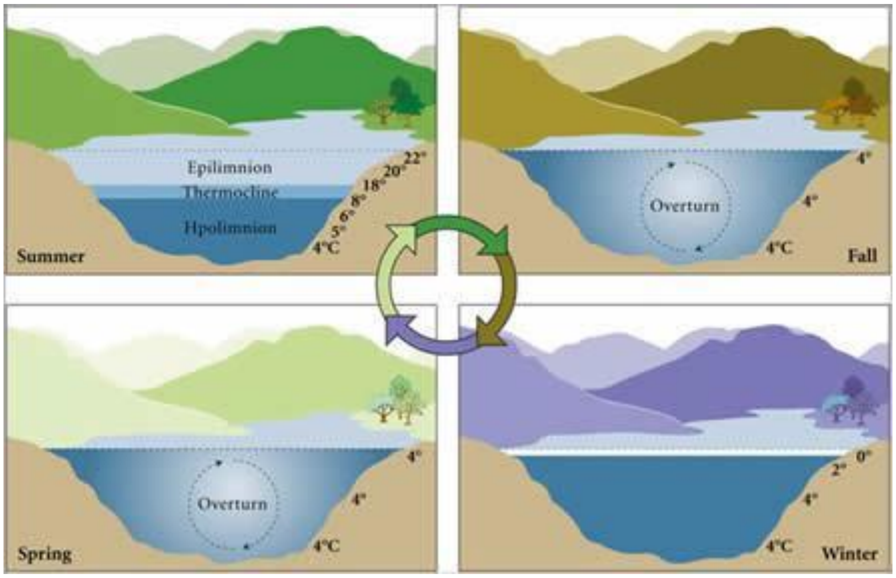
Water clarity is measured at the deepest location (**Figure 1, labeled WQ**) in the lake (N 41.43450° W 73.80624°) using an 8-inch circular disk with black and white alternating quadrants call the Secchi disk. The disk is lowered into the water on the shady side of the boat until it disappears from view using a view scope, then raised until visible again, the average between the depth the disk disappeared and the depth at which it re-appeared is the Secchi depth. Secchi disk water clarity measurements are estimates of light penetration, typically equal to about 15% of the light at the surface. Secchi disk depth has been shown to estimate the amount of phytoplankton and suspended sediments in the water column (Tizler 1988) .

Figure 1. Location of the in-lake water quality sampling location and prominent inlets sampled in 2019.

Lake Temperature

Temperature measurements are made at 0.5-meter increments from the lake surface to the bottom at the deepest location in the lake. Combined, measurements at all 0.5-meter depth increments are referred to as a lake profile. Water temperature in lakes and ponds in the northeast follows a seasonal pattern of warming and cooling (**Figure 2**). At ice-out in early spring, the water column has uniformly cold-water temperatures from top to bottom. As the strength of the sun increases during late spring and early summer, the lake water warms, but the depth extent of this warming is dependent on the water's clarity. Clearer water allows better sunlight penetration and deeper water column warming. Thus, the depth and development of a thermocline, or the zone of rapid temperature change, is dependent on both the depth of the lake and water clarity. The thermocline influences trends in dissolved oxygen, which affect the concentrations of nutrients and metals within the water column. Cooling waters in the fall result in a weakening thermocline and eventually water "over-turn," or when the temperature once again becomes uniform from top to bottom.

Figure 2. Diagrammatic description the seasonal thermal sequence in northeastern lakes



Dissolved Oxygen

Dissolved oxygen (DO) is measured at 0.5-meter increments at the same time as water temperature. At the surface of the lake where the lake water is in contact with the atmosphere, oxygen is dissolved into the water via diffusion. As water mixing takes place, the dissolved oxygen is circulated throughout the water column. In-lake processes also produce and consume dissolved oxygen such as photosynthesis (increases O_2) and Respiration (decreases O_2). Photosynthesis of algae and plants, the influx of high dissolved oxygen water from the watershed, and atmospheric diffusion represent sources of DO. Decomposition of dead organic matter including algae and plants, along with fish and zooplankton respiration, can consume dissolved oxygen. Usually, the dead materials settle to the bottom where bacteria are abundant, but little to no algae to photosynthesize. If there is enough material to decompose, the bacteria can utilize all the oxygen in the bottom waters creating an oxygen-depleted zone referred to as anoxia (or water with less than 1 mg/l dissolved oxygen). Lake water below the thermocline is stagnant and unable to have dissolved oxygen supplies replenished until fall overturn. For this reason, it is critical to track the level of anoxia during the summer.

Phosphorus and Nitrogen

Water samples were collected from the deepest spot in the lake at discrete depths representing the top, middle, and bottom of the water column (0.5m, 2.5m, and 5m). These samples were analyzed for total phosphorus, total nitrogen, ammonia nitrogen, and the combined nitrate/nitrite nitrogen.

Phosphorus and nitrogen are the two principal nutrients that drive aquatic plant and algae growth in lakes. Both nutrients are present in all lakes at some level and can enter the lake from the watershed in the form of natural wetland inputs, septic leachate, farm runoff, lawn fertilizers, and sedimentation from roads or streams. When the concentrations of these nutrients increase, particularly phosphorus, algae grow rapidly reaching nuisance conditions. In freshwater systems, phosphorus tends to be the limiting factor for productivity and is more closely monitored for the health of inland ecosystems. Low phosphorus in a water body equates to lower phytoplankton abundance and greater overall Secchi disk depth water clarity.

Lake water should ideally remain oligotrophic, meaning total phosphorus below 10ppb and total nitrogen below 200ppb (**Table 1**). We use the Connecticut standard for evaluating lake trophic state, rather than the NY standards, which are too coarse-grained. Typically, the bottom of the lake collects more phosphorus and nitrogen as the summer progresses because bottom-sediments release nutrients when oxygen in the bottom water is depleted. Just as anoxia increases over time, phosphorus and nitrogen also tend to increase over time as a waterbody becomes more eutrophic, or dominated by plants and algae. Nutrient results are compared to identify patterns in internal sediment release versus external watershed loading.

Due to lake stratification, these nutrients are not present in the same quantities throughout the lake. Typically, the bottom of the lake has more phosphorus and nitrogen as the summer progresses because bottom-sediments release nutrients when oxygen is depleted. When oxygen is present, phosphorus is bound to iron and is inactive and unavailable to algae for growth. By contrast, when oxygen is absent in the bottom waters, a suite of chemical reactions takes place. Chief among these reactions is the liberation of phosphorus from iron, making it available for algal growth.

Table 1.Parameters and defining ranges for trophic states of lakes in Connecticut.

Category	Total phosphorus (ppb)	Total Nitrogen (ppb)	Secchi Depth (m)	Chlorophyll *a* (ppb)
Oligotrophic	0 -- 10	2 -- 200	6 +	0 -- 2
Oligo-mesotrophic	10 -- 15	200 -- 300	4 -- 6	2 -- 5
Mesotrophic	15 -- 25	200 -- 500	3 -- 4	5 -- 10
Meso-eutrophic	25 -- 30	500 -- 600	2 -- 3	10 -- 15
Eutrophic	30 -- 50	600 -- 1000	1 -- 2	15 -- 30
Highly Eutrophic	50 +	1000 +	0 -- 1	30 +

Source: CT DEEP. 1982. DEC guidance values for total phosphorus and Chl. A is 20 and 10 µg/l respectively.

Phytoplankton and Zooplankton

Phytoplankton are free-floating microscopic algae in the water column. Zooplankton are the microscopic animals that feed on phytoplankton. Plankton represents the beginning of the lake food chain. Integrated phytoplankton samples were collected monthly using a 3-meter algae tube at the deepest site. At the same time, zooplankton samples were collected using a fine-mesh tow net. Phytoplankton populations increase with higher nutrients and cause declines in water clarity. Zooplankton are influenced by predators such as small fish, and some zooplankton taxa can regulate phytoplankton populations through their water column filtration capabilities. An understanding of lake plankton allows for a better interpretation of water quality data.

Water Quality Results

Secchi Disk Clarity

Water clarity was fairly stable during most of the season at between 2.5 and 3.0 meters. There was some slight improvement in August, but clarity declined in the fall to end the year with the season's poorest clarity of fewer than 2.5 meters (**Figure 3**).

The CSLAP water clarity dataset (**Figure 4**) represented by two sets of 5 years of data shows a wide fluctuation in water clarity both each year and over the time interval shown in the graph. Water clarity has varied between the lowest reading of 0.9 meters to the highest of 4.2 meters. The spread of readings during each season has declined over the last few years indicating a more stable water clarity condition. However, there is also a possibility that good readings are not occurring as frequently as before. It is important to note that the CSLAP Volunteers do not use a viewscope, which aids in eliminating glare and obtains a more consistent result. NEAR Secchi disk readings did use a viewscope.

Water clarity was mostly static during the season at around 2.8m, not great, but above the lower threshold of 2m. CSLAP data shows clarity has fallen below 2 meters several times and at least twice below 1.5m. In 2019, water clarity maximum of 3.2meters was much reduced from past years when maximum clarity has been better than 3.5meters. Generally, when the Secchi disk depth is 1.5m or less, the water column is dominated by cyanobacteria.

Figure 3. Roaring Brook 2019 Secchi disk depths

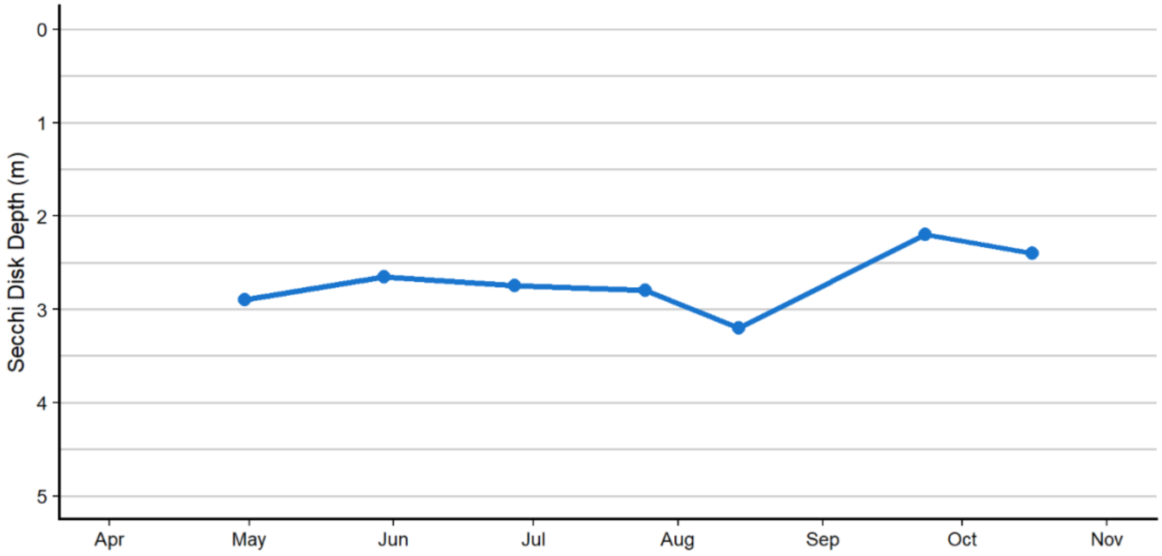
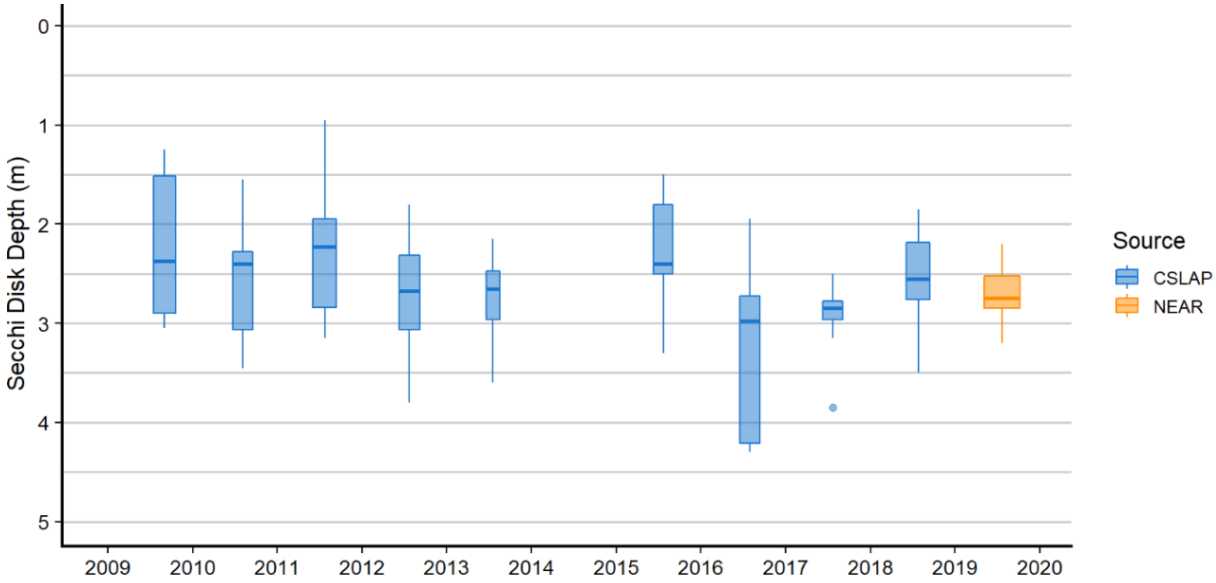


Figure 4. Historical water clarity record for Roaring Brook Lake. Data from CSLAP and NEAR. The main shaded areas represent the 25th to 75th percentile of data. The central bar represents the median values. The lines above and below represent the "whiskers" of the plot, which are the minimum and maximum values in the dataset. Dots are data outliers.



Temperature

In April, the water temperature was uniform from top to bottom (**Figure 5**). In May, the lake began warming more at the surface than the deeper water allowing the formation of slight thermal boundaries at 3.75 meters. Warming continued throughout the summer, with thermal boundaries present in August. By September the lake water was once again of similar temperature from top to bottom.

To further expand on the thermal structure, lake managers look to quantify the stability of stratification within a water body, which has implications for oxygen and nutrient dynamics. One of the most common ways to measure stratification strength is to compute the relative thermal resistance to mixing (RTRM). The RTRM is a ratio that describes the difference in water density between each meter. Higher RTRM values indicate stronger stratification (usually greater than 80) and imply that more wind energy is needed to mix two layers of water.

RTRM follows a similar pattern to the temperature profiles, with no resistance to mixing in April and October (**Figure 6**). From June to September, the depth of the strongest resistance to mixing (the longest bar on any given date in **Figure 6**) dropped progressively lower as more of the water column warmed.

Figure 5. Roaring Brook Lake 2019 temperature profiles.

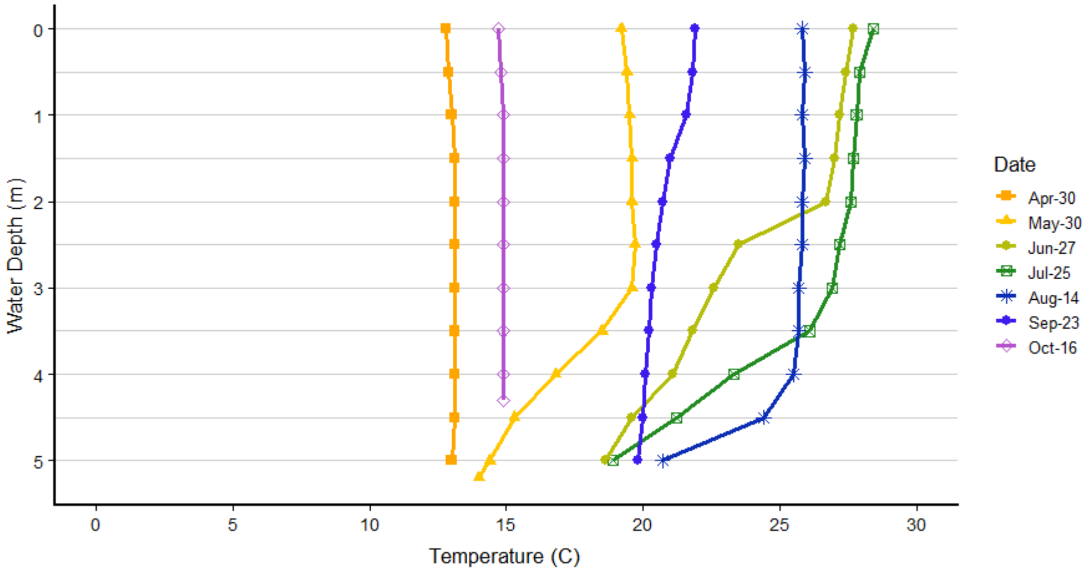
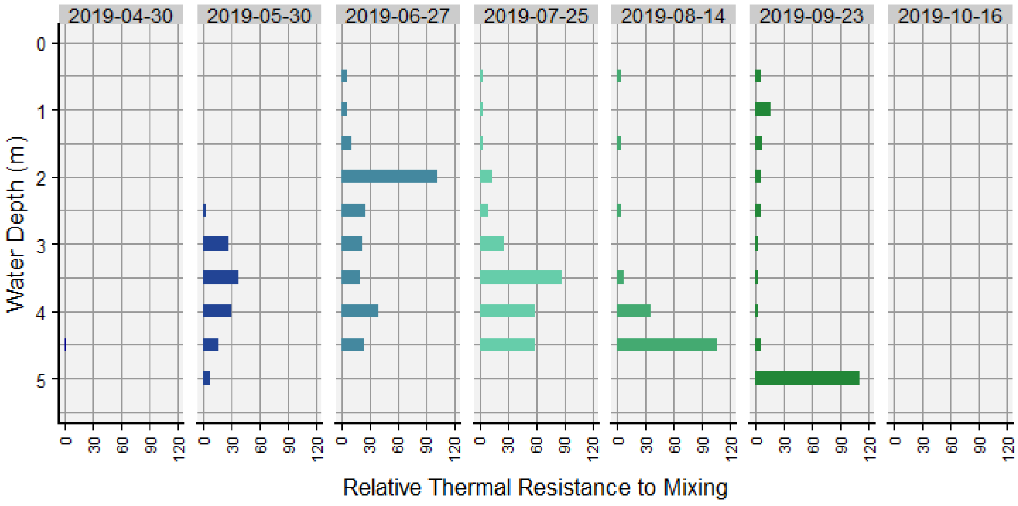


Figure 6. 2019 Relative Thermal Resistance to Mixing (RTRM). Absence of bars in April and October indicate that the lake was fully mixed during this time.



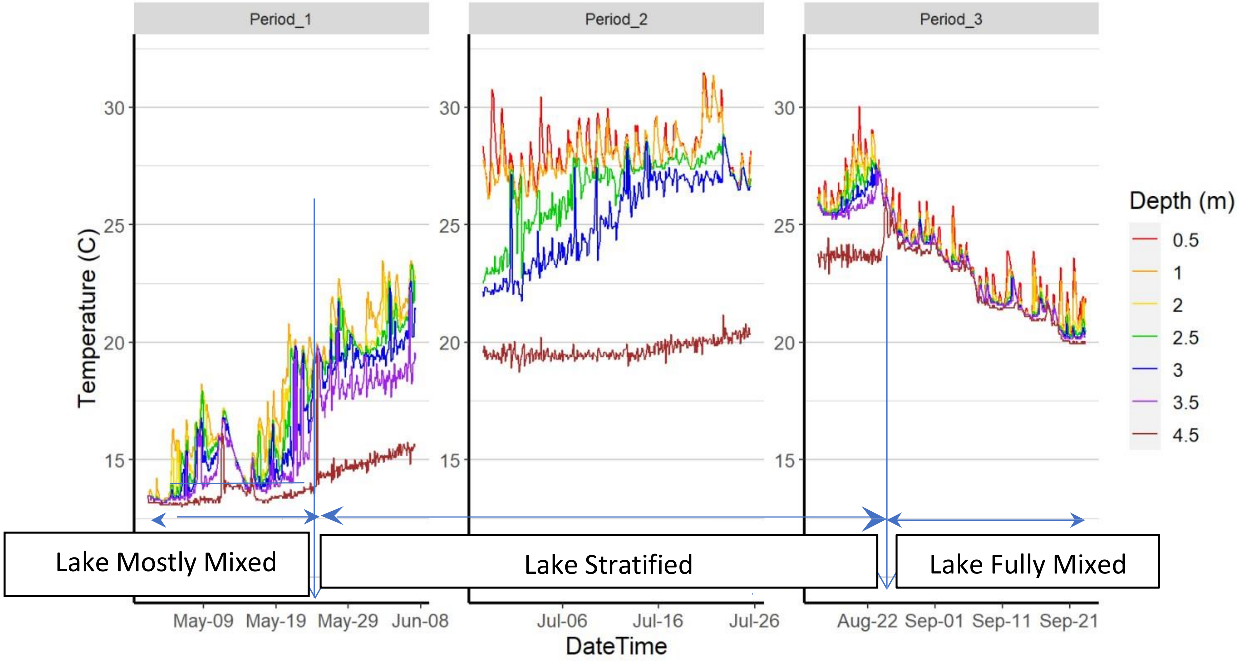
A suite of water temperature loggers was deployed in the lake at half-meter depth intervals, from top to bottom in the deepest water. The loggers were fixed at the following depth increments: 0.5, 1.0, 2.0, 2.5, 3.0, 3.5, and 4.5 meters. The recorders ran continuously between May 1st and Sept 26th, however, the receiver crashed due to data overload after about 30 days. The data is shown for each of the three continuous collection periods, Period 1, between May 1st and June 10th, Period 2, between June 27th and July 28th, and Period 3, between August 14th and September 26th (**Figure 7)**.

Period 1 shows the lake begins isothermal on May 1st, with a turbulent 20 or so days in May when daily gains at the surface were redistributed thorough the water column at night. The lake starts to gain heat at the surface faster than it can be redirected downward on about May 20th. After that date, the bottom water temperature separates from all water layers above, from this date on, the water at 4.5 meters is isolated. The data very clearly shows the lake developed initial stratification on May 20th. However, between May 20th and June 10th all water above 4.5 meters was uniformly gaining heat during the day and redistributing the heat during the night but always getting warming. There was one small mixing event on May BLANK, which only lasted 2 hours.

Period 2 starts with the lake still gaining heat, but now each layer is gaining heat slower than the layer above. The top couple of layers (0m, 1m, & 2m), have joined and behave as one layer as they track the daily gain and loss of heat, while the average temperature remains the same over the period. The water at 2.5m (green) and 3m (blue) show initially slower heat gains but each layer shared profound mixing events, exemplified by one-day spikes in the water temperature at 3m (blue) that equaled the surface temperature. Near the end of Period 2, the lake becomes isothermal to 3 meters.

Period 3 shows the lake water at 4.5m remained isolated from waters above until a profound mixing event on August 26th. After that date, the whole water column was turbulently mixing. The data very clearly shows how daily heat income at the surface was quickly lost each night with an overall trend toward colder water temperatures each day.

Figure 7. Results of continuous water temperature data loggers in Roaring Brook Lake in 2019.



Dissolved Oxygen

The dissolved oxygen (DO) profile data (**Figure 8**) shows the lake had good DO levels in the top 3-4 meters of water. The DO concentrations in this layer decline as the season progresses due to the warmer water naturally holding less DO. However, water below 3-4 meters shows severe DO consumption deflection, meaning profile lines reach the Y axis before getting to the bottom beginning in May.

The boundary between water with DO and water without is termed the anoxic boundary. The location of the anoxic boundary is measured down from the surface. The red dashed line in **Figure 9** shows the anoxic boundary in Roaring Brook Lake during 2019. The dashed red line indicates the boundary between water above the line with DO and water below the line without DO. The anoxic boundary starts at the bottom in April and gradually ascends upward during the season. The maximum ascent depth of 3.7 meters occurred in late July. Beginning in August, the anoxic boundary is forced downward as the lake mixes to deeper depths, see **Figure 7** panel 3. However, re-oxygenating of mid-depth levels appears delayed until October. This may be due to high amounts of oxygen demand from the deepest water being mixed lake-wide causing a lag in the return to fully saturated conditions. The evidence is shown in the September profile as DO consumption starting at 2 meters with a steady decline with depth until zero.

Figure 8. 2019 dissolved oxygen profiles.

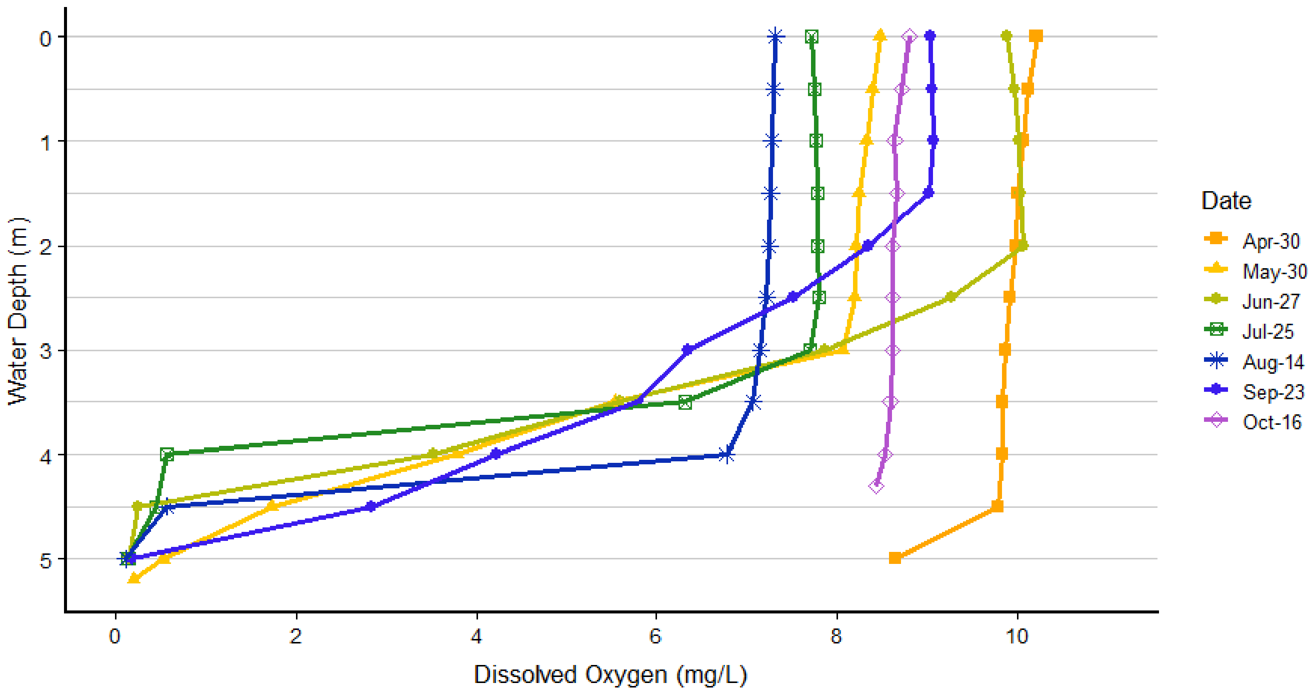
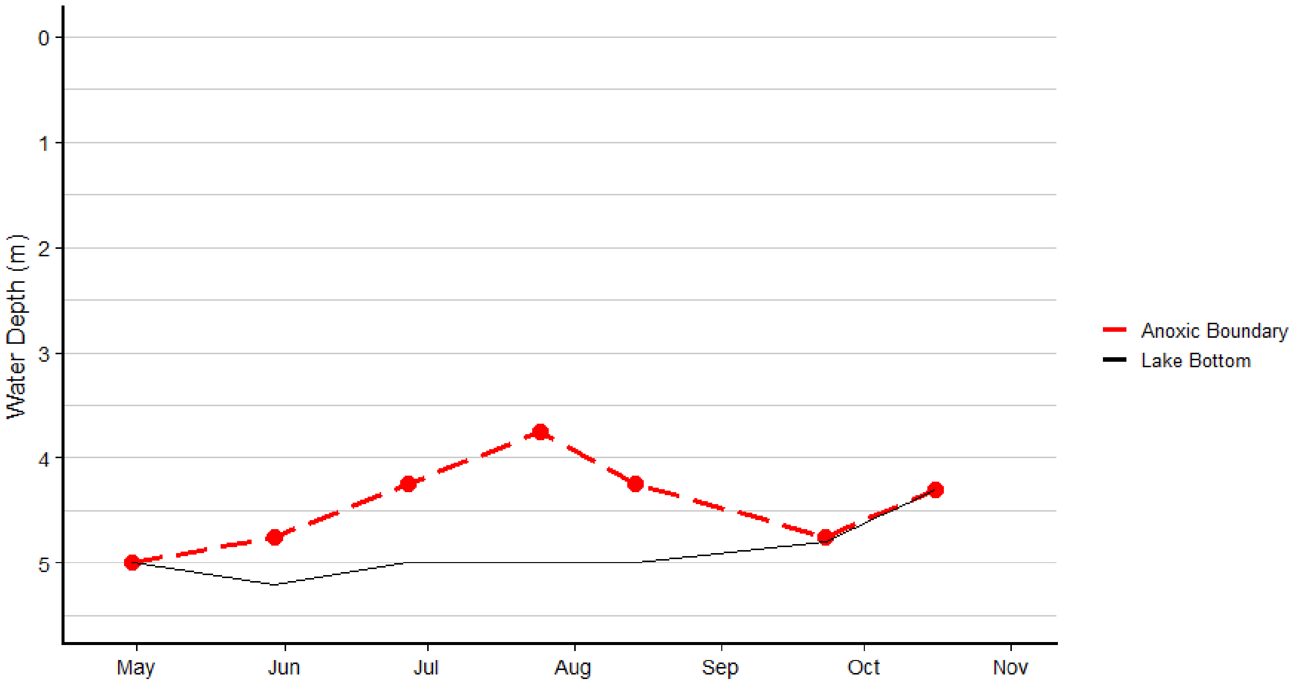


Figure 9. The anoxic boundary for the 2019 season. The anoxic boundary is defined as the depth at which dissolved oxygen concentrations dip below 1 mg/l. The increase in the lake bottom depth is due to the drawdown.



Nutrient Results

Phosphorus

Total phosphorus is most often the limiting nutrient for plankton/algae and cyanobacteria growth in lakes, therefore, robust lake management is focused on the measurement and management of phosphorus in the lake and watershed. The sources and amounts of phosphorus in a lake determine the magnitude of algae and cyanobacteria growth that is possible. As the quantity of phosphorus in a lake increases, there is a direct, although nonlinear, decline in Secchi disk depth. More phosphorus stimulates higher growths of plankton, often as cyanobacteria, making the water cloudier. Refer to **Table 1** for the expected declines in water clarity based on increases in phosphorus concentration in lakes. Once phosphorus in lakes exceeds about 20ppb, cyanobacteria blooms are inevitable. For these reasons, phosphorus measurement and management are the central aspects of lake management. therefore

Roaring Brook Lake phosphorus concentrations collected by NEAR during 2019 are given in **Table 2**. Samples collected from the 0.5 m and 2.5 m depths represent water that was mostly mixed (see **Figure 5**) so values from these depths should be similar to each other. Samples collected from 5 meters are from the deepest least mixed water in the lake that remained isolated from the rest of the lake water until August 26 (see **Figure 7** panel 3).

The phosphorus in the top two samples (0.5 and 2.5m) were not always the same with some differences large enough to represent the uneven distribution of phosphorus in the water despite existing mixing currents. In April and May, top phosphorus concentrations exceeded the middle, although values on those dates are close enough to possibly be statistically the same. However, higher surface phosphorus could be indicative of loading from surface flows in the spring. July had the best top and middle layer phosphorus concentration for the summer at 10ppb. In September, the middle phosphorus concentration was double the surface value. This is at a time when continuous data loggers show the whole lake to be homogenous.

Bottom water phosphorus concentrations show a drastic increase of about 10x between May and July. The bottom water became isolated from the atmosphere on May 19th shortly before the May sampling (see **Figure 7** panel 1). Samples collected from the bottom water showed phosphorus concentration in July of 208 ppb, and in August of 103 ppb. This phosphorus is from internal release from bottom sediments (verified by bottom water ammonia shown later). However, decreased concentration of bottom water phosphorus between July and August is likely due to the overall weakening of the thermal boundaries during that time allowing for greater leaching of isolated bottom water with the rest of the lake. Note both that the RTRM depth and strength declined between July and August such that thermal boundaries existed directly above the deepwater sample, and that the anoxic boundary had descended by about a half a meter to the depth of the deepwater sample. These aspects suggest that deepwater phosphorus from internal sediment release had begun to leach to upper water by the August sampling. Concentrations of 13 ppb in the top and middle layers in August are likely a result of that leaching and lake-wide re-distribution of bottom derived phosphorus. Phosphorus concentration in September still shows a steep gradient between top and bottom despite the lake being strongly mixed at that time. This suggests that sealing bottom sediments with oxidized sediments required to retard the release of phosphorus may be delayed at Roaring Brook Lake. Phosphorus concentration in October was excellent showing no hint of internal loading from the summer.

Table 2. 2019 total phosphorus concentrations (ppb), with red values over the target of 10ppb.

Depth	4/30/2019	5/29/2019	7/25/2019	8/14/2019	9/23/2019	10/16/2019
Top (0.5m)	15	18	10	13	10	10
Middle (2.5m)	11	15	10	13	20	7
Bottom (5.0m)	11	23	**208**	**103**	30	11

The 2019 data collected by NEAR appears to be in-line with most of the past data results **(Figure 11**). Phosphorus at Roaring Brook Lake remained at a mean of about 12 ppb, a similar range of 10-15ppb for at least the last three years. Phosphorus in 2019 showed improvement over conditions in 2010-2015 when concentrations were between 10-20ppb.

Figure 10. 2019 in-lake total phosphorus concentrations.

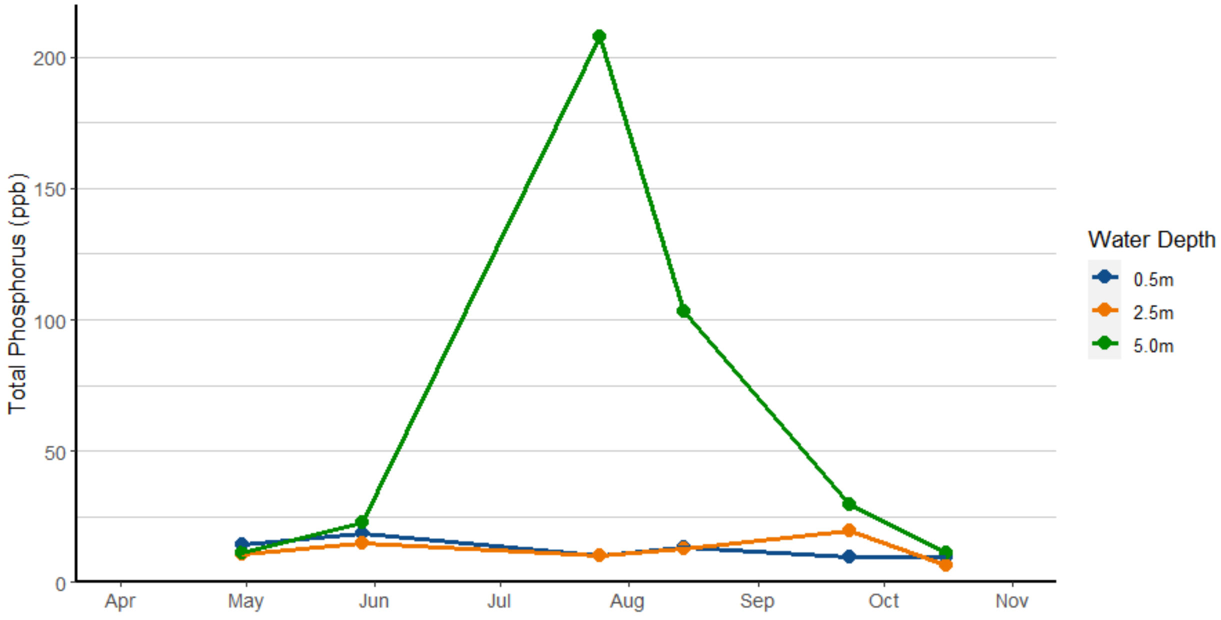
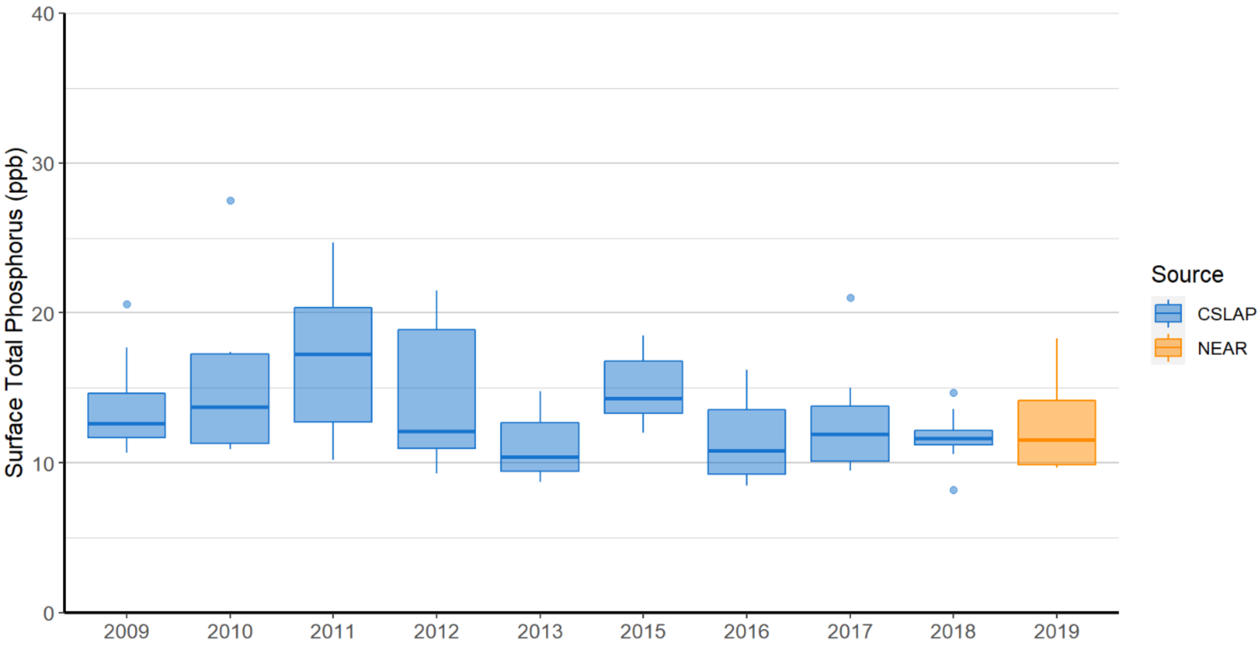


Figure 11. Historical surface total phosphorus concentrations from CSLAP and NEAR.



Nitrogen

Low productivity lakes have total nitrogen (TN) concentrations of less than 200ppb. TN concentrations at all three sampling depths in Roaring Brook Lake were elevated above 200 ppb for the entire sampling season (**Table 3).**

The elevated TN at the top and middle of the water column may be caused by nutrient loading from the watershed. At the bottom of the water column, the elevated TN was mainly the result of internal loading. TN in the bottom water reached a maximum concentration of 1,880ppb in August, at the height of anoxia.

Table 3. 2019 total nitrogen concentrations (ppb).

Depth	4/30/2019	5/29/2019	7/25/2019	8/14/2019	9/23/2019	10/16/2019
Top (0.5m)	412	470	334	408	443	442
Middle (2.5m)	377	442	344	428	445	425
Bottom (5.0m)	460	479	**835**	**1,880**	**725**	413

Historical nitrogen tracking at Roaring Brook Lake shows that total nitrogen appears to be increasing where 2019 the first year when the majority of the data points were above 400ppb. This is in contrast with most prior years when most data points were below 400ppb (**Figure 13**).

Figure 12. 2019 total nitrogen concentrations (ppb).

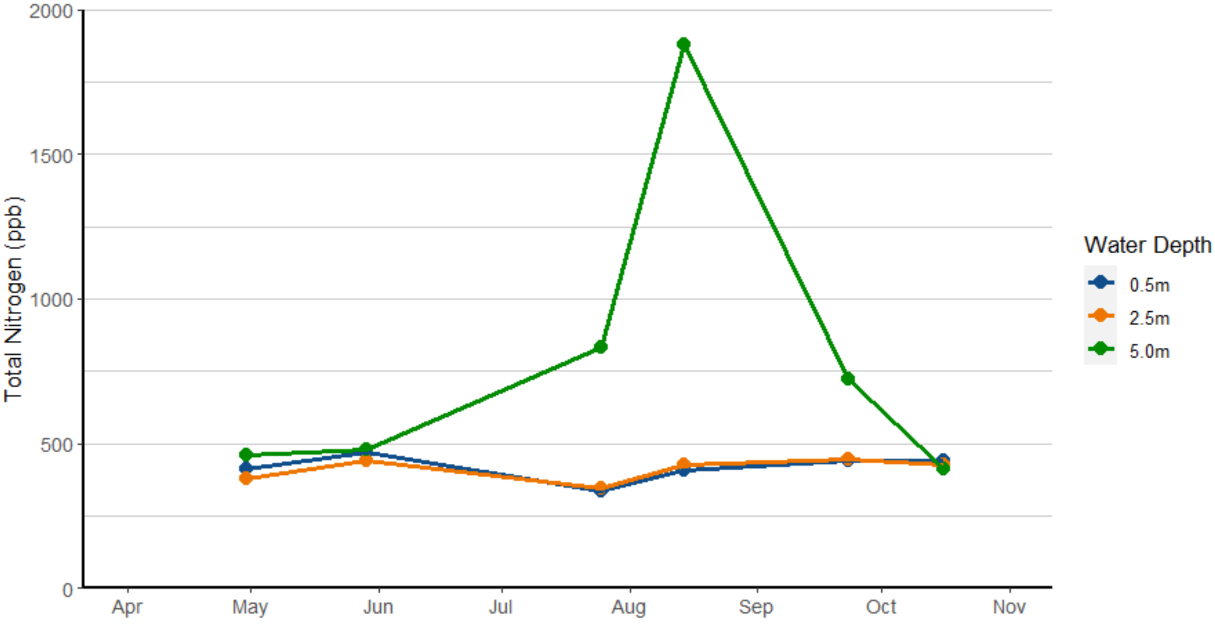
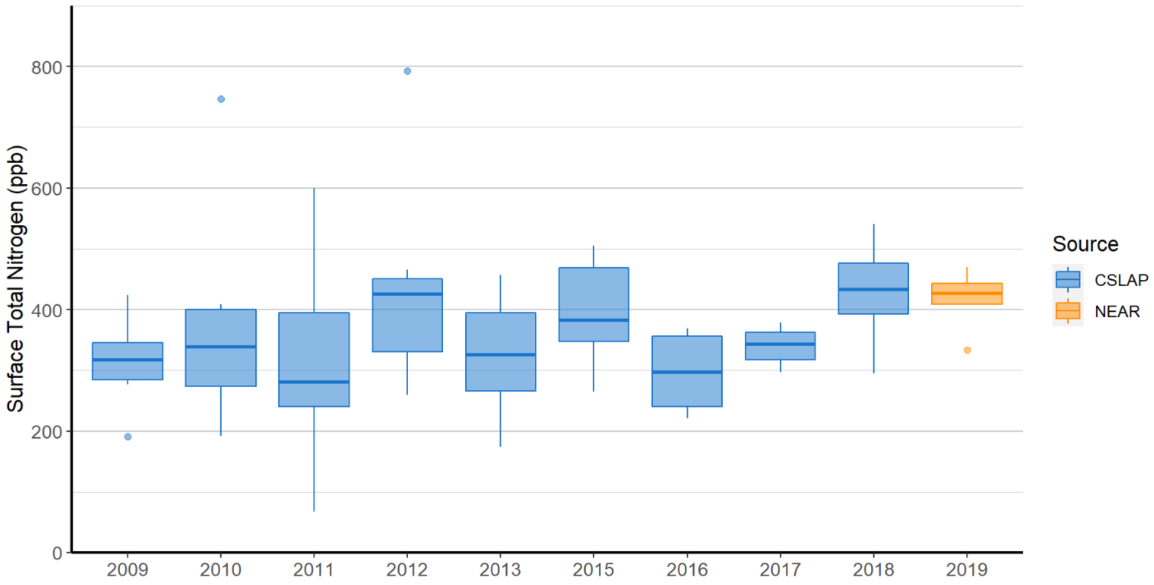


Figure 13. Historical and 2019 total nitrogen concentrations from CSLAP and NEAR.



Total Ammonia

Total ammonia (NH_3) in the surface water ranged from 5ppb to 53ppb across the sampling season (**Table 4**). NH_3 in the bottom water reached a maximum concentration of 516ppb in August, in conjunction with the elevated TP and TN concentrations.

Overall the ammonia concentrations in the surface water in 2019 were generally higher than in previous years, though with fewer extreme high values (**Figure 14**). Bottom water ammonia increased steadily as the lake stratified and anoxia developed. Ammonia is readily released from bottom sediments when overlain by anoxic water. Maximum bottom water ammonia concentration occurred a month after maximum phosphorus concentration suggesting that actual sediment release was higher in August than July. The presence of high ammonia in bottom water in September is evidence that sediment oxidation is delayed until October.

Ammonia concentrations in Roaring Brook Lake have been increasing steadily since 2013 (**Figure 15**). This may be due to either an increased rate of groundwater ammonia to the lake from septic systems around the lake or an increased rate of internal sediment release. In the case the higher ammonia concentrations in the lake should be closely watched.

Table 4. 2019 total ammonia concentrations (ppb). All values in red indicate elevated above-normal concentrations.

Depth	4/30/2019	5/29/2019	7/25/2019	8/14/2019	9/23/2019	10/16/2019
Top (0.5m)	47	49	34	47	44	53
Middle (2.5m)	37	47	21	5	45	32
Bottom (5.0m)	32	**183**	**104**	**516**	**255**	39
TN Bottom (5.0m)	460	479	**835**	**1,880**	**725**	413
TN – NH_3	428	296	**731**	**1364**	**470**	374
% NH_3	6.9	38	12	27	35	8.7

Figure 14. 2019 ammonia concentrations (ppb).

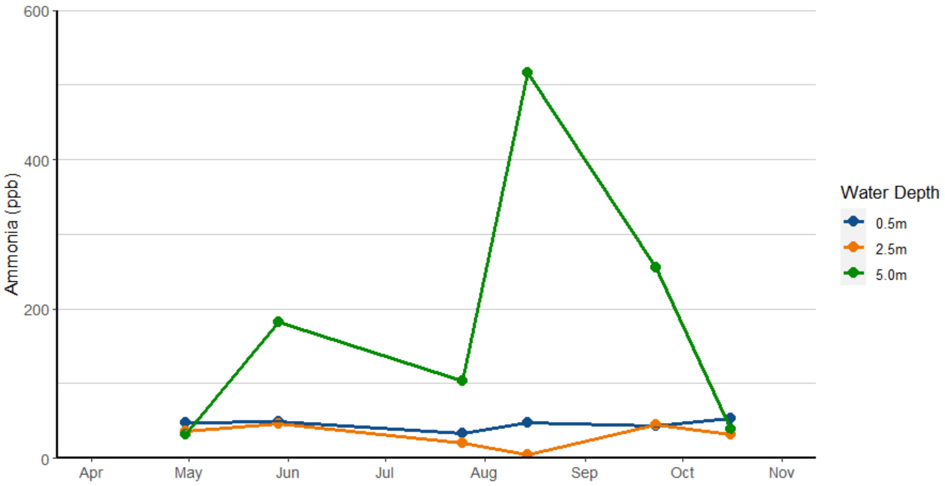
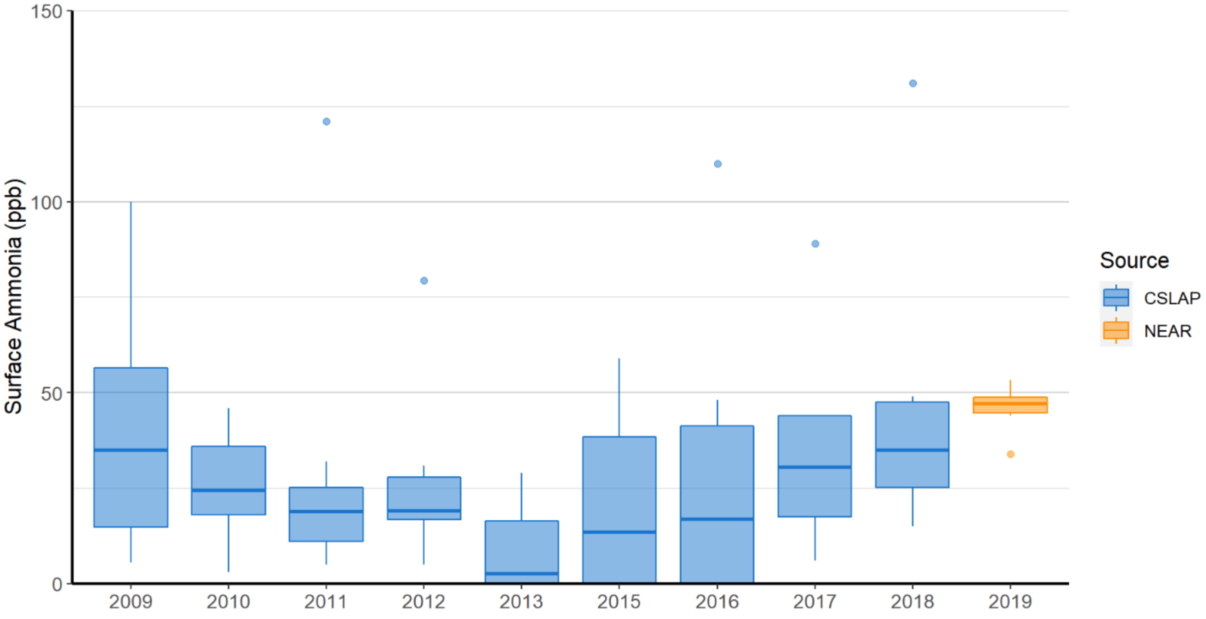


Figure 15. Historical and 2019 ammonia concentrations from CSLAP and NEAR.



Phytoplankton

Phytoplankton were collected using a 3-m integrated sampler once per month from April to October. Blue- green algae were the dominant taxa from June to August, with a high of 15,160 cells/ml in July (**Figure 16**). The dominant blue-green taxa were *Planktolyngbya* followed by *Aphanothece* and *Dolichosperum* (**Figure 17**), which are known toxin producers.

Figure 16. Dominant algae groups identified and enumerated in 2019.

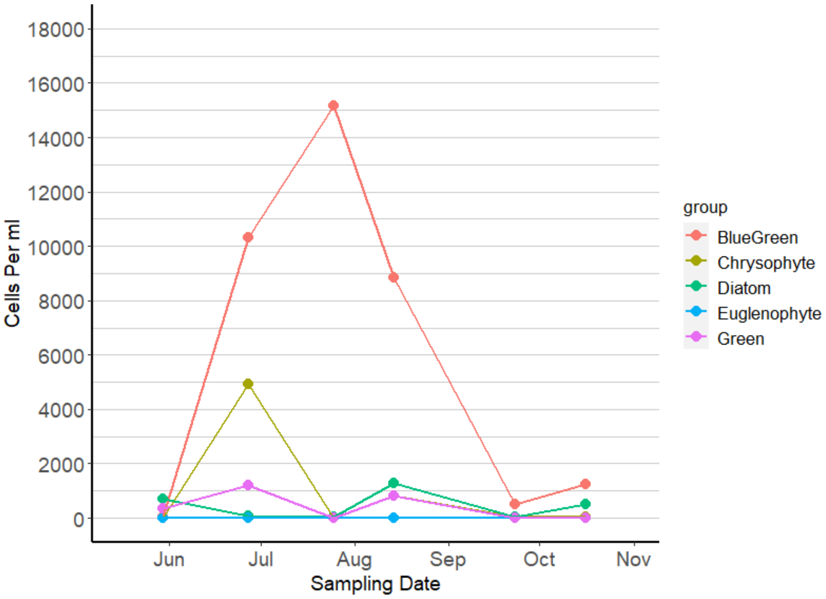
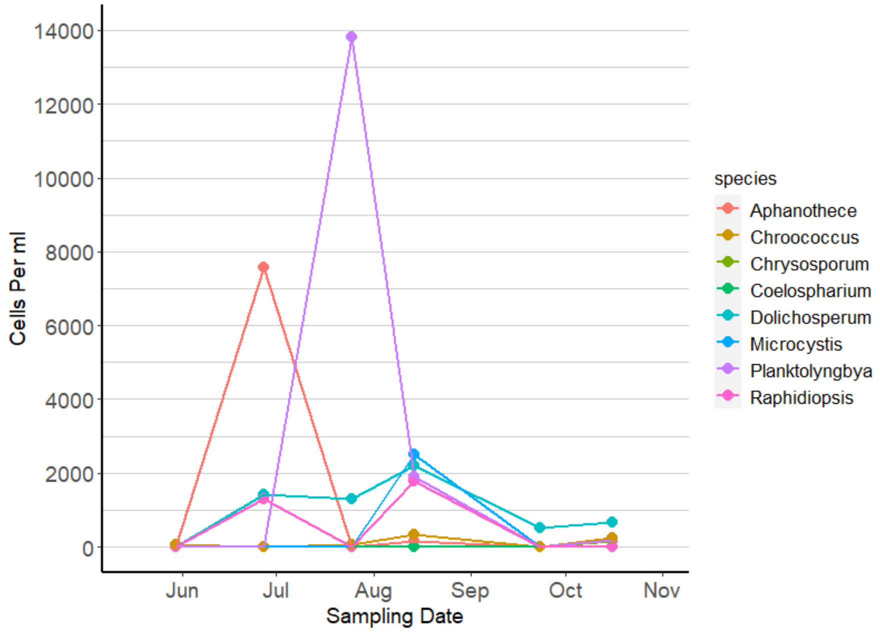


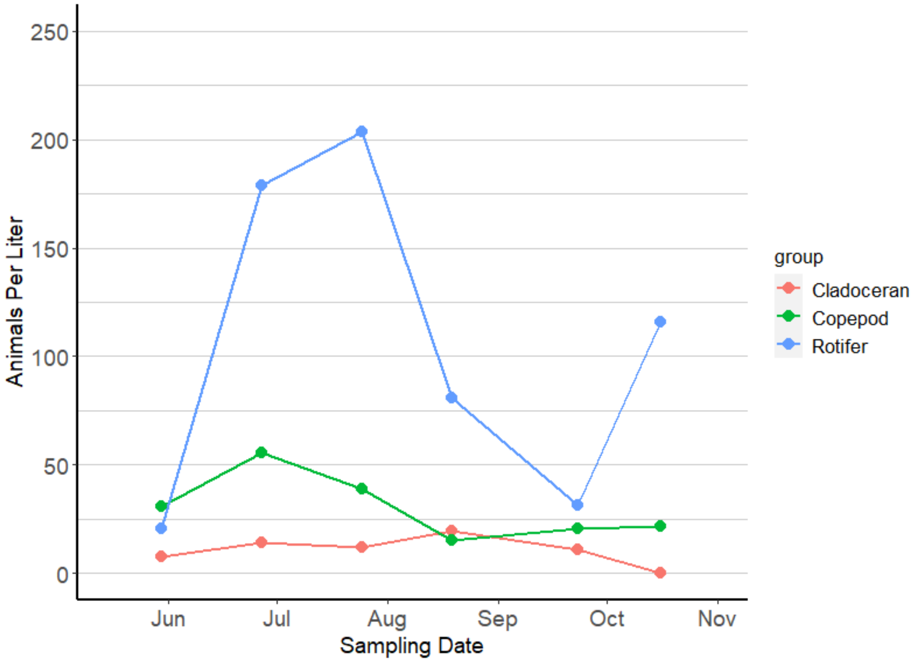
Figure 17. Blue-green algae taxa identified and enumerated in 2019



Zooplankton

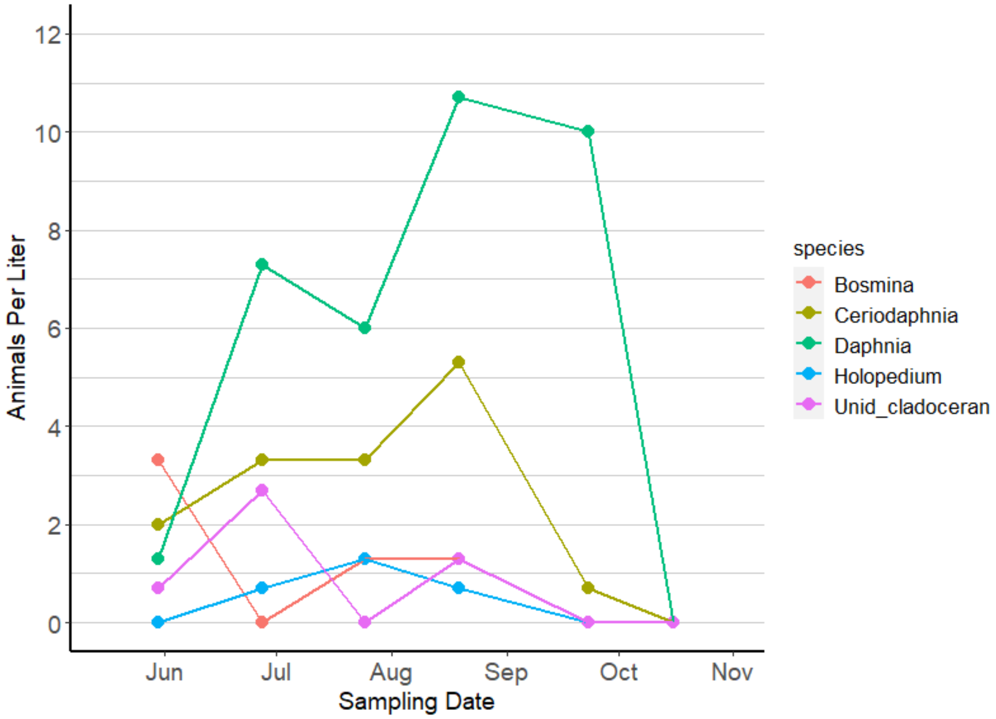
Rotifers were the dominant zooplankton group present throughout the season, with the densest rotifer population present in July (**Figure 18**). Rotifers are the smallest members of the zooplankton and usually are prey items for the larger copepods.

Figure 18. Dominant zooplankton groups identified and enumerated in 2019.



The cladocerans, which are the largest (in terms of body size) zooplankton in the lake were dominated by the daphnia. This is a great sign for the lake as daphnia are filter feeders and can increase water clarity during the early summer (**Figure 19**).

Figure 19. Cladoceran taxa identified and enumerated in 2019.



Aquatic Plants

Aquatic plants of Roaring Brook Lake were surveyed on August 12th, 2019. The survey consisted of creating waypoints every 150 to 200 feet throughout the entire littoral zone (area where plants can grow based on available light) of the lake. The survey utilized a combination of visual assessments, hand-raking in shallow water, grappling rake tosses, and depth soundings to view plants growing in deep water.

During the survey, 12 aquatic plant species were found in the lake, along with the cyanobacteria mat- forming genera *Lyngbya*, and two algae types, the macroalga *Nitella*, and filamentous Green algae *Spirogyra* (**Table 5**). The dominant species (greater than 20% frequency) were common bladderwort (*Utricularia macrorhiza*; **Figure 20**), stonewort (*Nitella;* **Figure 21)**, water starwort (*Callitriche sp.* **Figure 23**) and fanwort (*Cabomba caroliniana;* **Figure 22**). In past years, bladderwort has been a nuisance plant in Roaring Brook Lake. It is a rootless plant, allowing it to float into cove and shoreline areas in dense mats. We did not observe dense floating mats of bladderwort in 2019, despite its overall abundance and density on the lake bottom. Additional maps of plant species are located in appendix B.

Two invasive species, fanwort and (Eurasian milfoil, (*Myriophyllum spicatum)* were found during the survey. Fanwort was abundant, present at 21% of waypoint visited. However, its growth was confined primarily to the northern two-thirds of the lake, with just one small patch found in the cove at the lake’s southern end (**Figure 22**). Eurasian milfoil was less abundant, at 13% frequency. It was growing sparsely around the lake's shoreline, with most patches containing single or very few plants (**Figure 24**). Both species have the potential to become aggressive and impede recreational use.

Filamentous green algae were present in coves, as is typical of this group of algae (**Figure 23**). The presence of filamentous green algae species can be indicative of excess nutrients in the area. Usually, these pockets of eutrophication are the result of nutrient loading from the watershed, via runoff, an inlet, or a groundwater seep.

Table 5. Aquatic plant and algae taxa documented during August 12, 2019 survey. Asterisks indicate non-native taxa.

Common Name	Scientific Name	Frequency	Avg. Density
Large Bladderwort	*Utricularia macrorhiza*	47	59
Musk Grass	*Nitella sp.*	30	12
Fanwort*	*Cabomba caroliniana*	21	30
Water Starwort	*Callitriche sp.*	21	56
Eurasian Milfoil*	*Myriophyllum spicatum*	13	7
Coontail	*Ceratophyllum demersum*	6	9
Filamentous algae	*Spirogyra sp.*	5	9
Large-leaf Pondweed	*Potamogeton amplifolius*	4	11
Minor Naiad*	*Najas minor*	4	8
Tiny Bladderwort	*Utricularia gibba*	2	5
Cyanobacteria mat	*Lyngbya sp.*	0.5	20
Common Reed	*Phragmites*	0.5	NA
Red-leaf Pondweed	*Potamogeton epihydrus*	0.5	10
Narrow-leaf Pondweed	*Potamogeton* sp.	0.5	5
Sedge	*Carex sp.*	0.5	5

Figure 20. Locations of Utricularia macrorhiza (common bladderwort) during the August 2019 survey.

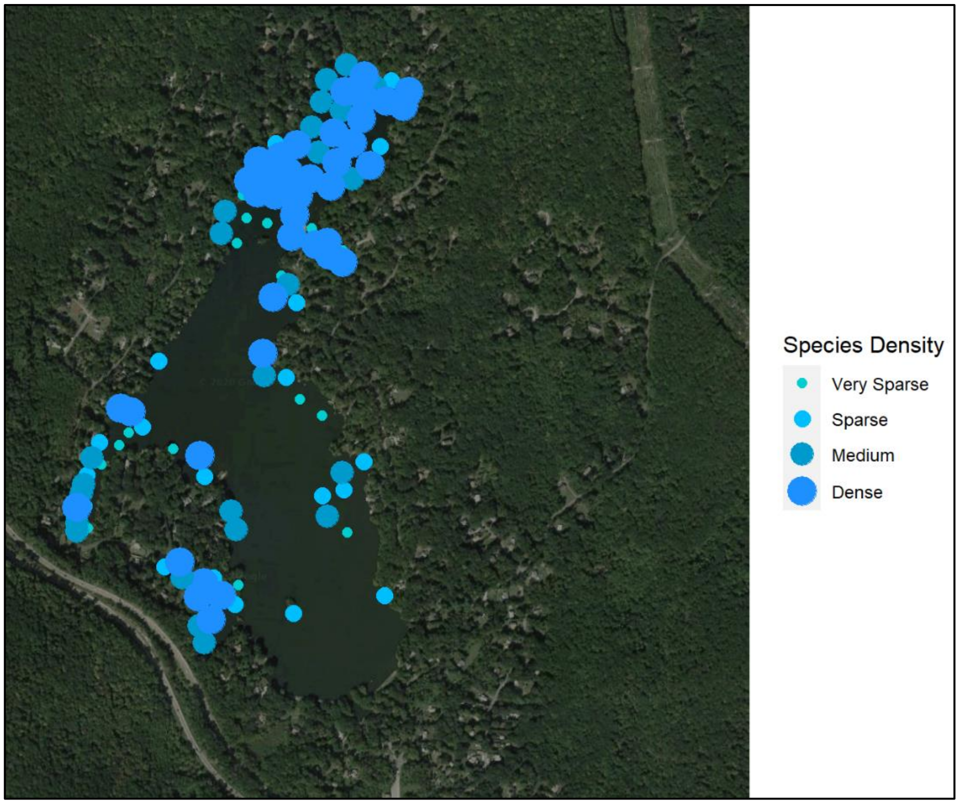


Figure 21. Locations of Nitella sp. (stonewort) during the August 2019 survey

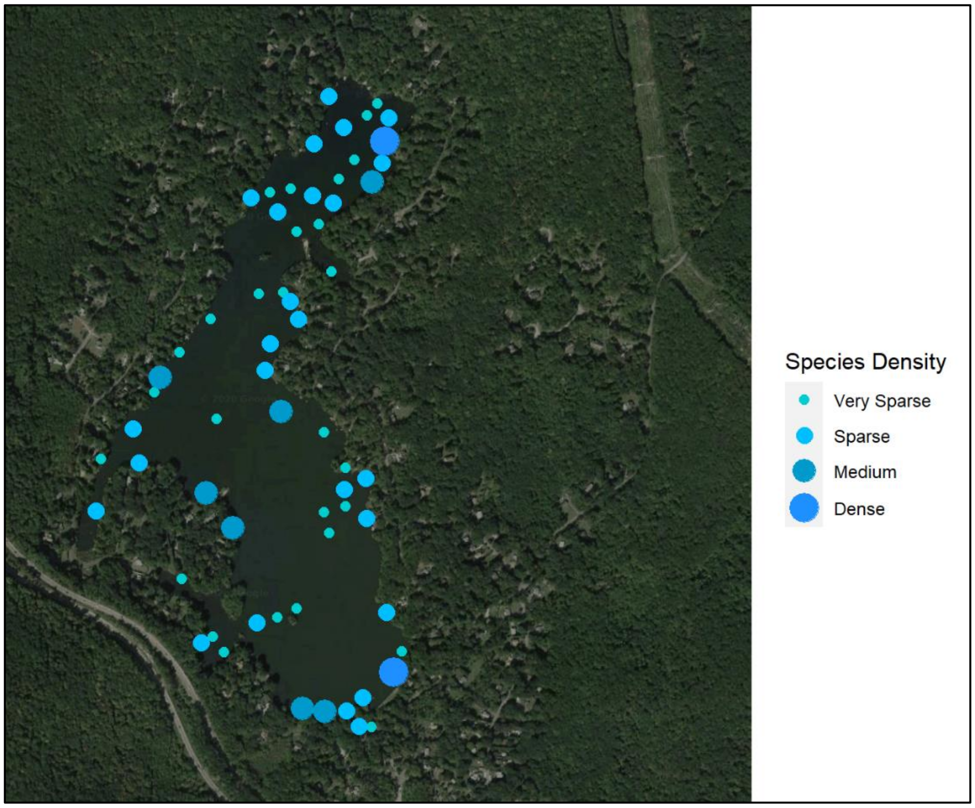


Figure 22. Locations of Callitriche sp. (stonewort) during the August 2019 survey

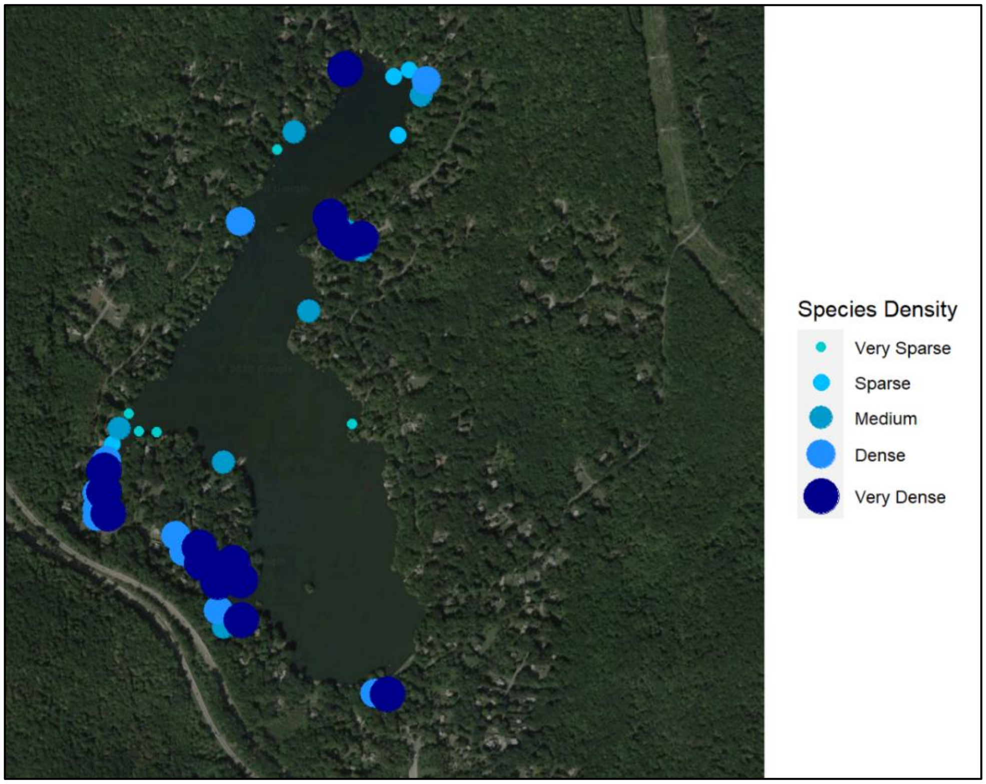


Figure 23. Locations of Cabomba caroliniana (fanwort) during the August 2019 survey.

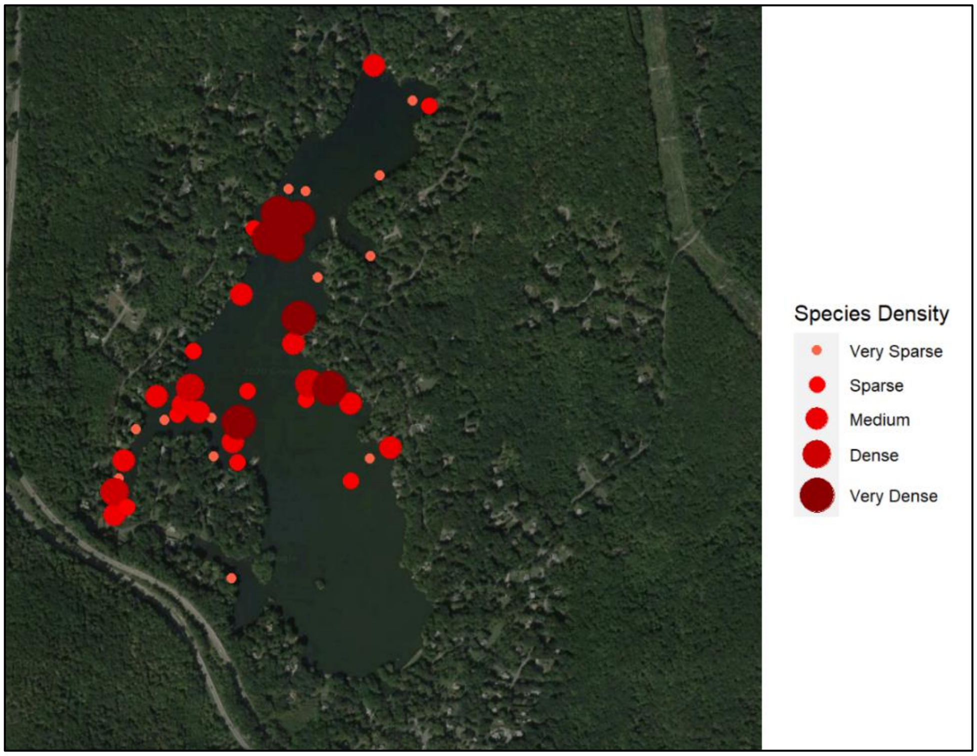


Figure 24.Locations of Myriophyllum spicatum (Eurasian milfoil) during the August 2019 survey.

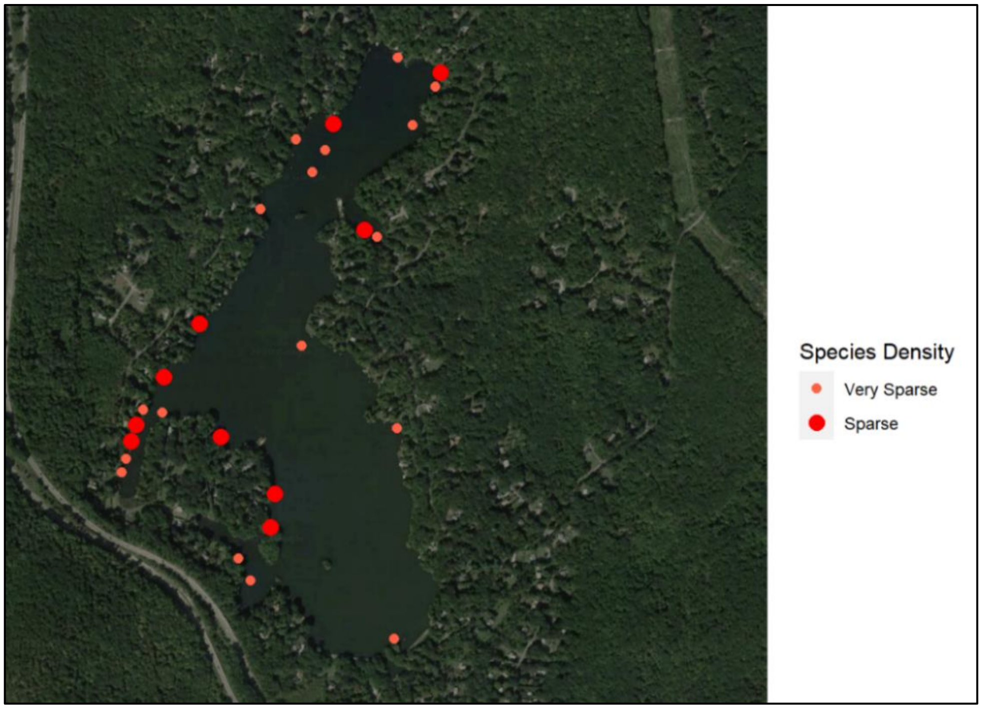
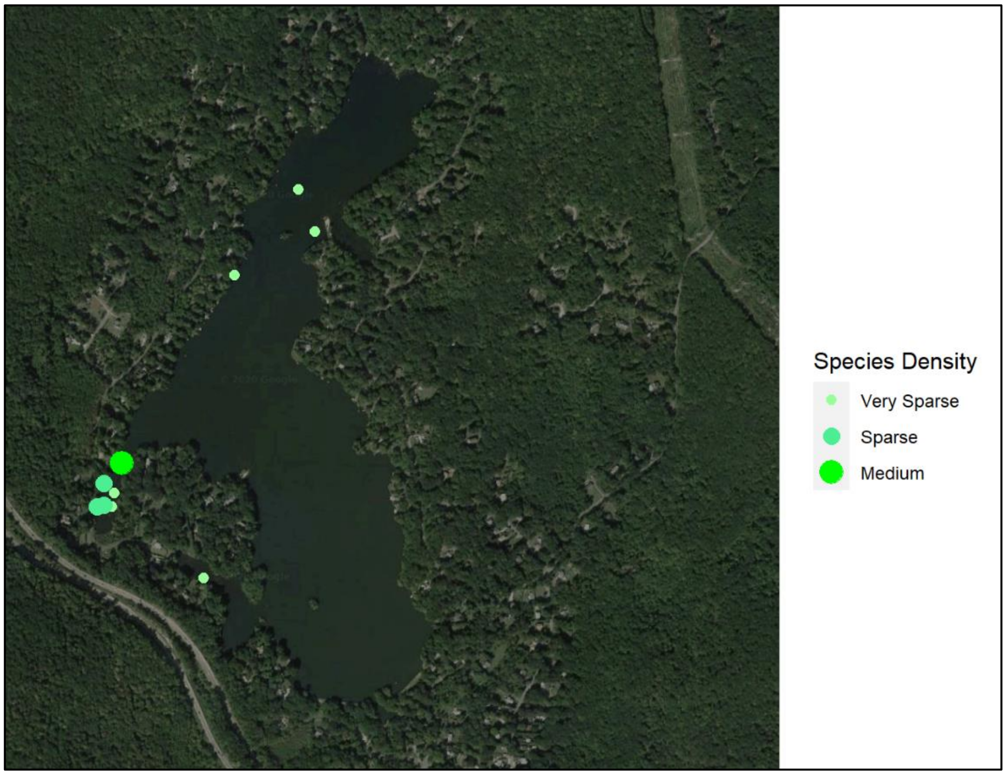


Figure 25. Locations of filamentous algae during the August 2019 survey.



Watershed Loading

All nutrients not of atmospheric sources originate from the watershed. As human development in a watershed increases, the amount of phosphorus and nitrogen released increases proportionally. Humans add phosphorus from increased impervious surfaces such as roads, driveways, rooftops, parking lots, decks, patios, etc. and other sources such as fertilizer (organic included) and onsite wastewater systems. Large scale changes to lake shorelines like the removal of trees or improper construction practices can also increase nutrient pollution.

Inlet Nutrients

NEAR collected water samples from 7 inlets and the outlet during four sampling events in 2019. The typical condition is for inlets to be dry with no flow. In May, Inlet 5 and Inlet 6 had elevated concentrations of both total phosphorus and total nitrogen, identifying these as areas with excessive nutrient inflow from the surrounding watershed (**Figure 25, Figure 26**). On all other sampling dates, all flowing inlets had TP concentrations near or below 100ppb, and TN concentrations near or below 1,000ppb.

In April and May, the inlet samples were tested for concentrations of ammonia. Two inlets had ammonia concentrations above 100ppb: Inlet 3 in April and Inlet 5 in May.

In addition to nutrient testing, all flowing inlets were tested for fecal coliform bacteria. Fecal coliform is a group of bacteria found in the feces of humans and animals. The presence of fecal coliform does not directly indicate contamination from septic systems but can help be an indicator of pollution. Inlet 1 contained elevated concentrations of fecal coliform in both June and August (**Figure** 28). Inlet 5 had elevated levels in May, and Inlet 7 had elevated levels in June, July, and August.

Figure 26. Inlet total phosphorus concentrations in May.

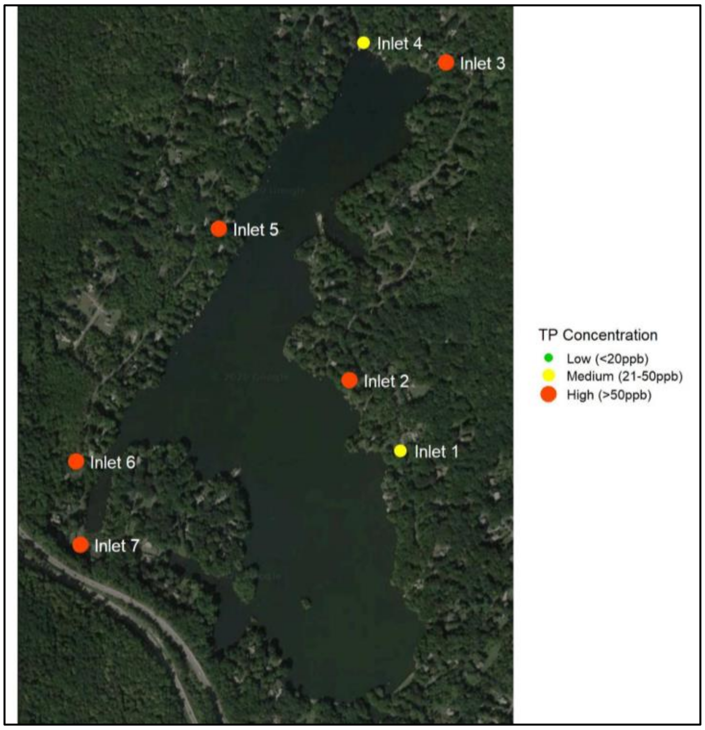


Figure 27. Total phosphorus concentrations in Roaring Brook Lake inlets. Red line indicates NYS Guidance value for total phosphorus (20 ppb).

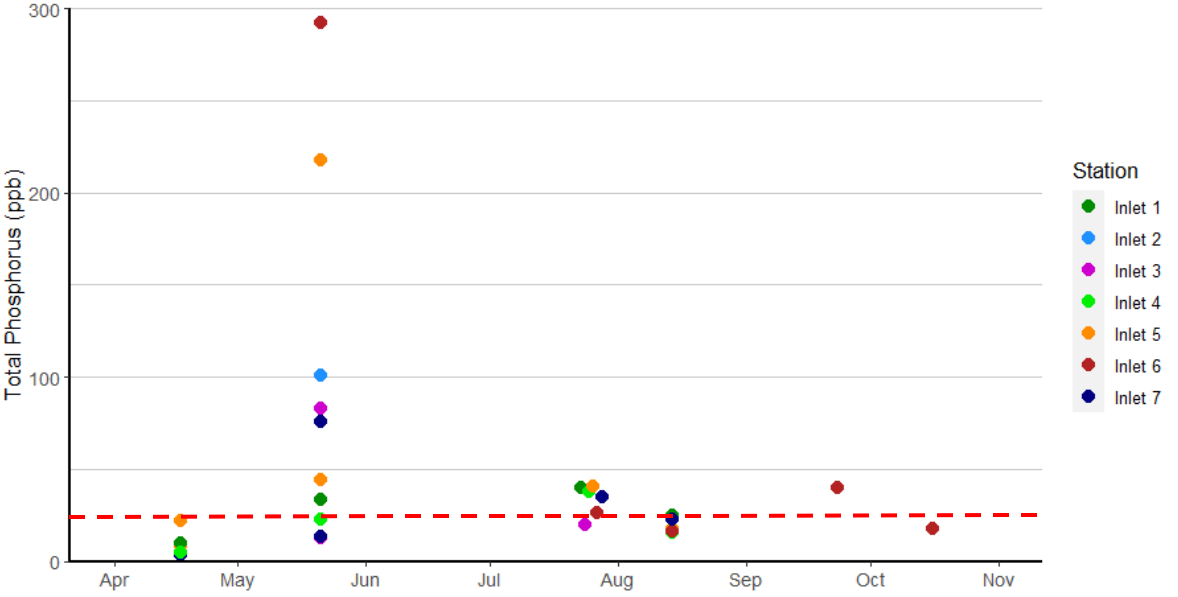


Figure 28. Total nitrogen concentrations in Roaring Brook Lake inlets.

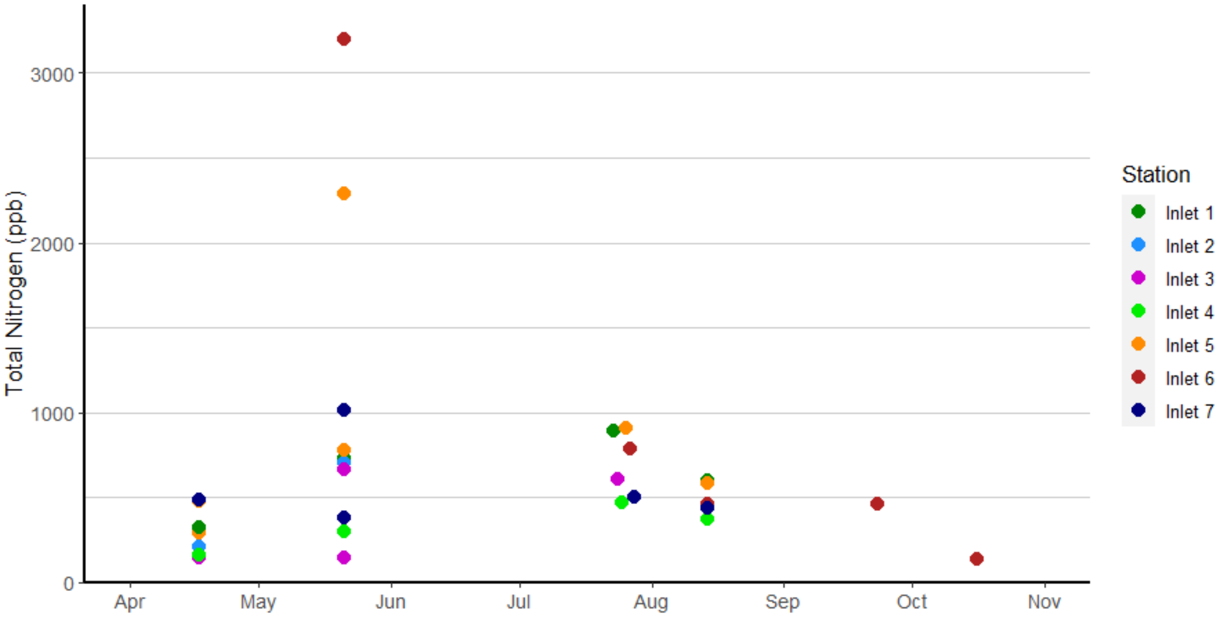


Figure 29. Ammonia concentrations in Roaring Brook Lake inlets.

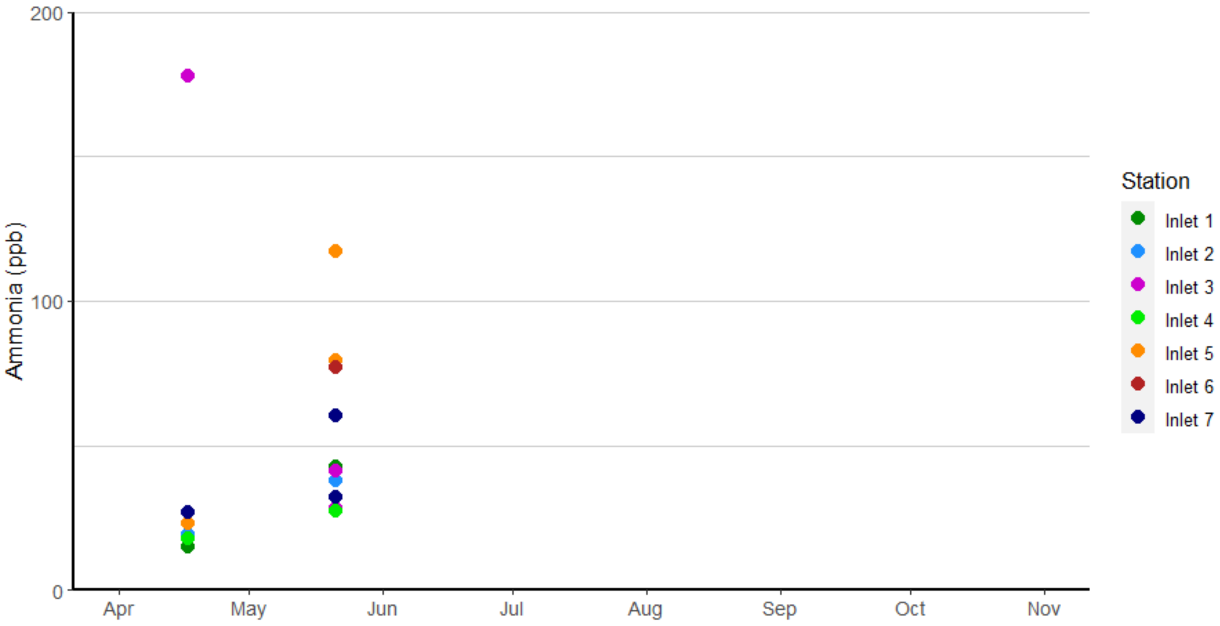
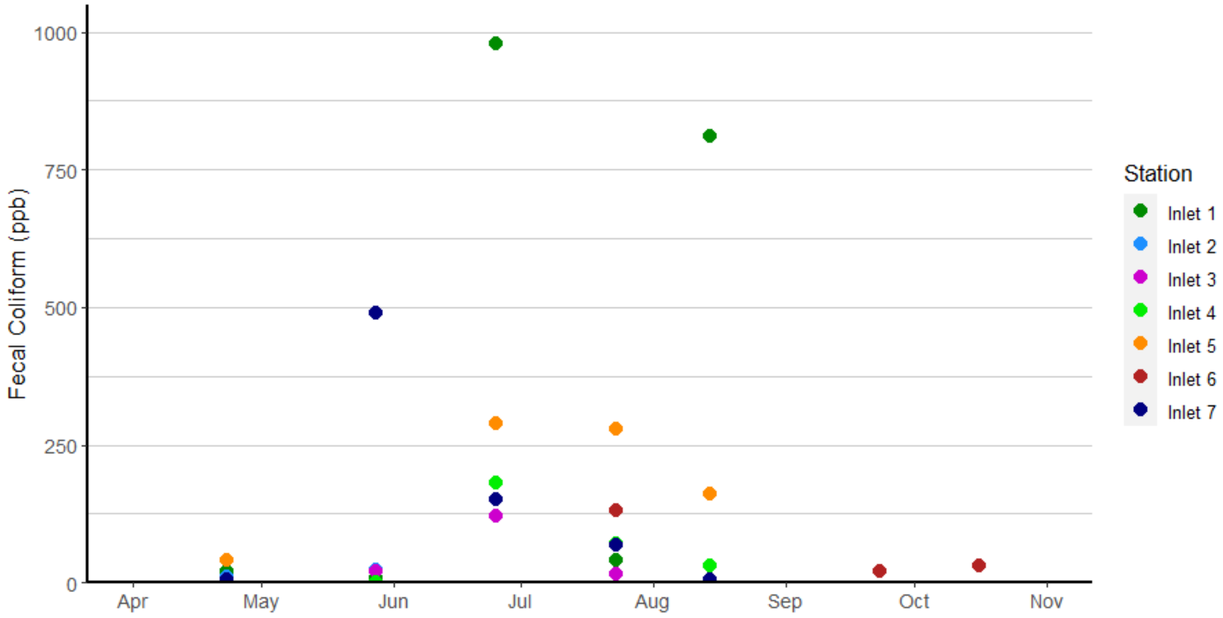


Figure 30. Fecal coliform concentrations in Roaring Brook Lake inlets.



Conclusions

Overall, the 2019 data suggests an impaired waterbody where harmful algae scums can form and potentially proliferate. Historically, phosphorus in 2019 appeared lower than most years back to 2013. Data prior to 2013 show generally higher phosphorus with most data points less than 15ppb. However, no samples in 2019 had less than 10ppb, as has been common in the past. The nitrogen concentration may be increasing in Roaring Brook Lake over the 10 years of monitoring. In 2009 showed TN between 280- 320ppb, now TN is 400 to 470ppb.

Currently, phosphorus values are not tremendously high in the epilimnion, but anoxic sediments inlet nutrients fueled by septic systems and stormwater sources have the potential to increase lake-wide phosphorus and nitrogen over time. The next sections discuss the various sources of nutrients that can affect Roaring Brook Lake and strategies to mitigate them.

The one nutrient that appears to be steadily increasing is ammonia. Most inlets contained moderate to low concentrations of ammonia, which would suggest that the increasing concentration in the lake is due to internal loading.

Internal Loading

One of the main goals of the 2019 monitoring effort was to understand how the lake functions with respect to defining the phosphorus cycling that is leading to periodic algal scums. Phosphorus was shown to be released from bottom sediments during at least late-July to mid-August, it is uncertain if the internal release of phosphorus continued into September, as ammonia did. Phosphorus formed a classic internal loading gradient in September, with concentration decreasing by half from bottom to middle and again from middle to top. The high level of ammonia at the bottom in September is evidence that internal release was still occurring, indicating that phosphorus was probably still leaching from the sediment but diffusing upward instead of accumulating.

The internal recycling of nutrients can have severe consequences on the total nutrient budget for the lake. Internal release mostly happens in the mid- to late- summer when surface inlets are dry. The nutrients are released into the bottom waters of the lake where cyanobacteria are resting waiting for nutrient spikes. The sediments of lakes store an enormous amount of phosphorus and nitrogen, along with other elements that are not normally available for algae growth. During the summer, when oxygen is lost at the bottom due to thermal stratification (See the description of monitoring components section), a few different chemical reactions take place to release these nutrients into the overlying waters. Depending on the lake size and shape (commonly referred to as lake morphometry) and on local weather, these nutrients can be brought to the surface where algae can utilize them for growth.

During the summer of 2019, we were able to gain the following information concerning the lake and the internal load:

1) The lake thermally stratifies at the deep section, with only two instances captured where mixing is occurring after stratification has set up (see temperature logger data graph; **Figure 7**).
2) Dissolved oxygen is lost at the bottom of the lake during the summer, starting at the end of May and continuing through the middle of September. The most severe oxygen loss was found during the end of July, with the anoxic boundary located at 3.75 meters.
3) This loss of dissolved oxygen has resulted in the release of phosphorus and nitrogen from the sediments during at least late-July to mid-August, probably into September as well.

This information leads us to believe that the internal loading at Roaring Brook Lake may be playing a role in algae scums throughout the season, as these nutrients can be readily available for uptake. There are still some unknowns such as the spatial extent of anoxia, and how much phosphorus can be released from the sediment if conditions get worse. Understanding these questions will aid the Town of Putnam Valley in making decisions on the best way to mitigate this load. Fortunately, it does not appear as though the loading is particularly severe at the moment. We commonly see more impaired lakes with bottom phosphorus values in the 500-2,000 ppb range and total nitrogen in the 2000-4,000 ppb range during anoxic conditions. Despite the relatively low load currently, plans for mitigating this source of nutrients should commence in the near term, before the load starts to drive more frequent, intense algae blooms.

While all sources of nitrogen and phosphorus should be evaluated and potentially remedied, the internal regeneration of nutrients deserves special attention. This recycling, mediated by the loss of dissolved oxygen in the bottom waters during the summer will perpetually limit lake restoration efforts. Many people assume that lakes are flow-through systems where, if you turn off the valve (external loads) on the bad water, or replace it with good water, the system gets better overall. This view is overly simplistic and fails to take into account that an overwhelming majority of nutrients are retained in the lake for some time. Grass clippings, leaves, excess fertilizer, stormwater carried sediment, septic tank effluent, and all other organic materials accumulate at the bottom of lakes and add to the pool of nutrients that can be recycled every summer. Simply put, even if you were to have every house on sewer, leach fields remediated with new, non-binding site saturated soil and had perfect stormwater best management practices system, many lakes will either slowly or never recover unless the internal recycling of nutrients is addressed.

This is not to say watershed remediation isn't important, as lakes that are relatively un-impacted benefit greatly from decreased nutrient loads. Efforts should be made to reduce inputs from septic systems, stormwater, waterfowl, and lawn practices (clippings and fertilizer), which will reduce the accumulation of organic materials that can be decomposed. However, these watershed practices cannot be truly effective on their own alone in most cases and will not provide measurable results without addressing nutrients that are internally recycling. Reducing impacts from the watershed will also prolong any positive benefits seen from internal loading estimates.

Strategies to mitigate internally loaded nutrients

Management of the internal load is generally done using 3 different approaches: 1) removing the sediment that is internally loading nutrients via dredging, 2) raising the oxygen concentration on the bottom of the lake via circulation or aeration and 3) binding the phosphorus to another element in the sediments, which prevents release under anoxic conditions, using Aluminum Sulfate, Lanthanum or another binding agent. For all three techniques, significant pre-study and design is needed to optimize results. These are not techniques to implement without proper monitoring. For our discussion, we will not be talking about dredging as it is often infeasible and cost-prohibitive.

Artificial circulation/Aeration

The loss of oxygen in the deep waters leads to the release of phosphorus, ammonia, and other deleterious compounds. Using circulation/aeration can help improve oxygen conditions and lead to less harmful algae. Circulation is the forced movement of water within a lake, using a variety of diffusers/pumps, etc. Oxygen is increased by increasing the interaction of water with the oxygenated air above the lake and by moving warmer, oxygenated water to the deeper regions, with lower oxygen.

Circulation in particular has potential added benefits in that the turbulence induced by the mixing favors other types of algae besides cyanobacteria. Diatoms, which are beneficial for the lake can do better in more turbulent systems. Many properly circulated lakes experience an increase in diatom dominance once the system is turned on. Some cyanobacteria (but not all!) do not like to be mixed and lose one of their key competitive advantages, buoyancy control when a lake is circulated.

Sizing is particularly important for circulation, as undersized systems are the #1 reason for system underperformance. Oxygen loss and stratification can happen if diffuser heads are spaced too far apart, and if the system is turned on after stratification sets up, there is a risk that the deeper, more nutrient concentrated water will be brought to the surface, fueling excess algae growth. When diffusers are sunk into the mud, water quality can be impaired in the short term by bubbles forcing sediment into the water column.

Suggested action:

Circulation can play a key role in Roaring Brook, but proper pre-study system design and maintenance are crucial for success. Knowing the spatial extent of anoxia and the potential for internally loaded phosphorus will aid in planning and system design. It is too early to recommend this technique but will certainly be a part of the conversation moving forward.

Phosphorus Locking Technology

Since phosphorus is the primary limiting nutrient for algae growth, control in lakes is often focused on reducing phosphorus. Lake sediments contain a lot of phosphorus (Sometimes over 100 times the concentration of the water column in certain situations) that is potentially available for release under anoxic conditions. Phosphorus locking technologies create insoluble bonds between phosphorus and another element, which does not dissociate when exposed to anoxic conditions. This greatly limits the phosphorus released and can greatly improve algal conditions.

The major compound used in phosphorus locking is aluminum sulfate (alum). When the alum is added to the lake water, a series of chemical reactions take place that eventually leads to the formation of aluminum phosphate ($AlPO_4$), which is stable, non-reactive, and non-toxic. Alum has been used successfully in many different lakes around the country, with positive results being observed lasting anywhere from 5-20 years depending on the lake size, watershed characteristics, etc (Welch and Cooke 1999; Huser et al. 2016).

Alum, similar to circulation requires a significant amount of pretesting, often including a laboratory scale jar test to accurately determine the correct dosage needed. Sediment testing, which will be done in the fall of 2020, will help us understand how much phosphorus can be potentially released under anoxic conditions, which will inform us on how effective an alum treatment may be.

Suggested action:

Alum is currently not registered for use in NY, but trials are going on now in a few regional lakes. It is widely believed that alum will be registered shortly, so future monitoring to plan for this should be undertaken. The pre-study requirements for circulation overlap with what would be needed for alum, with additional pH, alkalinity, and sediment testing further elucidating potential alum effects. A jar test may be useful to determine proper dosage rates, which will help the community plan financially.

Watershed Loading

The excess phosphorus and nitrogen in Roaring Brook Lake can be traced back to the watershed. As human development increases in a watershed, the amount of pollutants that enter a lake increase. This is especially true for nitrogen and phosphorus, which can be transported via multiple pathways. Individual homeowner practices on shoreline areas can increase nutrients via grass clippings from lawn maintenance, excess fertilizer, draining of lawns after rains through curtain drains, etc. Geese can also be a contributor to nutrients with improper lawn practices potentially favoring congregation. By far though, the two largest contributors to nutrient additions in lakes are septic systems and stormwater runoff. Therefore, we will focus our discussion on those two sources

Septic systems

The impacts of onsite wastewater effluent on nearby water bodies have become increasingly important given the expansion in the human population and desirability of waterfront properties. Traditionally, onsite wastewater is treated via a combination of the septic tank and leaching field, where wastewater effluent is presumed to be treated via a series of biogeochemical transformations that limit the migration of pathogens and excess nutrients through the soil (Burks & Minnis, 1994). However, nitrogen rapidly leaches from the soils into the groundwater, leading to serious concerns for shoreline areas as the septic- derived nitrogen feeds both aquatic plants and algae (Corbett et al., 2002). Phosphorus, on the other hand, tends to be rapidly “fixed” or retained by dry soils. In theory, the phosphorus from onsite wastewater should never reach the groundwater table. However, this treatment efficiency is highly variable depending on the distance in inches from the bottom of the leaching trenches to the groundwater table (Robertson, 1998 & 2008). Older onsite wastewater treatment systems may appear to be functioning properly, but they are actually placed too close to the groundwater table and may end up acting as flow-through nutrient pumps to the lake. The exact conditions are only detectable upon inspection and water sampling. Finally, the soil’s ability to absorb phosphorus may be saturated over time. Even properly functioning older septic systems may exceed the soil's natural ability to fix phosphorous over a period of twenty+ years (Lombardo, 2006).

Septic systems in the Roaring Brook Lake area also face some inherent challenges based on home location and soil type:

1) Lake lots are closely packed together, so there is little room for an adequately sized leach field for the effluent to be dispersed.
2) Soils in this area are largely rocky and well-drained with the dominant soil type being Charlton-Chatfield (CrC), followed by Chatfield-Hollis outcrops of varying slopes (Appendix A). These soils usually do not have sufficient pockets of good soil for septic system leach fields. At least 24 inches of loamy soils is required for adequate septic system leach fields.
3) Many lots on the lake were designed to be seasonal homes, and when they were converted to permanent dwellings, systems may have not been upgraded to reflect this change in usage.
4) Because of the rocky soil and small lot size, many RBL homes, especially lake-front homes do not have leach fields (Ina Cholst. personal communication). In fact, the majority of RBL lake-front homes do not have leach fields. In these homes, the septic tanks are connected to seepage pits, or similar structures, which disperse the septic effluent, without a second stage treatment by surface soil, at 5 to 9 feet below the soil surface. These seepage pit effluents are particularly high in both phosphorus and nitrogen.

Generally, nutrient over-enrichment and reduced water quality stems from a combination of sources, but since the lake has such a small watershed compared to its lake size (Ratio 10:1), combined with the limited development in the upper watershed it is appropriate to assume that onsite wastewater has a substantial impact on lake productivity, even including dissolved oxygen levels. This impact may also be highly variable from year to year depending on groundwater fluctuations, seasonal residence patterns, and the frequency and time from last septic pump-out.

Suggested action:

As a rule of thumb, septic systems in the watershed of a lake should be pumped and inspected at least every 3 years. In addition to the ecological advantage of removing high nutrient septic solids from the lake's watershed and transferring them to sewage treatment plants, is important to note that more frequent septic pumping decreases the likelihood of leaching field failure. We suggest that the present code, requiring that homes in the RBL District be pumped every 5 years, be amended to require septic pump-out every 3 years. This would be consistent with general consensus for water quality.

To facilitate regular septic inspection/pumping along with maintenance and replacement if necessary, the Town of Putnam Valley in coordination with the Roaring Brook Lake District community should consider setting up a grant program to offset costs incurred by homeowners for septic system maintenance. The program could match a set percentage of the cost of pump-outs, inspections, repair, and replacement from RBL District residents. Priorities for funding can be constructed in a wide variety of ways using different criteria to be determined at a later date. Offsetting the cost of septic maintenance can be an effective way to increase lake-wide septic performance, over the long term.

Stormwater Management

Managing stormwater or water originating from rain and/or snow is an important part of lake management. Lakes are passive collectors that sit at a low point in the landscape and accumulate water and materials that flow into them. The water and materials are retained in the lake until they are discharged to a point lower in the landscape. As a result, water bodies are heavily affected by runoff from their watershed, defined as all the land where water can flow downslope to the lake. Stormwater runoff carries pollutants such as sediments, roadway grease and oil, fertilizers, terrestrial pesticides, and excess nutrients into bodies of water. Stormwater runoff is one of the leading causes of poor water quality in lakes, rivers, streams, and ponds.

In an undisturbed world, rainwater would fall to the ground and be mostly absorbed by the native vegetation and natural soils. Yet when rainwater falls onto impervious surfaces such as paved roads, parking lots, and houses, the rain cannot sink into these materials and instead "runs off." This runoff then flows downhill into an area where the water has historically drained directly or indirectly into the lake. Stormwater is more effectively managed by slowing down the flow of water and infiltrating as much water into the soil as possible. Un-treated stormwater with an unimpeded path can pick up more pollutants on the way down, and can also erode beaches, gravel driveways, and other loosely packed soils. This erosion adds additional sediment into lakes and streams.

The best way to limit these impacts is the use of watershed best management practices (BMP). A BMP is a term applied to whatever set of watershed fixes is considered the best at this time. BMPs change over time as more knowledge on the efficiencies of fixes is gained. Currently, most BMPs involve infiltration of stormwater at or near its source through various storm-water retrofits referred to as Low Impact Development or LID practices.

To locate problem areas for stormwater management, NEAR performed a watershed visit on March 29th, 2020. NEAR circumnavigated the entire watershed looking for areas prone to erosion, catalog inlets, and general poor stormwater practices. The inlets referred to here are the same as in figure 24.

Inlet 1

Located on the western side of the lake, this inlet runs through a small wetland area before entering the lake. We measured two elevated fecal coliform levels in June and August (980 and 810 MPN/ml). Stormwater can affect the water quality of this stream, evidenced by the increased turbidity present in the stream (right picture below).

Suggested Action: Continue monitoring, look to mitigate runoff from the immediate north and south sections of Lake Shore Road. Take nutrient samples north of Lake Shore Road.

Note the highly turbid water plume in the stream during rain event in June

Inlet 2

Located on the western side of the lake, north of Holly Street. The stream is ephemeral, flowing until June. Sedimentation is an issue, as the catch basin on the lake-side of the road is covered in sand and loose dirt. During rainstorms, a large amount of that sediment will end up in the catch basin, and eventually make it into the wetland below, filling it in.

Suggested Action: Continue monitoring, install a sediment filter at the catch basin. This will help trap sediment and prolong filling in the stream before it enters the lake.

District Access at Inlet 2

The district access at inlet 2 has a bank that is eroding. High water levels and wave action has carved out a part of the bank which will add more sediment into the lake.The slope of the beach also lends itself to high stormwater flows, especially in early spring, when ground vegetation is not thick and cannot slow down water.

Suggested Action: Repair this erosion by either grading out the slope or putting some sort of retaining wall (stone or earthen) to limit erosion.

Severe bank erosion is accelerating sediment transport into lake.

Alpine Place

The steep slope at alpine place can create a flume of stormwater rushing down into the two catch basins at the bottom of the street. Nutrient samples taken during a storm event indicate a potentially high load entering the lake (TP: 348 ppb, TN: 1302ppb; **Table 6**).

Accumulation of Sediment in Catch

Suggested Action: The catch basin across the street leads into a small dry detention basin before stormwater flows into the lake. Currently, the basin has a significant amount of sediment buildup that can compromise infiltration. This basin should be cleaned out to increase storage capacity.

Inlet 5

The largest inlet to Roaring Brook Lake is Inlet 5. This inlet also has some of the high nutrient and fecal coliform values. This sub-watershed is the largest of the inlets and contains the highest number of houses so higher nutrient and fecal coliform concentrations are expected. The stream becomes quite severely turbid during storm events, becoming muddy only a few hours after rainfall.

Suggested Action: Continue monitoring, the upper end of the inlet should be added to monitoring, as that can help narrow down the source of high nutrients and fecal coliform. The stream should also be walked if possible, to identify areas prone to erosion.

Drainage Pipe, West Side of Lake

A pipe with water containing iron flocculant. Sources of the iron in the water should be considered. Water with either high nitrogen or phosphorus concentrations was found flowing out of the pipe on three separate occasions (**Table 6**).

Suggested Action: Contact homeowner where the pipe is located to discuss possible remediation actions.

Inlet 7

Inlet 7 drains part of the Taconic Parkway and therefore may have a significant number of constituents that we don't routinely test for, including heavy metals, and volatile organic carbon compounds. runoff. High fecal coliform and nitrogen were documented in May. There is a settling wetland before the stream crosses the road.

Suggested Action: Continue monitoring the stream. Inspect the settling wetland above the road to look at sediment deposition and perform maintenance if necessary.

Table 6. 2019 Stormwater nutrient samples.

Stormwater Site	Date	latitude	longitude	Total Phosphorus (ppb)	Total Nitrogen (ppb)	Nitrate + Nitrite
Alpine Place #7	4/17/2019	41°26'30.75"N	73°48'20.80"W	348	1,302	NA
Moon Beach Pipe	4/17/2019	41°26'22.01"N	73°48'42.16"W	91	745	NA
Roaring Brook # 25	4/17/2019	41°26'40.66"N	73°48'11.77"W	7	371	313
Moon Beach Pipe	8/14/2019	41°26'22.01"N	73°48'42.16"W	16	1,390	NA
Moon Beach Pipe	10/16/2019	41°26'22.01"N	73°48'42.16"W	624	991	163
Roaring Brook Cove Road	10/16/2019	41°26'10.59"N	73°48'42.14"W	126	660	2

Aquatic Plant Conclusions

The management strategy for aquatic plants on Roaring Brook Lake can be categorized as extremely aggressive. The combination of the 500 grass carp stocked in 2011 and the annual drawdown exert tremendous pressure on the aquatic plant community. The drawdown in past years has been as deep as 96 inches, with 48-60 inches being common. Drawdowns in cold, dry winters freeze the roots of plants, killing them off before the growing season starts. Most often plants in the 0-4 ft depth range are effectively controlled in good drawdown years. At the same time, grass carp would be grazing in deeper waters, picking off plants in the 5-12 ft depth range. The combination of these two techniques means that little to no plants can grow in the 0-4 ft range and only a limited amount of plants can grow in the 5-12 ft range, restricted to plants that grass carp do not prefer.

Despite the aggressive approach, there are still plants in the lake. The majority of aquatic plants are present in deeper water (5-12 feet) consisting of bladderwort, fanwort, and musk grass. Plants still being present in the middle of the lake is a good sign that indicates that despite the aggressive methods employed, the vegetation has either 1) not been removed entirely, or 2) has recovered since the initial grass carp stocking. Lakes should have some vegetation for fish and macroinvertebrate habitat, stabilization of shorelines, and holding of lake sediments in place. Completely de-vegetating a shallow lake like Roaring Brook can have negative impacts and, in some cases, can lead to increased harmful algae blooms. It is unclear which one of the scenarios took place at roaring brook due to the lack of detailed plant data before and after grass carp stockings.

One thing we can say with some certainty is that the aquatic plants in roaring brook will most likely start to increase in abundance and distribution in the next few years. The grass carp are getting older and their numbers are expected to dwindle further. Using an estimate of 20% annual mortality, there are only expected to be 67 fish left by the end of 2020 (**Table 7**). That means ~13.4% of the original fish remains from the 2011 stocking. Even though larger grass carp can be more effective for aquatic weed control than smaller ones because they need to intake more calories to sustain their body size, over 10 years of yearly attrition, their effects on aquatic plants will start to diminish.

Table 7. Estimated grass carp remaining in Roaring Brook Lake annually based on various mortality scenarios. Fish are assumed to live until 20 years old.

Year	Number of Fish Remaining
2011	500
2012	400
2013	320
2014	256
2015	205
2016	164
2017	131
2018	105
2019	84
2020	67
2021	54
2022	43
2023	34
2024	27
2025	22
2026	18
2027	14
2028	11
2029	9
2030	7

Drawdowns in the future may become a more erratic and unreliable aquatic plant management technique due to climate change. We have already seen two mild winters with minimal ice coverage and sub-freezing temperatures in 2018 and 2019. Drawdown is most effective when the time that plant material is exposed to dry, freezing conditions are maximized. Mild winters that have warm temperatures or intermediate snow cover may provide wet soils, which act as insulators where plant material can survive. Increased precipitation can also make the onset of drawdown slower and require more outflow to maintain a certain water level over the winter. The unpredictability of future winter conditions confounds the effectiveness of drawdowns.

Suggested Action

Declining grass carp age and increased uncertainty in future drawdown success in our opinion will only help the aquatic plant community rebound. To be prepared for this rebound, the Town of Putnam Valley should continue to monitor the aquatic plant community. Increases in the height of aquatic plants or their increased prevalence in shallow areas would indicate that existing control measures are not adequate. Also, the increase in plants such as pondweeds would indicate that the grass carp are not numerous enough to control plants lakewide, as pondweeds are a preferred food item for them.

Concluding Remarks

In summary, while Roaring Brook Lake does exhibit signs of a stressed system with periodically high nutrient inputs, the lake is certainly not at a stage where lake remediation is infeasible. Proper management of septic systems and stormwater can slow down the eutrophication process and buy the Roaring Brook Community time. However, as is the reality for many lakes, the internal fraction of phosphorus needs to be addressed to truly mitigate harmful algae blooms in the long term. Continued monitoring aimed at collecting the proper information to assess the feasibility of internal loading management techniques should be prioritized along with watershed remediation.

Literature Cited

Connecticut Department of Environmental Protection. 1996. Caring for Our Lakes. Watershed and In-Lake Management for Connecticut Lakes.

Corbett, D, K. Dillon., W. Burnett, G. Schaefer. 2002. The spatial variability of nitrogen and phosphorus concentration in a sand aquifer influenced by onsite sewage treatment and disposal systems: a case study on St. George Island, Florida. Environmental Pollution, Vol. 117, p337-345.

Eichler, L. W., R. T. Bombard, J. W. Sutherland, and C. W. Boylen. 1993. Suction harvesting of Eurasian watermilfoil and its effect on native plant communities. Journal of Aquatic Plant Management 31:144–144.

Huser, B.J., Egemose, S., Harper, H., Hupfer, M., Jensen, H., Pilgrim, K.M., Reitzel, K., Rydin, E. and Futter, M., 2016. Longevity and effectiveness of aluminum addition to reduce sediment phosphorus release and restore lake water quality. *Water Research*, *97*, pp.122-132.

Lombardo P. 2006. Phosphorus Geochemistry in Septic Tanks, Soil Absorption Systems, and Groundwater.
Prepared by Lombardo Associates, Inc., Newton, MA. Investigations Report 02-4306.

Lusk, M. & T. Obreza, 2011. Onsite Sewage Treatment and Disposal Systems: Phosphorus.
UF/IFAS Document #SL349, reviewed October 2017.

NYSFOLA. 2009. Diet for a Small Lake: The Expanded Guide to New York State Lake and Watershed Management.

Robertson, W.D., S.L. Schiff, and C.J. Ptacek, 1998. Review of Phosphate Mobility and Persistence in 10 Septic System Plumes, GROUNDWATER, Vol. 36, No. 6.

Robertson, W.D. 2008. Irreversible Phosphorus Sorption in Septic System Plumes? GROUND WATER, Vol.
46, No.1, p51-60.

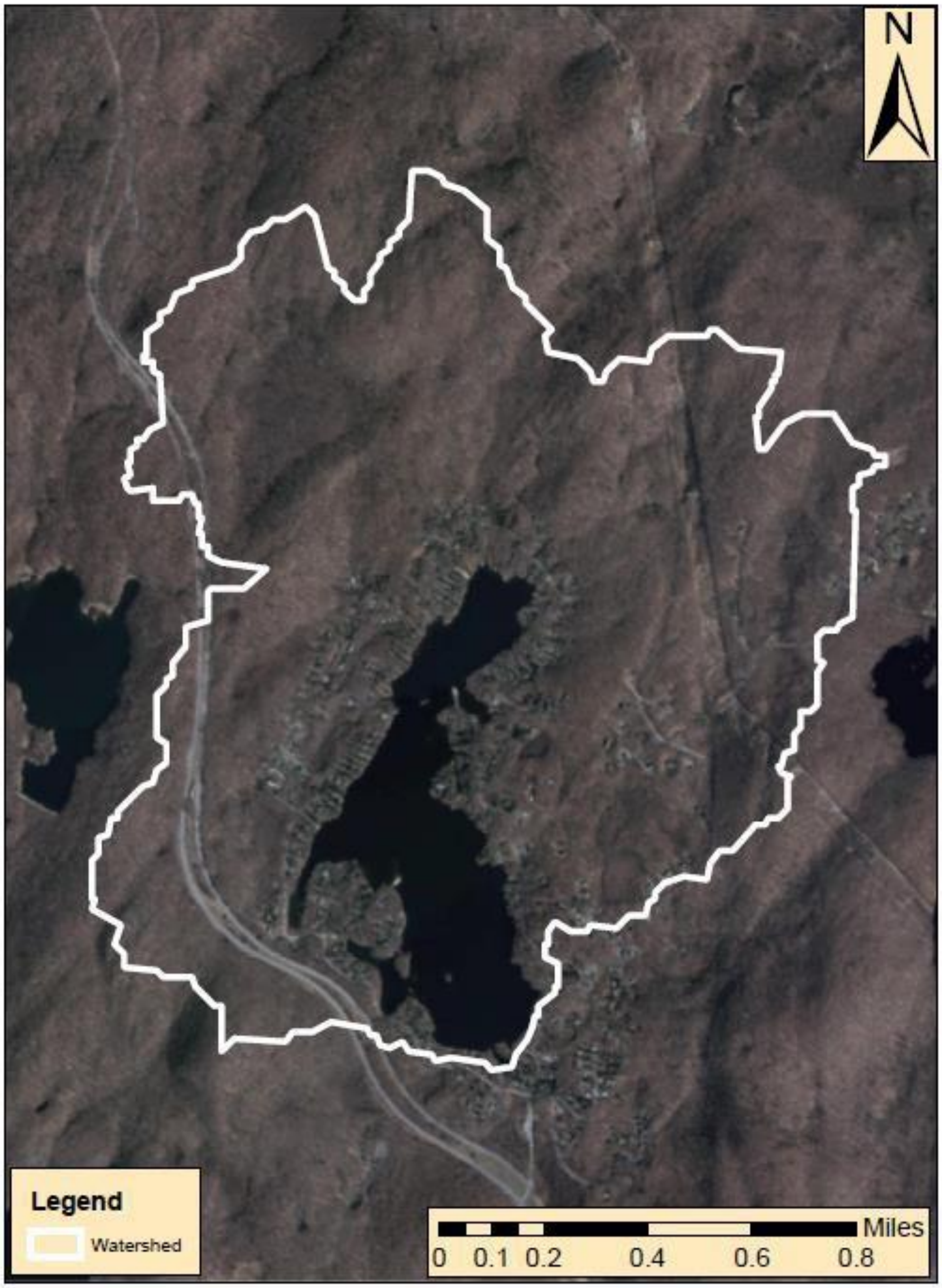
Tilzer, M.M. 1988. Secchi disk — chlorophyll relationships in a lake with highly variable phytoplankton biomass. *Hydrobiologia* **162,** 163–171

Welch, E.B. and Cooke, G.D., 1999. Effectiveness and longevity of phosphorus inactivation with alum. *Lake and Reservoir management*, *15*(1), pp.5-27.

Wittman ME, Chandra S, Reuter JE, Schladow SG, Allen BC, Webb KJ. 2012.The control of an invasive bivalve, *Corbicula fluminea*,using gas impermeable benthic barriers in a large natural lake. Environ. Manage.49:1163–1173.

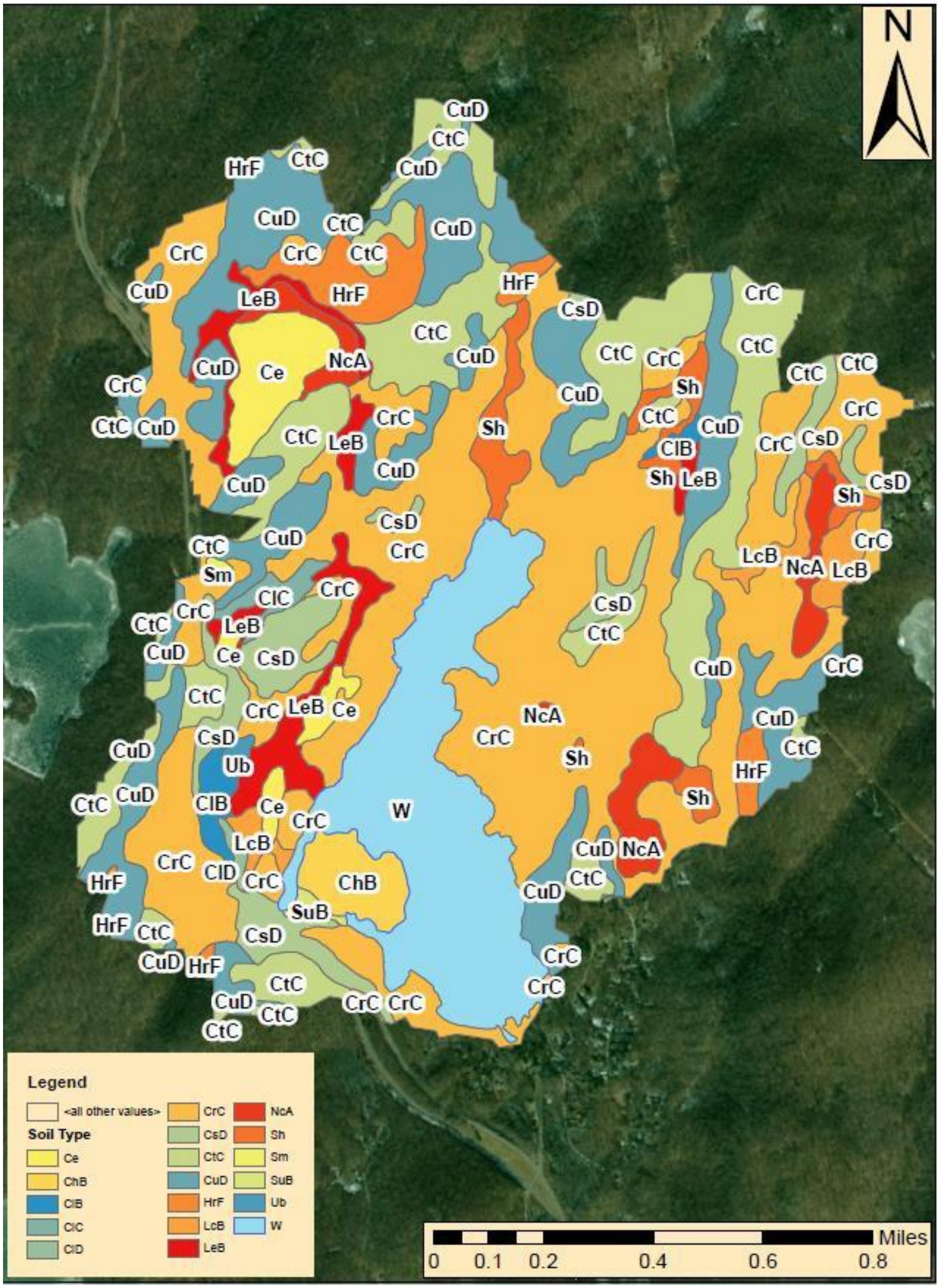
Appendix A: Supplemental Watershed Information

Roaring Brook Watershed Map



Roaring Brook Soils Map

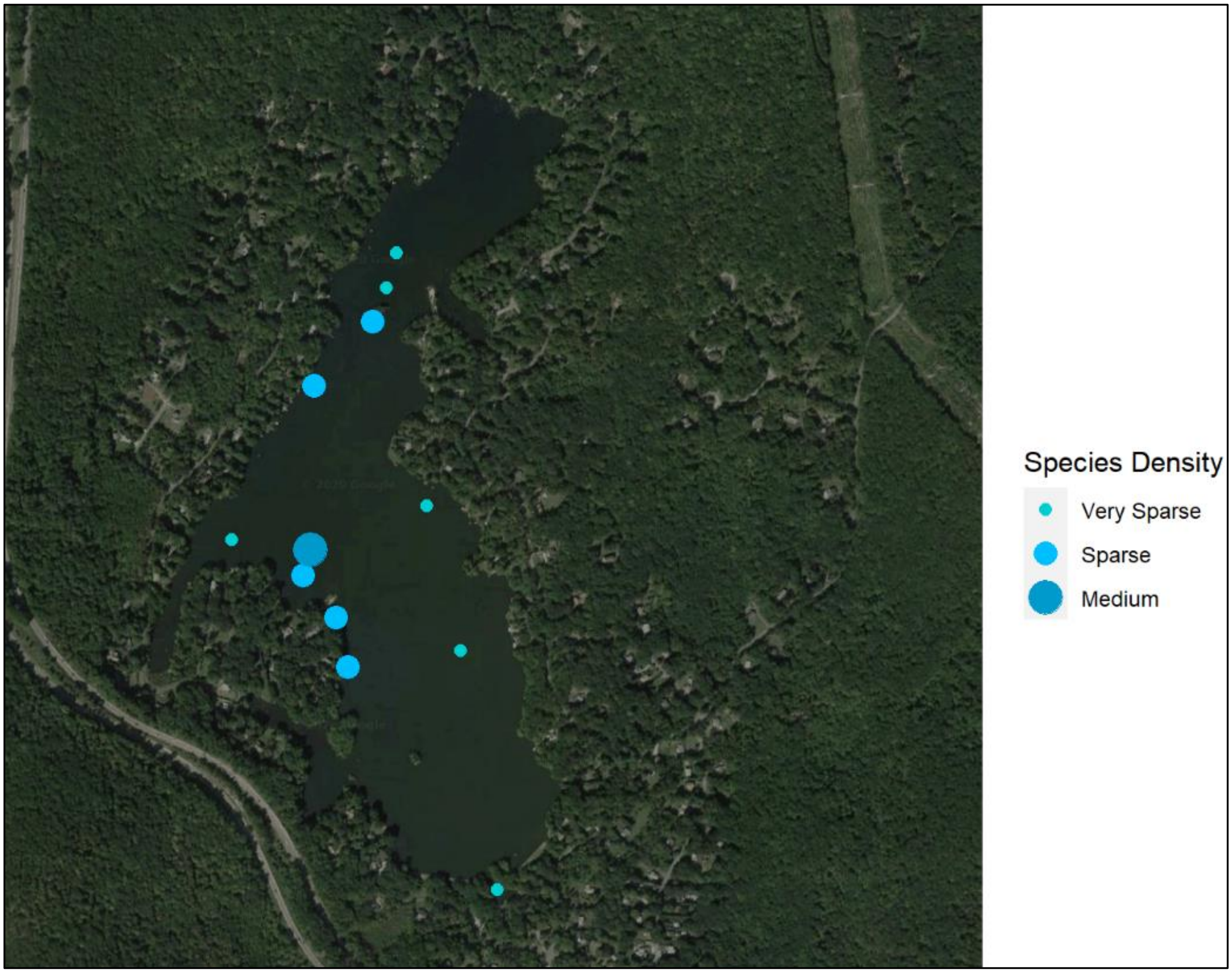
(See table on next page for abbreviation descriptions)



Map Unit Symbol	Map Unit Name	Acres in Watershed	Percent
Ce	Catden muck, 0 to 2 percent slopes	28.7	2.70%
ChB	Charlton fine sandy loam, 3 to 8 percent slopes	16	1.50%
ClB	Charlton fine sandy loam, 3 to 8 percent slopes, very stony	8.7	0.80%
ClC	Charlton fine sandy loam, 8 to 15 percent slopes, very stony	5.9	0.60%
ClD	Charlton loam, 15 to 25 percent slopes, very stony	1.8	0.20%
CrC	Charlton-Chatfield complex, 0 to 15 percent slopes, very rocky	370.8	34.70%
CsD	Chatfield-Charlton complex, 15 to 35 percent slopes, very rocky	49.2	4.60%
CtC	Chatfield-Hollis-Rock outcrop complex, 0 to 15 percent slopes	155.2	14.50%
CuD	Chatfield-Hollis-Rock outcrop complex, 15 to 35 percent slopes	177.8	16.70%
HrF	Hollis-Rock outcrop complex, 35 to 60 percent slopes	28	2.60%
LcB	Leicester loam, 3 to 8 percent slopes, stony	15.6	1.50%
LeB	Leicester loam, 2 to 8 percent slopes, very stony	34.1	3.20%
NcA	Natchaug muck, 0 to 2 percent slopes	28.1	2.60%
Sh	Sun loam	25.5	2.40%
Sm	Sun loam, extremely stony	1.2	0.10%
SuB	Sutton loam, 3 to 8 percent slopes	1.9	0.20%
Ub	Udorthents, smoothed	1.6	0.20%
W	Water	117.5	11.00%
Totals for Watershed		**1,067.50**	**100%**

Appendix B: Supplemental Plant Maps

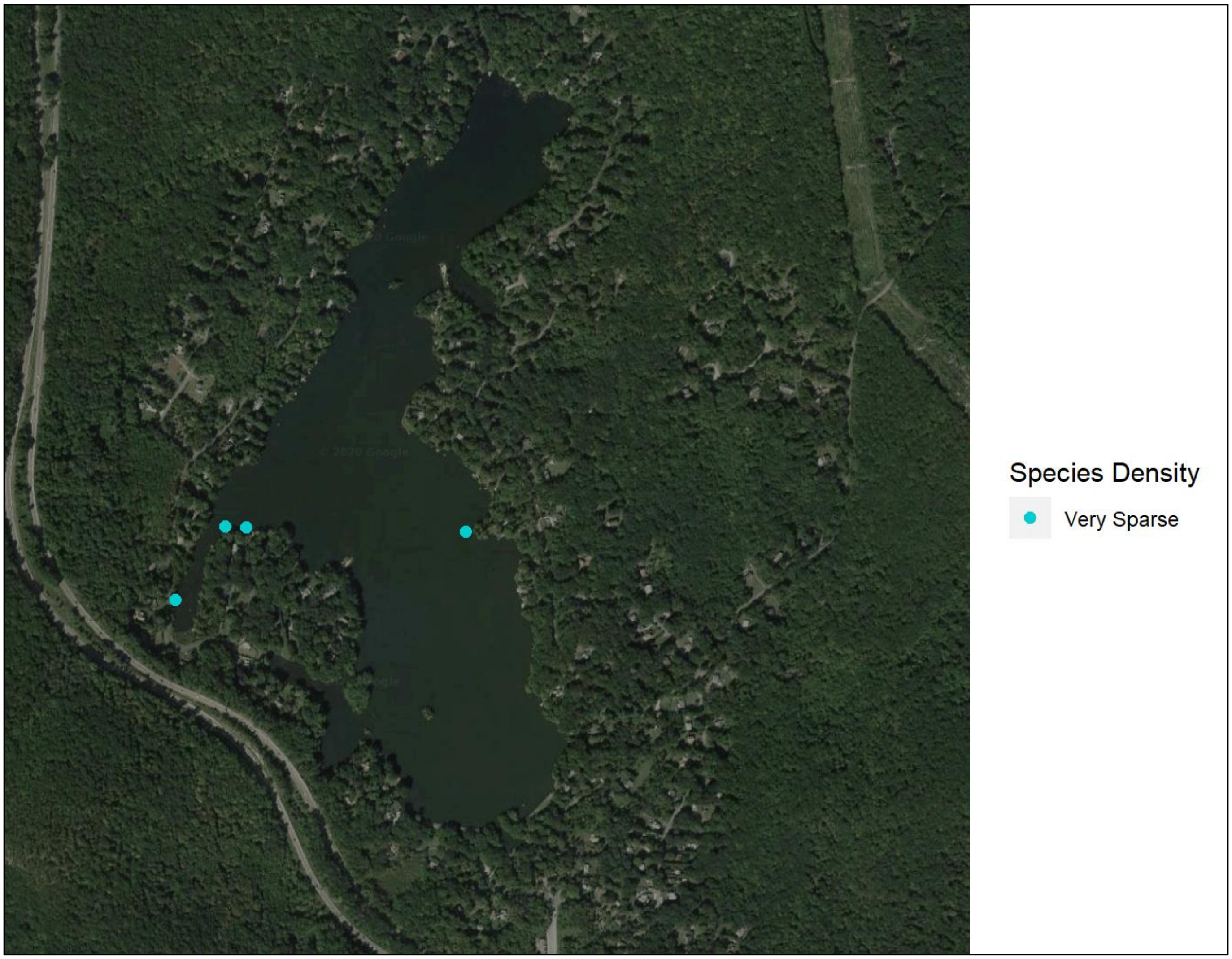
Coontail (*Ceratophyllum demersum*)



Largeleaf Pondweed (*Potamogeton amplifolius*)

Minor Naiad (*Najas minor*)

Tiny Bladderwort (*Utricularia gibba*)



Appendix C: Additional Aquatic Plant Management Options

Suction Harvesting

One of the more common hand-harvesting techniques is diver assisted suction harvesting (DASH). With DASH, divers hand-pull aquatic plants, including the root system, then insert the plants into a suction hose suspended above the lake bottom. The hose then pulls the plants up to a catchment area on a boat (Eichler et al. 1993). Suction hoses allow divers to spend less time traveling to and from the boat with traditional dive bags filled with plants. The hose also pulls away some of the sediment that is disturbed during the hand-removal process, making it easier for divers to continue working in an area because visibility is not completely obstructed. The main advantage of this aquatic plant management technique is its selectiveness, as divers can target small invasive plant clumps, resulting in less collateral damage to native plants in the same area.

Suction harvesting can be used around docks and swim areas to control localized areas of aquatic plant growth. This technique can be cost-intensive, costing around $2,000 per day for covering around 0.2 to 0.5 acres per day.

Benthic Barriers

Benthic barriers are mats that prevent plant growth by blocking out light (Wittmann et al. 2012). Barriers are most often used around docks, in swimming areas, or to open and maintain boat-access channels (NYSFOLA 2009). A permit is required in New York State to install benthic barriers. The advantage of using benthic barriers is that they can be installed from the shore in shallow water, particularly in those areas of recreational activities. However, in waters deeper than six feet, divers are needed, which increases labor costs. Costs of material and labor vary depending on screening material and whether the application involves an initial or repeat installation (NYSFOLA 2009).

Barriers are most effective when installed early in the growing season and maintenance is critical to minimize plant regrowth due to sediment or silt deposits on top of the mats (CT DEP 1996). Benthic barriers require a relatively flat bottom with no obstructions such as rocks or stumps for best results. There are many types of benthic barriers; most are comprised of synthetic fabrics like polypropylene, polyethylene terephthalate (PET), Typar, Hypalon, or polyvinyl chloride (PVC) coated fiberglass, (Wittmann et al. 2012). Most barriers used in macrophyte control are made of gas-permeable materials to prevent the buildup of decomposition gases underneath the barriers. Barriers that are not permeable or properly vented cause billowing and may rise to the surface negating its use.

Barriers, like suction harvesting, can be used in areas like swim beaches or docks. If done in shallow water and on a small-scale using volunteers, they can be relatively inexpensive. Larger areas in deeper water require professional divers, which significantly increases the cost. Some of the cove areas or gradually sloped swim areas are great candidates for benthic barrier installation, provided maintenance is performed regularly.

Chemical Methods

Chemical management involves the use of EPA-registered aquatic herbicides to control invasive and/or nuisance aquatic plants. Herbicides must be applied by licensed applicators and permits must be issued before a treatment can be conducted. There are currently 15 registered active ingredients approved for use in aquatic areas. Each of them has its strengths and weaknesses in terms of effectiveness, selectivity, potential non-target impacts, etc. If applied correctly, some herbicides can provide multiple years of control. There are two main categories of aquatic herbicides, based on the chemical activity on the plant:

Contact Herbicides

- Generally only affect the area of the plant where the chemical is applied
- Not formulated to kill plant root systems
- Regrowth in following seasons can be expected

Systemic Herbicides

- Affect the plant’s metabolic or growing processes
- Products move through plant tissues to affect the entire plant
- Longer control times and better chances of eradication.

Effective herbicide treatment planning lies in public education and outreach. Herbicides are a controversial topic for many people, and there are stories in the news concerning their use and misuse. While safety and precaution are necessary for any herbicide treatment, there are a few things to keep in mind when evaluating these techniques. Primarily, herbicide use is the most regulated plant management technique available. Products are not allowed to be sold in the US unless they go through a multi-year, stringent EPA-review process, and are subject to follow up reviews in subsequent years. The product then goes through a secondary review by the NYSDEC. Even then, herbicides can only be applied in NY by certified pesticide applicators with significant training approved by the NYSDEC. There is more scientific peer-reviewed literature on herbicide uses in the US than there is on any other aquatic plant management technique combined. This base of literature means there is a much better understanding of how these products work and how to safely apply them than any other management technique available today. Based on the scientific literature and registration process, these listed herbicides were determined to be safe and effective.

Costs of herbicides are based on a variety of factors such as treatment area and volume, product, formulation, and permitting. Usually, there is a base cost associated with permitting, herbicide treatment equipment mobilization, and required public notifications. Base costs vary from ~$600 to

$1,200 per acre, with herbicide product and application costs varying from ~$200 to $900 per acre.

We currently do not think herbicides are an appropriate technique for roaring brook, but due to the presence of Fanwort, an extremely aggressive invasive species, they are worth mentioning. Fanwort is poorly controlled by suction harvesting due to its extensive root system and it is currently unknown how preferable a food item they are for grass carp. Our group manages a few lakes with fanwort infestations in CT and herbicide management has been the most effective control.

Additional Grass Carp Stocking

Supplementing the population with additional grass carp can help keep a lid on the aquatic plant growth, but stocking the right amount is key. De-vegetating a lake, as discussed before is not a desirable outcome for lake ecology and should be avoided. Therefore, a conservative stocking number should be used If a grass carp stocking is a technique to be chosen. NYSDEC regional fisheries biologists will have the final say on the maximum amount of grass carp that can be added to a lake but starting conservatively is a safe approach. After the fish are stocked, 3-4 years should be given to properly monitor the aquatic plant community. If at that time, there has either been no change in the plants, or if there is an increase in plant height or palatable species, then an additional stocking can be warranted.