Background

Lake Quinsigamond is a naturally formed, 4 mile long, 475 acre lake nestled between eastern Worcester and western Shrewsbury, with Grafton to the south. It empties into Flint Pond to the south and later into the Quinsigamond River, ultimately joining the Blackstone River. Lake Quinsigamond and Flint Pond are generally managed as one system, given the direct flow between them. The waterbody has a maximum depth of 85 feet, and a water residence time of about 6 months. There are about 7 major tributaries that feed the lake from both the Worcester and Shrewsbury side. The Lake is spanned by three major roadways, Interstate 290, Route 9 and Route 20.

Lake Quinsigamond is a major recreational asset, hosting rowing, swimming, fishing, water skiing, jet skiing, and other motorized and non-motorized boating. The Massachusetts Department of Conservation and Recreation (DCR) manages two parks with bathing beaches on the Worcester side of the lake, and the Town of Shrewsbury manages a boat ramp on the eastern shore. Management of the lake is shared by the City of Worcester, the Town of Shrewsbury, the Town of Grafton, and the Lake Quinsigamond Commission. The lake is considered a great pond, meaning that it is bigger than 10 acres in its natural state, and within the jurisdiction of Chapter 91.

Water Quality Summary

Lake Quinsigamond has been listed on the Massachusetts 2016 Integrated List of Waters for the following impairments: non-native aquatic plants, *Enterococcus* bacteria, excess algal growth, and low dissolved oxygen. It received a Total Maximum Daily Load (TMDL), or a “nutrient budget”, in 2002 for phosphorus. At that time, it was suggested that management plans be created to achieve 200 day’s supply of oxygen in the hypolimnion (lower, colder layer) during the summer months. The TMDL also identified Flint Pond as having an impairment for turbidity, because it had an average Secchi transparency of below 4 feet, which is both an ecological health and human recreational safety concern.

The Lakes and Ponds Program began regular monitoring of the lake in 2017 to collect data on nutrients, bacteria, and cyanobacteria, which have also been identified as threats to lake health. Over the years, the program has given water quality at Lake Quinsigamond a rating of “good”, up through 2020.

That year, there were no concerns about industrial or emerging contaminants, and cyanobacteria did not seem to be a concern in the summer months, even though blooms were present under the ice and in the winter. In 2020, Lake Quinsigamond had challenges with fecal bacteria causing high numbers of beach closures, especially at Regatta Point. An invasive mollusk has been identified in the lake, *Corbicula Fluminia*, but the extent of the infestation and how it is affecting recreation and ecology is still unknown. In 2021, a new invasive aquatic plant was identified in the lake and there are currently 7 invasive aquatic plants present that were managed by the Lake Quinsigamond Commission, with support of the Lakes and Ponds Program.

Management Summary

The Lake Quinsigamond Commission began to implement an invasive aquatic plant management plan in 2018 in order to reduce the density of five invasive aquatic plants that were identified by a survey that year. Being such a large lake, the work is ongoing, though extensive progress has been made. The Worcester Lakes and Ponds Program began regular monitoring of the lake in 2017 to collect data on nutrients, bacteria, and cyanobacteria, which have also been identified as threats to lake health.

Sampling Analysis and Overview

Lake Quinsigamond was visited semimonthly from May through November and sampled at seven locations: The major aboveground tributaries, Coal Mine Brook and Poor Farm Brook in Worcester, and Billings Brook in Shrewsbury; the two deepest parts of the lake (the northern site is about 90 feet deep and the southern site is about 75 feet deep); and the outlet at the Irish Dam located in the southern part of the lake in Grafton (see *Figure A*). In-lake sampling sites were sampled at the surface of the water, as well as 2 feet from the bottom of the lake. Parameters evaluated included: Secchi transparency, temperature, dissolved oxygen, pH, total phosphorus, total dissolved phosphorus, *E. coli*, and litter. Total suspended solids, ammonia, and nitrate were sampled monthly, and lake profiles were performed for temperature, pH, and dissolved oxygen. Altogether, there were about 12 sampling events. All routine sampling events were split between two consecutive days. Seven of the days were considered wet-weather events, meaning that there were more than 0.1 inches of rain in the 24 hours prior to sampling. These events included 4/26 (1.1 inches of rain), 6/5 (0.26 inches), 6/19 (1.04 inches), 7/24 (0.26 inches), 9/11 (1.75 inches), 9/25 (1.5 inches), and 11/6 (0.9 inches).

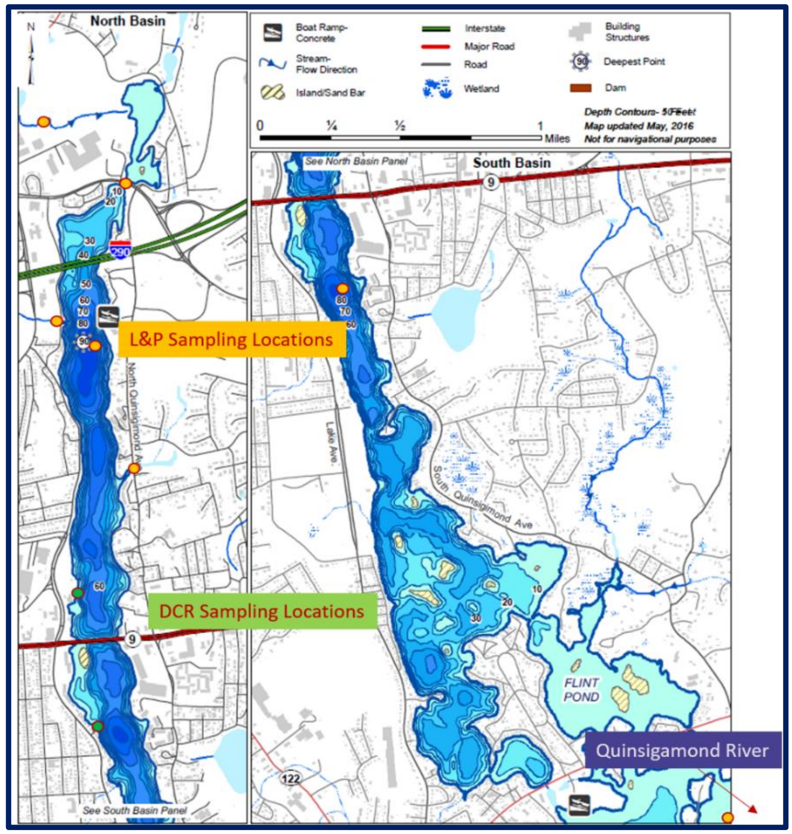


Figure A *– Lake Quinsigamond map and approximate sampling locations*

In addition, the Massachusetts Department of Conservation and Recreation tested the two beach areas for *Enterococcus* as an indicator of fecal bacteria on a weekly or twice-weekly basis during the summer months. Volunteers from the Worcester Cyanobacteria Monitoring Collaborative took samples for phycocyanin and particle counts monthly on 5/22, 6/19, 8/21, 9/25 and 10/26.

Raw data are displayed and explained below. No statistical analysis has been performed. Subsequent ratings of “excellent”, “good”, “fair”, and “poor” for reported values are based on the Massachusetts Department of Environmental Protections SMART Monitoring Watershed Report Card Criteria. While the report will refer to previous data collected by the program, one must be cautious in comparing data sets of this nature over relatively short time period.

Quality Assurance/Quality Control

To have confidence that the data that were collected are representative of local conditions, Quality Assurance/Quality Control (QAQC) checks were employed along at all steps of the sampling and analysis process to verify the validity of the data. Duplicate samples, or two measurements or samples taken in a row, were compared to ensure precision. Matrix spikes compared results to known benchmarks to ensure they were close to their true value. Blanks were samples of pure water that were submitted as samples to the lab to test the equipment, technique, and the lab analysis. All checks were carried out randomly to ensure that each parameter received robust review. When data failed to meet acceptable criteria for these checks, they were either flagged as being slightly less robust or censored entirely. Flagged data points are marked with a red flag and censored data are not included in this report (see *Figure B*).

Fecal Bacteria

Recreational contact with water contaminated by bacteria may make people ill. *Enterococcus* is a type of bacteria found in the digestive tract of warm-blooded animals, including humans. While most strains are harmless, some can make you very sick. These bacteria can come from pet and goose waste running into the water, from human waste, illicit sewer connections to the storm water

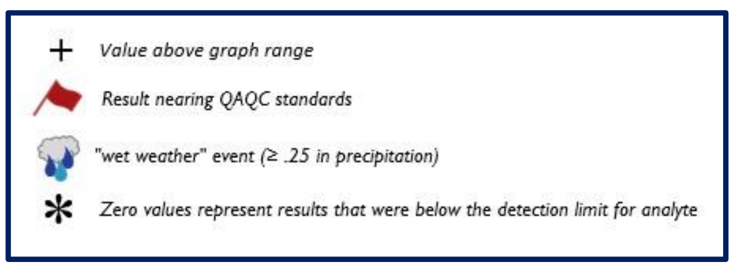


Figure B - Data points with QAQC abnormalities or other notable attributes are marked on figures.

system, or from leaking septic tanks, and improper application of manure on land. The Commonwealth of Massachusetts has strict water quality standards for public bathing beaches, and the Department of Conservation and Recreation tests the water for *Enterococcusi* on a weekly basis during the summer months. If the readings are too high, the State is required to close the beach until they return to safe levels. The Lakes and Ponds Program also samples for *E. coli,* another fecal bacteria indicator, semimonthly at one in-lake site to understand it's prevalence in the middle of the lake. Samples are collected from the water's surface and sent to an external lab for analysis.

Bacteria at Lake Quinsigamond. Lake Quinsigamond has had inconsistent results from year to year when it comes fecal bacteria and beach closures at its two beaches, Lake Park and Regatta Point. 2019 saw very few beach closures, while 2020 had 8 days of closures at Lake Park and 40 at Regatta Point. 2021 had slightly fewer closures, with a total of 6 days of closures at Lake Park and 35 at Regatta Point. None of the exceedances occurred on wet weather days, although there were several smaller rainfall events in the timeframe of the closures.

Fecal bacteria exceedances are often localized and can pose a recreational risk in some places while others are unaffected. Along with DCR's beach testing, the Lakes and Ponds Program conducted open water sampling for *E. coli* at the northern in-lake site. All but two results were in the "excellent" category with the others rating "good". The Lake Quinsigamond Watershed Association (LQWA) tested

***Beach Enterococci* Bacteria Results**

Table 1 – (above) In 2021, the beach at Regatta Point was closed for 35 days due to fecal bacteria exceedances. The beach at Lake Park was closed for 6 days.

Table 2 – (right) *E. coli* results from open water sampling were consistently in the "excellent" and "good' categories and never approached the recreational threshold.

OPEN WATER E.COLI	
26-May	30.5
9-Jun	5.2
24-Jun	4.1
14-Jul	14.8
27-Jul	13.5
11-Aug	8.6
25-Aug	37.9
15-Sep	4.1
29-Sep	18.5
13-Oct	4.1
22-Nov	2.0

Excellent	*Good*
Fair	*Poor*
Results in colonies/100 ml	

13 locations on the lake, including many tributaries, for *E. coli* bacteria over 10 sampling events in 2021. While there were several areas around the lake that had inconsistent and consistent exceedances in the recreational threshold, generally near stormwater inflows, mid-lake results generally supported Lakes and Ponds Program results. Data for this project can be found on LQWA.org. All results suggest that while there seems to be sources of bacteria coming from the outside of the lake, they are not surviving very long by the time they enter the water.

Water Clarity

Water clarity, or the level of transparency of water, is an important measure of water quality. Algae, microscopic organisms, eroded particles, and re-suspended bottom sediments are factors that interfere with light penetration and reduce water transparency. Water clarity is important for several reasons in a lake. Clear water allows light to penetrate to greater depths and encourages the growth of aquatic plants, which provide food, shelter, and oxygen to aquatic organisms. Turbid water, or water filled with particles, will warm up faster as it absorbs heat from sunlight. This causes oxygen concentrations to fall because warm water can hold less oxygen than cool water. Finally, clear waters are pleasant to the eye, and safer for recreational contact. Water clarity can be measured with a Secchi disk or by quantifying total suspended solids (TSS). A Secchi disk is a weighted black and white disk on a calibrated line that is lowered into the water until it is no longer visible. Secchi readings are collected on each lake visit. TSS is a measure of the dry weight of suspended particles in a given amount of water. TSS samples are taken on a monthly basis and submitted to a lab for analysis.

Water Clarity at Lake Quinsigamond. Secchi clarity is generally high at Lake Quinsigamond. It was over 10 feet, or in the "good" category, at both sites in the beginning of the 2021 sampling season. Readings decreased into the "fair" category during the mid-summer months, and while they increased again in the northern portion of the lake, they did not in the southern portion (see *Figure C*). These results suggest that there are distinct dynamics in each of the basins of the lake, and on average, water clarity was lower throughout the lake in 2021 than in 2020.

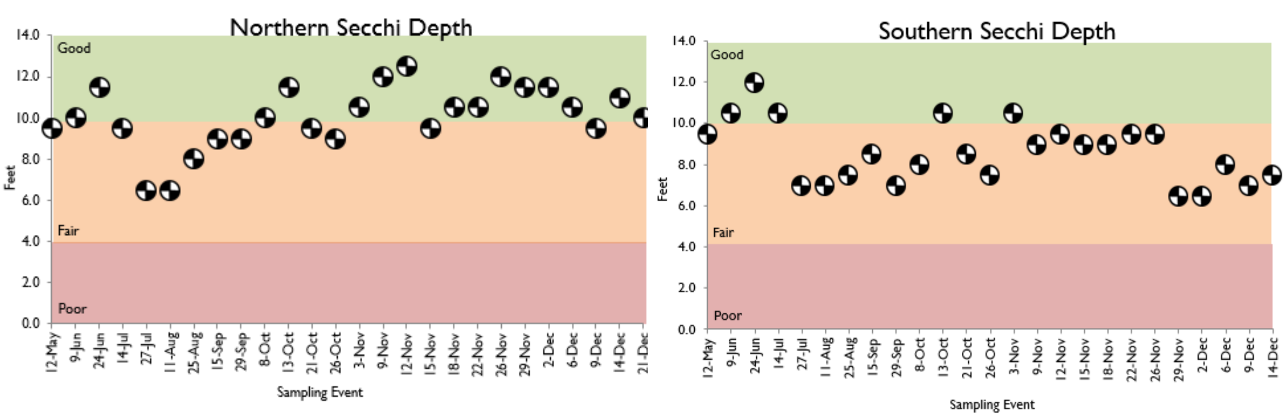


Figure C – Clarity was in the "fair" to "good" range in both sites, but generally lower at the southern site than the northern site for most of the season.

Temperature and Stratification

Water temperature is important to both the biological activity and water chemistry in a lake. Organisms tend to live in a preferred band of temperatures, and when temperatures are too cold or warm, they may experience stress. Water temperature affects the speed of chemical reactions in addition to how much oxygen can be held in the water. The extent to which water circulates through a lake affects the ability of that water to support aquatic life by mixing oxygen and nutrients up and down the water column. Because the density of water changes with temperature, variations in temperature can cause cold water to settle in a layer on the bottom while warm water stays on top, resulting in stratification. While a natural process, stratification can create a physical barrier that prevents the replenishing of oxygen on the bottom layers of the lake, and the rise of sediment nutrients to the top. Lake Quinsigamond is home to cold water fish species including trout, stocked by MassWildlife in the spring and fall. These fish are sensitive to a number of factors related to stratification, such as elevated temperatures and low dissolved oxygen (DO). To understand whether stratification is occurring, depth profiles are measured in which temperature, and DO readings are taken at 5 foot increments throughout the water column.

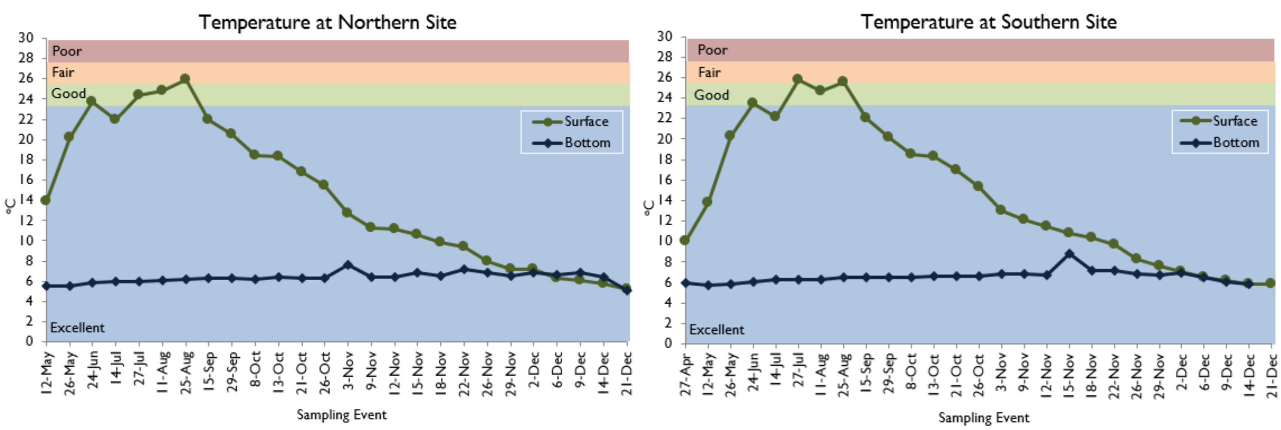


***Figure D** –Temperature at the bottom at Lake Quinsigamond was consistently around 6°C, while the surface temperatures peaked at 25.8°C.*

Temperature and Stratification at Lake Quinsigamond. Surface temperatures at the northern and southern sampling sites were in the "excellent" category for most of the season apart from the summer months from mid-June to mid-August, when temperature increased into the “good” category, and on at least one occasion at each site into the “fair” category. Throughout the entire season, the temperature at the bottom of the lake was rated as “excellent”.

To determine the extent of the warming throughout the entire water column, depth profiles were taken at each site (see *Appendix A and B*). During the season’s first readings in April, the temperature difference was relatively small between the surface and bottom of the lake, only 4.1 ºC. As the surface of the water warmed in May, the water below the surface also began to warm and float on the denser, colder water below, creating what is known as a thermocline, and preventing the mixing of oxygen to the water at the bottom. As temperature increased at the surface to levels that are considered stressful to fish, the colder water below became more devoid of oxygen. This pattern continued through September. From early

October through late November, as the surface temperature dropped, and the thermocline became less severe. Temperature was uniform again in the water column again in December.

Dissolved Oxygen

Oxygen in the water is essential to aquatic life, just like it is for life on land. Because algae, plants, fish, and other aquatic organisms require a certain amount of oxygen to survive, dissolved oxygen (DO) is an important indicator of water quality. It is a highly variable parameter with daily and seasonal variation. DO concentrations can be affected by temperature, pressure, aeration, diffusion, decomposition, rate of photosynthesis, and respiration by aquatic life. Lakes experiencing nutrient loading can suffer from low DO due to increased algal growth and excessive decomposition of organic material. This can lead to fish kills and other ecological issues. DO is measured using a galvanic DO sensor on a handheld probe at the water's surface, two feet from the bottom during routine sampling and at 5 foot increments when depth profiles are being taken.

Dissolved Oxygen at Lake Quinsigamond. Surface DO was rated "excellent" all season at the northern and southern sites. At the very bottom of the lake, DO was almost 0 mg/l, or anoxic, for the middle portion of the season (see *Figure E*). Due to increased mixing related to lake thermal dynamics in the winter months, DO at the bottom returned to the "excellent" category in early December in both locations, though the exact date of this return was different at each site.

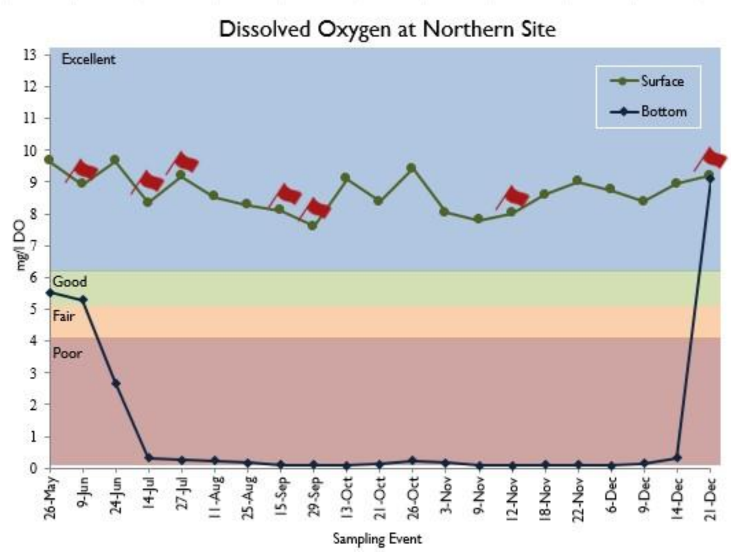


Figure E – Surface DO stayed in the "excellent" category all season in the northern and southern sites. At the bottom of the lake, DO dropped to almost 0 mg/l between July and December.

In order to determine at what depth in the water column oxygen depletion occurs, DO readings were taken at 5 foot intervals and plotted with temperature (see *Appendix A and B*). At the beginning of the season, the entire water column was uniformly oxygenated. In late June, DO at the bottom of the lake began to decrease, and the depth of this decrease became shallower as the season went on, even as the surface of the water had sufficient oxygen for fish and wildlife. The band between oxygen rich and oxygen poor waters sometimes occured in less than 5 feet. As thermal stratification decreased in the fall, oxygen stratification also subsided, until the entire water column was fully oxygenated once again. Full mixing of the lake was noticed first in the shallower southern site on December 6th and later at the northern site on December 21st.

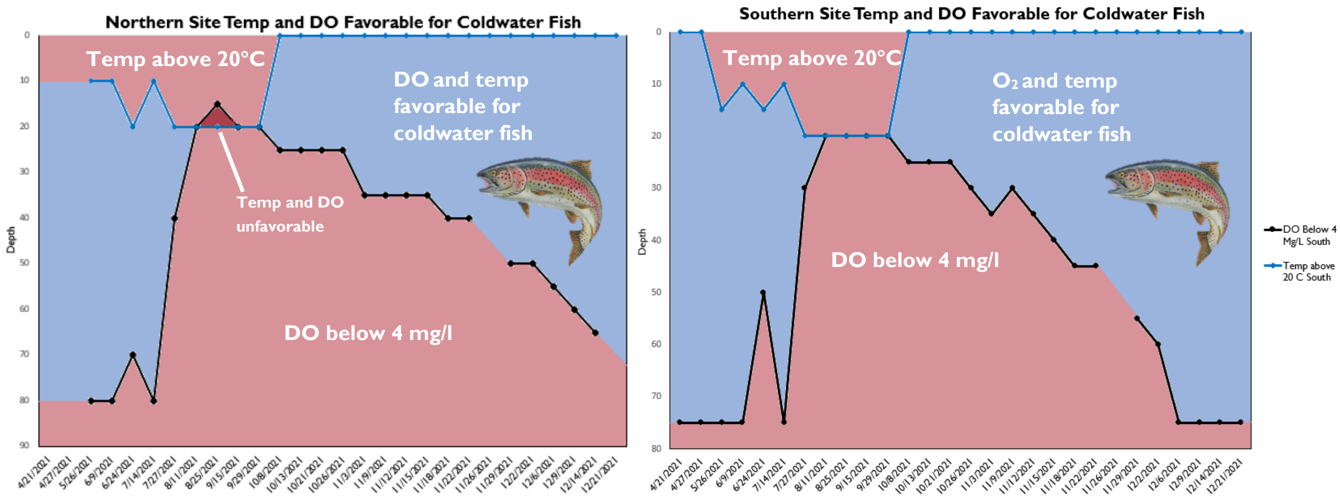


Figure F – Over the course of the season, coldwater fish experienced pressure at the top and bottom portions of the water column due to elevated temperature and reduced DO. In both sites, fish experiences pressure from both low oxygen and high temperature conditions in late July and August.

Coldwater fish species such as trout have a narrower band of tolerance for temperature and DO conditions than warmwater species, preferring a water temperature below 20°C and a DO above 4 mg/l. The depth profile results were used to determine the portion of the water column that met these specifications during each sampling event (see *Figure F*). The northern and southern sites showed similar trends in the summer months, with temperatures increasing above 20°C near the water's surface and DO decreasing below 4 mg/l near the lake bottom, resulting in a condition known as "the squeeze", creating a situation where the risk of a fish kill is elevated. During the first two sampling events in April, the entire water column was habitable for cold water fish, in terms of both temperature and DO. At the beginning of May, however, the surface temperature began to rise above 20°C until the beginning of August when the first 20 feet of water from the surface down were above this threshold. In June, DO concentrations on the bottom began to decrease below 4 mg/L. This threshold became shallower in the northern site in the water column until 8/25, when all water below 15 feet of depth from the surface was considered uninhabitable. At both sites, the period between 8/10 and 10/8 therefore had unfavorable conditions for coldwater fish from both the surface and the bottom. After this period, the surface temperature decreased and the DO threshold began to descend in the water column until the entire water column was once again habitable at the end of the sampling season. Thankfully, even with this theoretically stressful situation, no fish kills were noted on Lake Quinsigamond in 2021.

pH

pH is a measure of the number of hydrogen ions (H^+) in a substance. The more H^+ that are present, the more acidic the solution. On a scale of 0-14 units, 7 is a neutral pH. As you increase from 7, the solution is more basic, and as you decrease, it becomes more acidic. In waterbodies, pH can change due to respiration and photosynthesis by aquatic organisms. A pH that is too high or low can have implications on the health of aquatic organisms. However, a high pH can also promote chemical reactions that release phosphorus from lake sediments. Like DO, pH can vary throughout the day and season. Healthy lakes in this area have a pH between 6.5 and 8.5. A low pH can be the result of external forces like acid rain. pH is monitored using an ion-selective electrode (ISE) pH sensor on a handheld monitoring probe. These readings are taken at the water's surface and two feet from the bottom.

pH at Lake Quinsigamond. pH at Lake Quinsigamond ranged between 6.6 and 8.2. Readings were consistently higher at the surface than the bottom at both the northern and southern sites. At both locations, the maximum surface pH was 8, first occuring in late July and again in late October. Higher pH readings coincided with periods of lower water clarity. While pH at Lake Quinsigamond remained in a healthy range, the changes in pH around times of reduced clarity signal conditions favorable for harmful algal blooms.

Nutrients

Nutrients, primarily nitrogen (N) and phosphorus (P), are food sources for aquatic plants and algae. Although aquatic plants and algae are the basis of the food chain, and necessary for a healthy lake ecosystem, an overabundance of either nutrient can lead to issues such as harmful algal blooms and excessive plant growth. Overgrowth of these organisms can lead to conditions where oxygen is depleted in the water column, potentially causing fish kills. These nutrients have many known sources in urban lakes including fertilizers, pet and goose waste, illicit sewer connections, and runoff that washes over land and into the storm sewer system. Additionally, under the right conditions, P can be released from the sediments at the bottom of the lake, becoming more available for uptake by organisms. Nutrients are measured in the lakes by collecting samples and submitting them to an external lab for analysis. N takes several forms in

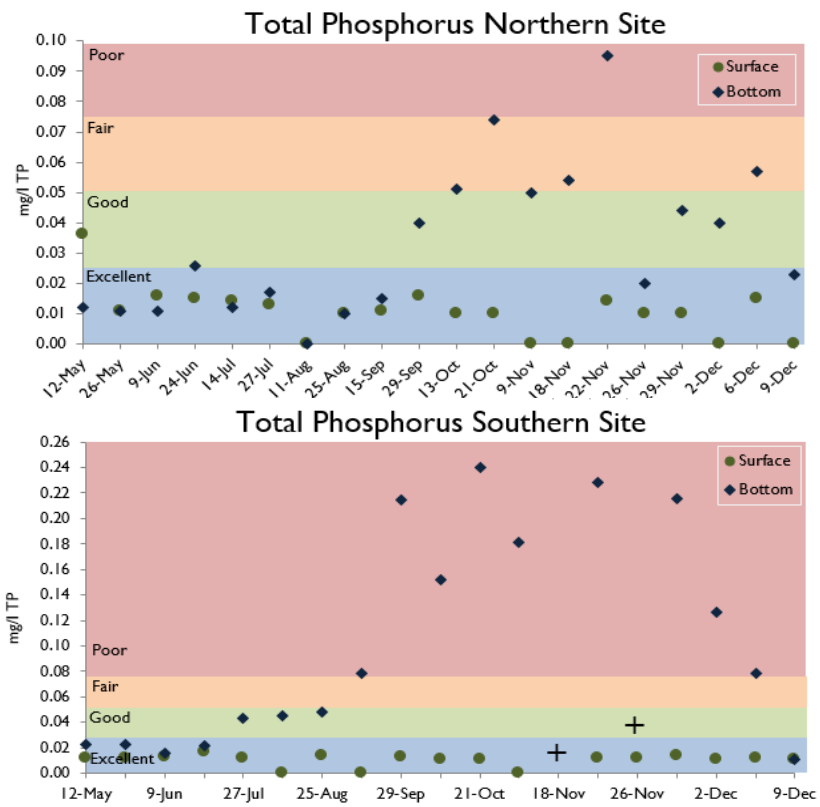


Figure G – Surface TP stayed in the "excellent" category almost all season at both sites. On the bottom of the lake, TP increased as the season went on, especially in the southern sampling site.

water bodies. To measure nitrogen, samples are collected for NO_3 and NH_3 at all sites monthly. For phosphorus, samples are collected bi-weekly for total phosphorus (TP) at all sites and total dissolved phosphorus (TDP) at all deep sites.

Nutrients at Lake Quinsigamond. Generally, surface TP readings were low, ranking in the "excellent" category all season at the northern and southern sites (see *Figure G*). At the bottom, both sites started out the year in the "excellent" category and started to rise as the season went on. At the northern site, bottom TP increased into "good" in late September and continued to rise into "fair" and "poor" through late November. The accumulation of TP at the bottom was especially severe in the southern site, where the TP concentration was measured as high as 0.43 mg/l on a November sampling date.

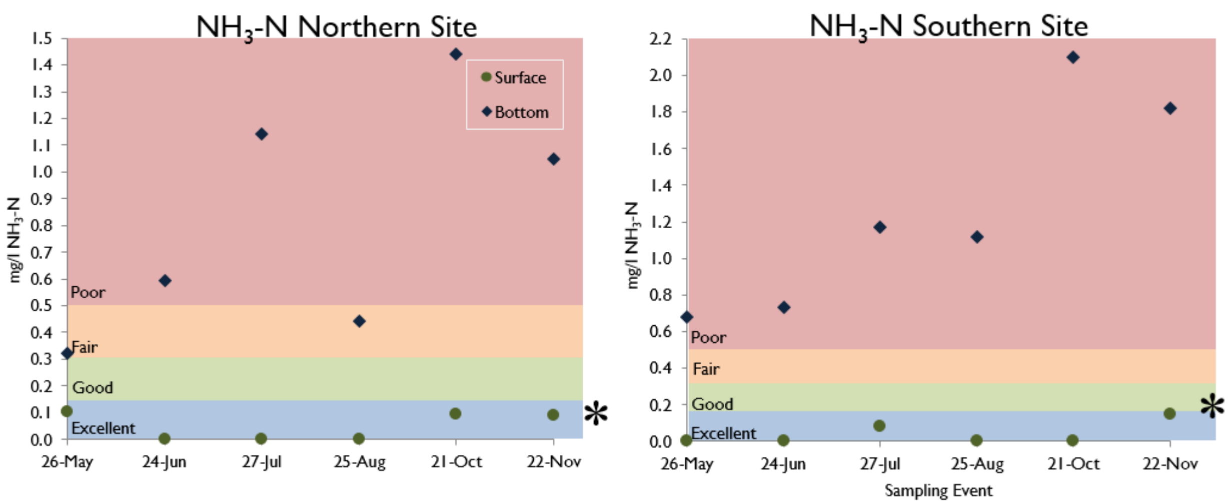


Figure H – Surface NH_3 stayed in the "excellent" category all season at both sites. On the bottom, NH_3 was consistently "poor" and "fair".

At the surface, NH_3 was also low, with readings in the "excellent" range at both sites for almost the entire season (see *Figure H*). Similar to TP, however, on the bottom, NH_3 results were much higher, generally in the "poor" category all season at both sites. As the season went on, NH_3 concentration continued to increase on the bottom, especially in the southern site, with a reading as high as 2.1 mg/l in October. This trend is common for deep lakes that experience stratification as anoxic conditions at the bottom do not allow for microbes to process nutrients and make them available for use by primary producers.

Cyanobacteria

Cyanobacteria are naturally occurring microorganisms in aquatic ecosystems. They are bacteria that use sunlight, N, and P in a similar way to algae. While they are present in small numbers in healthy ecosystems, under warm, high-nutrient conditions they can reproduce quickly, causing a bloom. Cyanobacteria blooms, in addition to being unsightly and smelly, can cause low oxygen conditions that are harmful to aquatic life. Cyanobacteria can also produce toxins that are harmful to humans and pets. It is therefore important to understand cyanobacteria dynamics in our lakes and ponds.

Because of this, the MA Department of Public Health has advisory thresholds for cyanobacteria, and if the density of cyanobacteria cells is too high, a waterbody must be closed for recreation. During the summer months, as the potential for blooms increases, the Lakes and Ponds Program contracts an environmental consultant to perform cell enumerations, or cell counts, of cyanobacteria to determine if there is a public health risk and inform management. Another way to quantify cyanobacteria is though the measurements of their photosynthetic pigments. Cyanobacteria and algae use the pigment chlorophyll to harness the sun's energy, converting carbon dioxide to sugars for growth and reproduction. Unlike algae, cyanobacteria also use a pigment called phycocyanin. Because of this, the concentration of phycocyanin is an indicator of cyanobacteria's relative abundance in a waterbody. This concentration can be measured using a tool called a fluorimeter. This year, samples collected by the WCMC were used to conduct fluorometry analysis and measure concentration of phycocyanin and compare them between waterbodies over the course of the sampling season.

Cyanobacteria at Lake Quinsigamond. Cyanobacteria are generally not a concern at Lake Quinsigamond, but complaints of low water clarity in the summer months prompted the Lakes and Ponds Program to take cyanobacteria cell count samples from the swimming area at Regatta Point Beach. Result indicated that cyanobacteria

Worcester Cyanobacteria Monitoring Collaborative

Photo Credit: Stephane Tam

The Worcester Cyanobacteria Monitoring Collaborative (WCMC) is a group of community science volunteers that is working to better understand the diversity and abundance of algae and cyanobacteria in local lakes and ponds. Volunteers collect data monthly between spring and fall at 22 waterbodies in and around Worcester, including Coes Reservoir. Samples are collected for pigment analysis, particle counts and qualitative analysis under a microscope. In the future, this program aims to provide robust quantitative data to local government and community members to assist in making public health and lake management decisions.

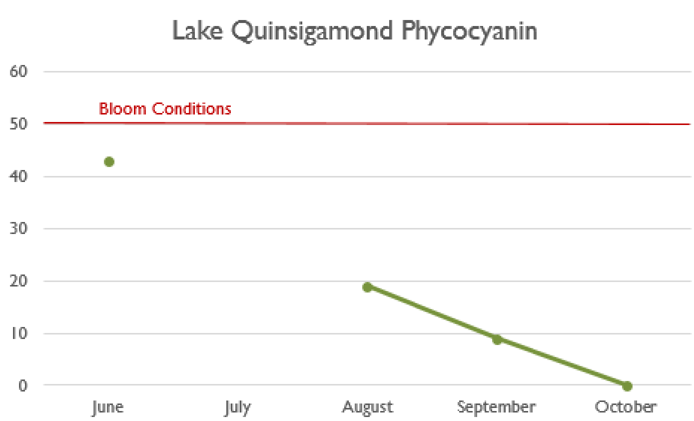


Figure I – Phycocyanin results never exceeded the level at which we would expect to see a bloom (50units). However, in the June sampling event the result was close at 43 units.

Cyanobacteria Cell Counts (cells/ml)	
16-Aug	18,944
8-Sep	16,579

Figure J – Cyanobacteria cell counts were conducted during August and September, but never resulted in concentrations exceeding the recreational threshold of 70,000 cells/ml.

were present, but neither of the two results were above the recreational threshold (see *Figure J)*. Results from WCMC pigment sampling at Regatta Point Beach did show high concentrations of phycocyanin pigment in June, but also suggested a continuous decrease in concentration throughout the year (see *Figure I*). Unfortunately, phycocyanin samples were not collected in July, so it is not possible to know if the concentration continued to climb before a lower result was reported in August. While valuable, these results they are not descriptive of the lake as whole. To fully understand cyanobacteria dynamics in Lake Quinsigamond more samples are needed at closer intervals throughout the season.

Invasive Aquatic Plants and Animals

Native aquatic plants and animals are vital parts of any lake ecosystem. Native plants provide food, shelter, and oxygen to other aquatic organisms. Their uptake of nutrients reduces the likelihood of algal blooms, and their root systems stabilize sediments. Native animals play invaluable roles in food webs and their removal can disrupt the ecology of a system. An invasive plant or animal is an organism that is not native, or did not originally come from the area. These plants and animals become nuisances when their natural constraints, such as predators or environmental limitations, do not exist in their new home, allowing them to multiply at a rapid rate. When aquatic plants and animals become too numerous, they can reduce our ability to enjoy our lakes and ponds, as well as crowd out local species. Invasive organisms can arrive by hitching a ride on boats, pets, or boots to get from place to place. Some are released with good intentions as a beautiful addition to a landscape or a sport fishing opportunity but end up causing harm to the ecosystem in which they were introduced. Professional surveys, visual inspections from Lakes and Ponds Program staff, and observations from community members are used to make management decisions. When invasive plant and animal communities become problematic, a decision is made on whether to intervene with management.

Invasive Plants and Animals at Lake* Quinsigamond*. Being such a large waterbody, it is no surprise that people come from far and wide to use Lake Quinsigamond. For that reason, it is especially vulnerable to invasive aquatic plants and animals, which can travel as hitch hikers on boats and trailers. Shell remnants of the invasive mollusk Asian clam (*Corbicula fluminea*) have been noted in and around Lake Quinsigamond for several years, especially in the northern portion of the lake. While they have not yet been impeding recreation, recent studies suggest that this mollusk could be selectively filter feeding on algae that usually compete with cyanobacteria, allowing the cyanobacteria to prosper.

Lake Quinsigamond is home to invasive plants as well. A 2018 invasive aquatic plant survey found 6 invasive aquatic plants throughout the lake, including sacred lotus (*Nelumbo nucifera*), fanwort (*Cabomba caroliniana*), variable-leaf milfoil (*Myriophyllum heterophyllum*), curly-leafed pondweed (*Potmogeton crispus*), brittle naiad (*Najas minor*) and Eurasian milfoil (*Myrophyllum spicatum*). The Lakes and Ponds Program supports the Lake Quinsigamond Commission in administrating the invasive plant management plan for the lake. Some of the challenges that they face have to do with a rare plant that has been found in the central portion of the lake, making the application of herbicides to this area difficult to permit. As the different options are being reviewed, the northern and southern portions of the lake are being treated with herbicides. In 2021, Half Moon Cove, which had been choked with Eurasian milfoil, as treated with the herbicide, Procellacor. Five acres of Flint Pond were also treated for fanwort and milfoil, though procurement challenges pushed the treatment to the end of the season. This year, the invasive water chestnut was identified at several locations throughout the lake. Because Lake Quinsigamond is so big, and because it has been so long since the last survey was conducted, it is not easy to know the extent of the spread of invasive aquatic plants. The Lakes and Ponds Program is committed to contracting a new study for invasive aquatic plants in 2022 to help guide future management.

Litter

Litter, or inappropriately disposed waste, is harmful to the ecological, aesthetic, and recreational value of lakes and ponds. Improperly discarded plastic and Styrofoam products can be mistaken as food by aquatic organisms and can kill them. Mounds of trash and rotting organic material can cause infestation by disease-carrying vermin. Additionally, it looks and can smell unpleasant to beachgoers and hikers. Finally, sharp objects like syringes, broken metal, or glass can pose a threat to swimmers and other beach visitors.

Litter is a difficult parameter to measure in a quantitative way. This year, a new method was employed to quantify litter at lake access points so its accumulation can be better understood. Originally developed by WPI students, this method records scored observations in five categories so litter can be quantitatively tracked and compared between lake access points throughout the season.

There were five categories that were used for judging "*Overall Conditions"*, including cleanup effort, atheistics, safety, litter density, and the impact on the functionality of the site. Each one of these categories receives a score from 1-5. The final score then can be between 5 (the best) and 25 (the worst). The second portion of the classification includes "*Litter Characterization"*, which compares the different classes of litter found that day, and includes things like bottles, glass, tobacco products, textiles, and other things commonly found in public spaces.

Overall Litter Conditions

Date	Clean Up Effort	At a glance	Safety	Litter Density	Impact/Functionality	Matrix Score
6/8	3	2	3	2	2	12
6/23	2	1	1	2	2	8
7/13	2	1	2	2	2	9
7/28	2	2	2	2	2	10
8/10	2	1	2	2	2	9
8/24	2	1	2	2	2	9
9/14	2	2	2	2	2	10
9/28	2	2	2	2	2	10
10/12	2	2	4	2	2	12
10/20	2	2	2	2	2	10
11/10	4	2	3	3	2	14
11/23	2	2	2	2	2	10

Table 3 – For the "Overall Litter Conditions" category, Lake Quinsigamond usually scored around 2, indicating that litter was present, but conditions were not severe.

Litter at Lake Quinsigamond. At Lake Quinsigamond, the area surrounding the Lake Park Beach was assessed using the litter tracking tool. All results for the categories “clean up effort”, “at a glance”, “safety”, “litter density”, and “impact/functionality” had an average score of around 2, indicating that litter was present, but conditions were not severe and cleanup would not be extremely difficult (see *Table 3*). There were occasional days where “clean up effort” was rated even better, bringing the average score for the season down. Of the litter categories noted, “small items”, “tobacco products”, and “food packaging and containers” scored the highest, or worst, often with a score of 3 or higher (see *Table 4*). Results in other categories were more variable than other sites, with results as high as 4 on some days and as low as 1 on other days. It was not common to see litter accumulate in the water here, potentially because the bottom is rocky and devoid of reeds for trash to get caught in. Large pieces of junk were sometimes left here by beachgoers such as a set of beach chairs and an umbrella. Overall, litter was managed well at Lake Park Beach.

Figure K – Litter at Lake Park Beach and the Irish Dam spillway.

Litter Characterization

Date	Bottles	Plastic cups	Glass	Bags	Food packaging	Tobacco products	Recreational/toys	Textiles/clothing	Junk	Small items
6/8	4	4	2	1	3	1	3	3	1	3
6/23	1	1	1	1	3	3	2	1	1	5
7/13	3	1	2	1	3	3		3	2	4
7/28	3	2	2	3	2	3	2	1	1	4
8/10	1	2	1	2	3	3	2	2	2	4
8/24	1	1	1	1	3	4	1	2	1	4
9/14	3	2	1	1	3	3	1	1	2	4
9/28	2	4	2	3	2	3	2	1	2	3
10/12	2	2	3	2	3	3	1	1	3	3
10/20	1	3	2	3	3	3	1	2	2	3
11/10	3	3	2	3	2	3	2	2	2	3
11/23	3	2	2	2	3	2	1	3	3	3

Table 4 – Of the litter categories, “small items”, “tobacco products”, and “food packaging and containers” scored highest, indicating higher densities of these items at the beach.

Tributaries

Tributaries are streams that flow into a lake or pond. They collect surface runoff from rain or snowmelt along with some groundwater and carry it through the stream channel to the waterbody. In some cases, tributaries make up a large portion of the water going into the lake, and the quality of the water here can give us hints about where certain impairments in the lake are originating. Outlets are the major exits for water in the lake. Most of the abovementioned water quality parameters are measured at the major natural tributaries and outlets of the lakes in the Worcester Lakes and Ponds Water Quality Monitoring Program.

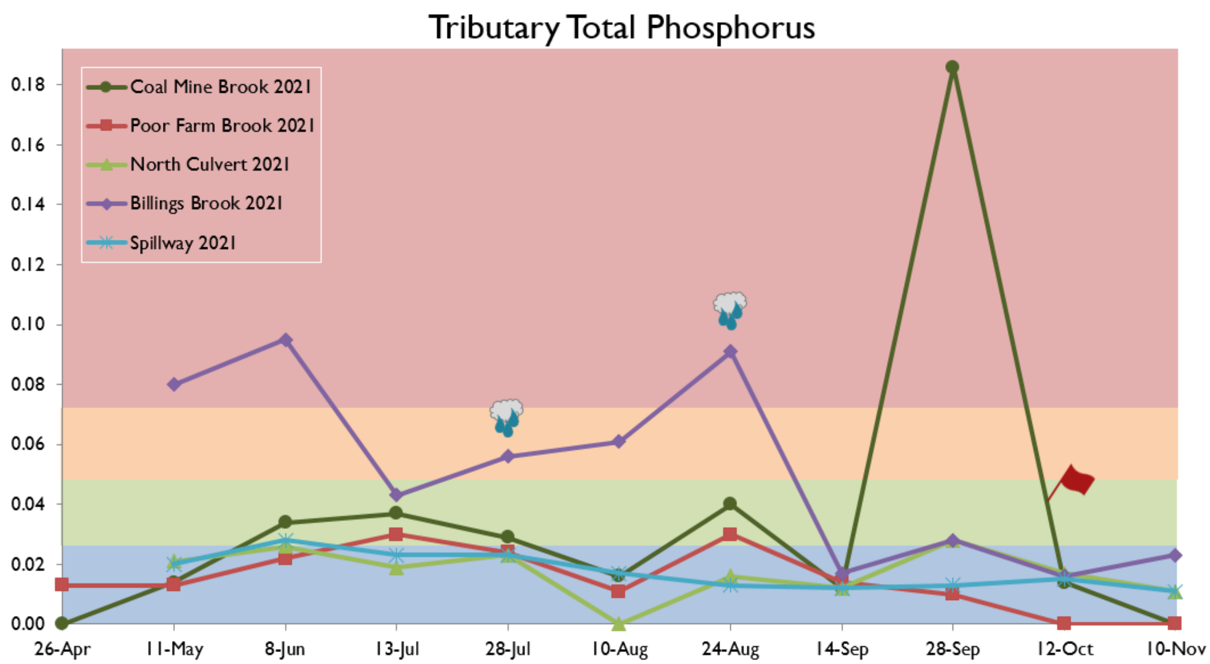


Figure L – The Lake Quinsigamond Tributaries' TP results generally rated "excellent" except for Billings Brook for most of the season and Coal Mine Brook on 9/29, a notable rain event.

Tributaries at Lake Quinsigamond. Lake Quinsigamond has a number of natural and stormwater tributaries throughout Worcester and Shrewsbury. As a part of this monitoring program, the Lakes and Ponds Program measured the parameters described above in three of the natural tributaries: Coal Mine Brook (Worcester), Poor Farm Brook (Worcester), and Billings Brook (Shrewsbury). These streams were chosen based on accessibility, time constraints, and the tributary's contribution to the total volume of water entering Lake Quinsigamond during storm events, as described in the documentation supporting the development of the 2002 TMDL. The major inflow from Mud Pond ("the North Culvert") was also sampled at the northern culvert under Route 70. The main outlet of the lake, right above the Irish Dam, located in Grafton below Flint Pond, was also sampled to examine the quality of the water as it enters the Quinsigamond River.

Dissolved oxygen (DO) concentrations at Coal Mine Brook and Poor Farm were rated "excellent" all season. The spillway at the Irish dam fared similarly, although DO dipped into the "fair" category for two dates in August. As seen in the past, Billings Brook and the North Culvert were less predictable, starting in the “excellent” category and dropping into “fair” and” poor” periodically early in the season and more consistently between August and October.

Total suspended solids (TSS) were measured monthly at the tributaries. Although most readings were in the “excellent” category (<1.0 - 6.3 mg/l), Billings Brook and Coal Mine Brook had elevated results duering some sampling events. Billings Brook results were consistently higher than other locations, with the highest measurements of 55 mg/l. Coal Mine Brook’s highest measurement was 44 mg/L during a rainstorm on 9/28. It appears that these locations are negatively affected by wet weather events.

Total phosphorus (TP) samples taken in the tributaries to Lake Quinsigamond had results that generally rated in the “excellent” category. Billings Brook was more varied in its results, ranging from “good” to “poor”, with the highest concentrations in early June and late August (see *Figure L)*. The only other tributary TP sample result that rated “poor” was from Coal Mine Brook on 9/28. Although the sampling day did not meet the rainfall total to be considered a wet weather event, heavy downpours, elevated water level, and reduced clarity were noted during sampling. The water level in Coal Mine Brook is known to rise quickly and carry higher concentrations of nutrients during heavy rain events.

Ammonia (NH_3) in the tributaries was in the “excellent” category all season, except for two results in Coal Mine Brook that coincided with rain (8/24 and 9/28), which were noted to have elevated concentrations of TP as well. Nitrate (NO_3) was consistently below 1 mg/L, ranking as “excellent”, all season.

Ongoing Projects

Stormwater Remediation. One way to keep our lakes healthy is to prevent nutrients and bacteria from getting into them. Stormwater is one of the major contributors of these contaminants, so identifying ways to intercept and filter this stormwater before it gets there is a priority. This last spring, the Lakes and Ponds Program constructed a biofiltration unit off Lake Ave North, right next to Coal Mine Brook, a major tributary of Lake Quinsigamond (see *Figure M*). This unit will filter road runoff from Lake Ave North through plantings, mulch, and high-performance media before releasing it into the lake. The capacity of the unit is enlarged by the presence of an underdrain. The unit is located at the beginning of the East West Trail, and visitors can learn more about the importance of stormwater at the educational placard there. The Program plans to continue to look for opportunities to filter stormwater and educate the public about water quality in 2022.

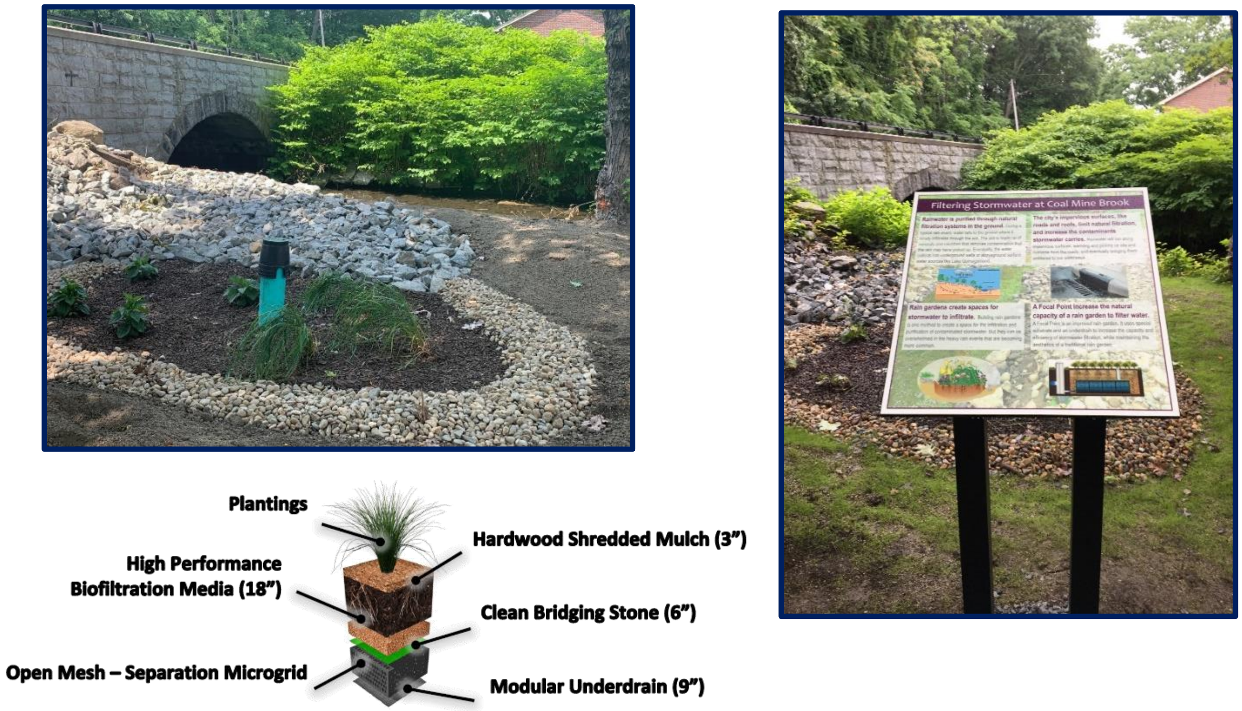


Figure M– Biofiltration unit off Lake Ave North, right next to Coal Mine Brook, a major tributary of Lake Quinsigamond.

Continuous Monitoring. The Lakes and Ponds Program visits Lake Quinsigamond twice a month to collect water quality data, but because of its size, it is sometimes difficult to capture all the lake changes that are happening during these two visits. One potential solution is the use of continuous monitoring buoys. These solar-powered, Frisbee-sized devices can collect and remotely deliver data on important water quality parameters like water temperature and the pigments associated with cyanobacteria every 30 minutes, 24 hours a day. Previously, this type of technology was inaccessible to small municipalities due to its price. However, new companies are making advances to bring down the price of this technology, and Worcester is working with them to provide feedback. Lakes and Ponds deployed two of these buoys in Lakes Quinsigamond in 2021 between June and December and were able to compare the data they collected to our sampling data and continue to work out kinks in the technology. The hope is to eventually deploy these devices in more locations to complement other monitoring efforts, and make the data available to the public in real time.

Figure N–Two continuous monitoring buoys were deployed in Lakes Quinsigamond in 2021.

State of the Lake

The overall state of Lake Quinsigamond in 2021 is “good”, although there are several parameters that need additional attention. Clarity in the lake was lower than usual in 2021, and while no winter blooms were observed, elevated cell counts were present around the beach areas in the summer months. Thankfully, these results never reach levels dangerous to humans or wildlife. The lake’s surface water temperature has improved over 2020, although oxygen stress is still a concern in the deeper areas. There were fewer beach closures in 2021 over 2020 due to fecal bacteria indicator exceedances, but not significantly. However, the issue seems to be isolated to specific shoreline areas and bacteria in the middle of the lake are not a concern. Regardless, the impact to recreation due to it give bacteria is negative.

Invasive aquatic plants were not heavily managed this year in the lake, with challenges due to the lack of updated maps. And it is uncertain what the extent of the current infestation is for both plants and the invasive mollusk, *Corbicula fluminea*. Additionally, in 2021 litter was quantified for the first time using a new tool, and Lake Park had an excellent score compared to other local lakes.

Plan for 2022

Water Quality Monitoring

In 2022, the Lakes and Ponds Program plans to continue to monitor Lake Quinsigamond in order to track changes in water quality. In addition to the standard parameters taken every month, two rounds of sampling for industrial contaminants will take place. This sampling includes compounds which one may expect to find in a post-industrial city, or emerging contaminants of concern, including heavy metals, PCBs, PFAS, and others, and were last sampled at Lake Quinsigamond in 2019. At that time, none of the results were of concern. 2022 results will be compared to 2019 results to ensure that there are no new threats to Lake Quinsigamond. Additional samples for cyanobacteria pigment analysis will be collected throughout the lake in order to better understand the threat of cyanobacteria blooms there throughout the season in various portions of the lake. All data will be compared to the data received from the continuous monitoring devices.

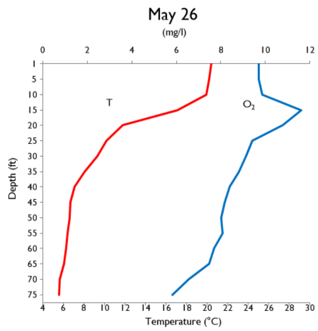
Litter Tracking and Management

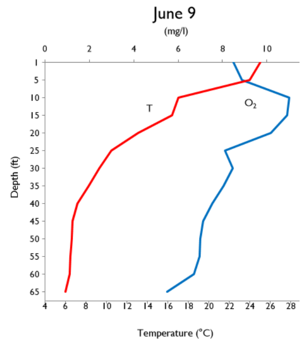
The Lakes and Ponds Program plans to continue to refine its new Litter Tracking Tool to better understand patterns in litter and trash at the parks at Lake Quinsigamond. In addition, we will continue to work with our partners, including the Massachusetts Department of Conservation and Recreation, and Worcester Green Corps, to use this data to create litter reduction strategies.

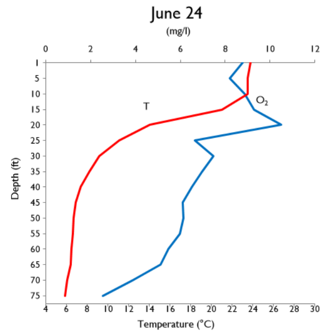
Invasive Aquatic Plant Mapping, Reduction, and Prevention

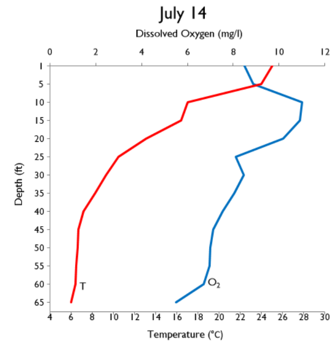
Lake Quinsigamond is a large lake with multiple invasive aquatic plants, and their growth patterns change from year to year. However, an aquatic mapping effort has not been conducted since 2018. In 2022, the Lakes and Ponds Program is committed to helping address this issue by sponsoring a new plant mapping effort on the lake, which will be used to update the management plan. Additionally, we will continue to support the Lake Quinsigamond Commission in the execution of that plan.

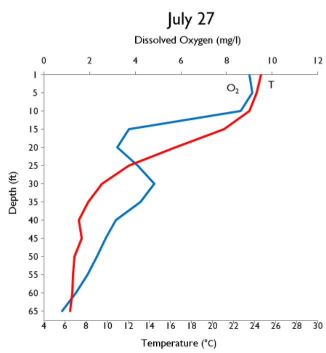
Appendix A: Profiles - Northern Site

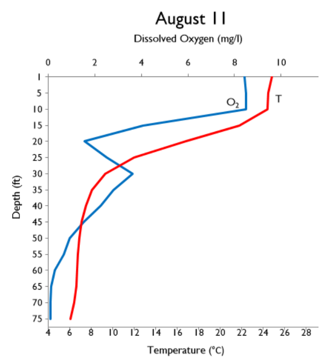


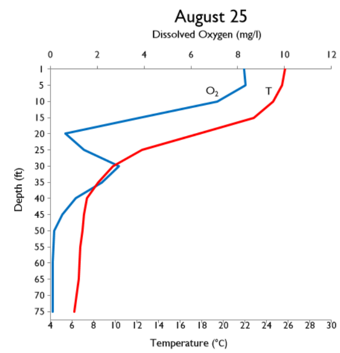


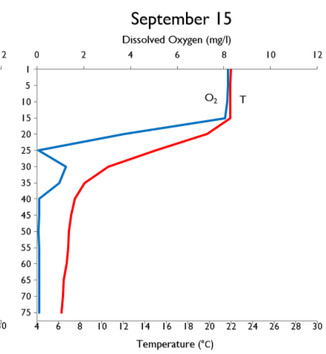


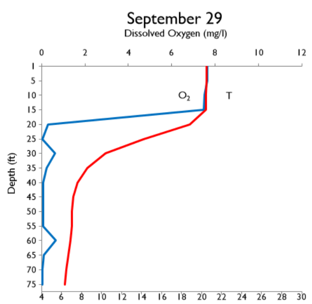


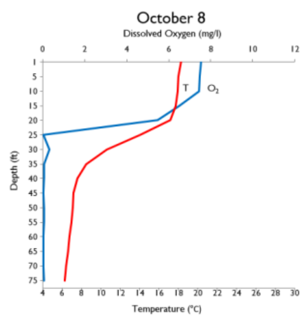


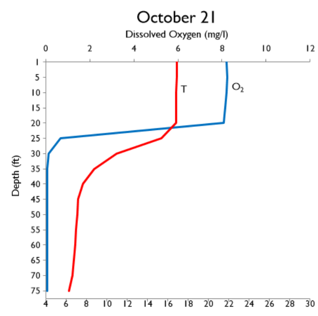


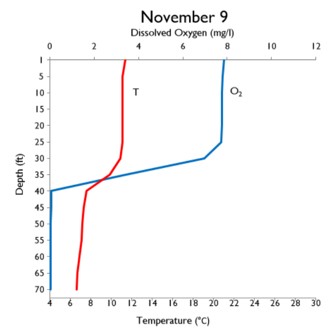


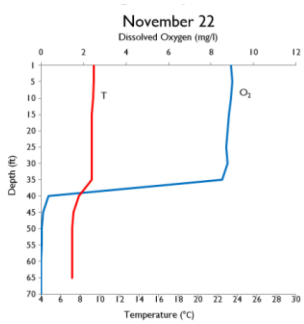


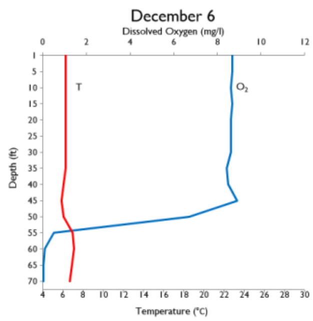


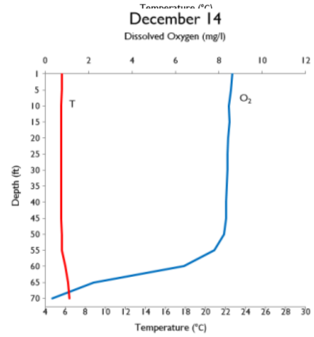


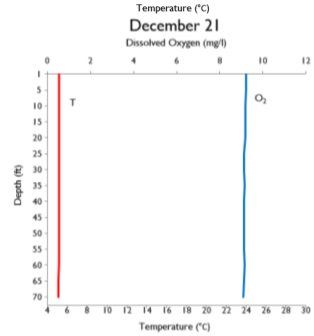












Appendix B: Profiles - Southern Site