Summary

As a highly used lake with borders in three municipalities, Lake Quinsigamond is both valuable, and vulnerable. Previously, non-native aquatic plants, *Enterococcus* bacteria, excess algal growth, and low dissolved oxygen have been among the principle water quality concerns for the lake. Sampling in the 2018 season suggests that these problems continue to be a concern. In the summer of 2018, the state beaches were closed for more days than they were open due to exceedances in bacteria indicators. Additionally, Asian clams, an invasive mollusk, have been found in several parts of the lake. Management of nutrients and invasive species (both plants and animals) should be a priority, and the source of the bacteria needs to be tracked and mitigated. The City of Worcester is working with the Lake Quinsigamond Watershed Association and Commission to implement an invasive species management plan, nutrient loading reduction projects, and a new volunteer water quality monitoring program.

Background

Lake Quinsigamond is a 4 mile long, 475 acre lake nestled between eastern Worcester and western Shrewsbury. It empties into Flint Pond to the south and later into the Quinsigamond River and ultimately the Blackstone River. The lake is of high recreational and economic value to all adjacent communities. The lake and Flint Pond are generally managed as one system, given the direct flow between them. 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. It has a maximum depth of 85 feet, and a water residence time of about 6 months. The Lake is spanned by three major roadways, Interstate 290, Route 9 and Route 20. The western, Worcester perimeter of the lake is zoned primarily for low density residential homes; up to three-family above Route 9, and single-family below Routh 9. The northernmost section of the lake is zoned as Business Office, and the section right below Route 9 is Business Limited. There is a small swath of General Manufacturing on the lower portion of the Lake perimeter. On the Shrewsbury side, the perimeter of Lake Quinsigamond is zoned for low-density single- and multi-family residences. Only the small portion around Route 9 is zoned for Commercial Business. The Lake receives stormwater from Worcester, Shrewsbury, Grafton and MassDOT highway I-290.
Lake Quinsigamond is a major local asset, hosting rowing, swimming, fishing, water skiing, jet skiing, and other motorized and non-motorized boating. People come from all over the world to participate in events around these activities. The lake is stocked in the spring and the fall with trout. It is managed as a warm and cold water fishery, supporting largemouth bass, chain pickerel, yellow perch, white perch, bluegills and pumpkinseeds, as well as rainbow smelt.

The Massachusetts Department of Conservation and Recreation (DCR) manages two parks with bathing beaches on the Worcester side of the lake. While a wildlife survey was not conducted this past year, turtles, amphibians, birds, and fish were spotted throughout the 2018 season. Management of the lake and pond is shared by the City of Worcester, the Town of Shrewsbury, the Town of Grafton, and the Lake Quinsigamond Commission.

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

Following the second season of monitoring by the Worcester Lakes and Ponds Program, we confirmed that the lake was still impaired for bacteria, invasive aquatic plants, and nutrients, which were exacerbating low dissolved oxygen conditions. Additionally, lake residents have continued to find shells of the Asian Clam, a known invasive mollusk, around the shoreline.

**Current Management**

Up to this point, several strategies have been used to mitigate the abovementioned issues. For invasive aquatic plants, the Lake Quinsigamond Commission has been coordinating an annual Lake drawdown of about 3 feet to control the growth of some invasive aquatic plants. A drawdown involves the lowering of the lake water level in the winter to expose the roots of plants to freezing temperatures and kill them. Additionally, the Commission has contracted a local lake management company to selectively apply herbicides in August of 2018, and hopes to continue to implement this plan in the future. The Department of Conservation and Recreation has also installed “Prevent Hitchhiker” signs at the boat ramps and around other access points on the Lake to raise awareness about the transport of aquatic invasive species. To address the Asian clams, the Lake Quinsigamond Watershed Association has begun talking with the Massachusetts Department of Environmental Protection for guidance; and has been mapping sightings of the shells throughout the lake. For nutrient management, The Town of Shrewsbury has worked with local groups to support the construction of rain gardens and other BMPs around the Lake, as has the City of Worcester. Worcester has also continued to implement its Stormwater Management Program, including illicit connection detection, leaf collection, street sweeping and catch basin cleaning to reduce nutrient loading to the lake via stormwater discharge. For the bacteria
concerns, the Lakes and Ponds Program has begun to investigate possible sources for bacteria contamination using available data from the surrounding towns.

Since the early 1980’s, no comprehensive water quality analysis has been performed on the Lake until 2016, when the Lake Quinsigamond Commission contracted ESS Group to develop an aquatic vegetation management plan, and the City of Worcester contracted the engineering firm Brown & Caldwell to perform watershed delineations, water quality measurements and sampling of inputs, outputs and lake water. In 2017, the City of Worcester began its Lakes and Ponds Water Quality Monitoring Program, to provide a consistent baseline for a number of parameters across Worcester waterbodies. This data will complement the 2018 City of Worcester Lakes and Ponds Water Quality Monitoring Program data, which provides a baseline consistent with the measurements occurring at the other Worcester lakes and ponds.

**Sampling Analysis and Overview**

Lake Quinsigamond was visited semimonthly from April through mid-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 is about 90 feet deep and the southern 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 measured at the surface, 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, cyanobacteria density, phycocyanin and chlorophyll. We also tested for total suspended solids, ammonia, and nitrate on a monthly basis, as well as performed lake profiles for temperature and dissolved oxygen. Additionally, the Massachusetts Department of Conservation and Recreation tested the two beach areas for *Enterococcus* as an indicator for harmful bacteria on a weekly or twice-weekly basis during the summer months. Altogether, there were 14 sampling events. Most sampling events took place on a single day, however, due to time constraints, two sampling events (April 26-27 and May 22-23) were split between two consecutive days. Nine of these days were considered dry-weather days, as in, there was less than 0.1 inches of rainfall 24 hours prior to data collection. Seven of the days were considered wet-weather, when there was more than 0.1 inches of rain in the 24 hours prior to sampling. These 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. Map of Lake Quinsigamond sampling sites.](image)
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 data from 2017, one must be cautious in comparing data sets of this nature over a two year period.

**Bacteria**

**What does it mean to find bacteria at our beaches?** Recreational contact with water contaminated by bacteria may make people ill. *Enterococcus* is a type of fecal streptococci bacteria that is found in the digestive tracts of humans and warm-blooded animals and is an indicator of fecal contamination. Some types of *Enterococcus*, as well as other bacteria found in fecal waste, are known to cause serious illness when humans are exposed to them in water. These bacteria run into water from pet and goose waste, human waste from illicit connections to the storm water system, leaking septic tanks or discharged sewage, and improper application of manure on land, rangelands, and feedlots. The Commonwealth of Massachusetts has strict water quality standards for public bathing beaches, and the State tests the beaches on Lake Quinsigamond on a weekly basis during the summer months. If the readings are too high, they are required to close the beach until readings return to safe levels.

Bacteria are a major threat to water quality at Lake Quinsigamond. The Massachusetts Department of Conservation and Recreation tested the water 21 times at each of Lake Park and Regatta Point Park Beach between late May and the end of August of 2018. During this time, Regatta Point experienced sixteen exceedances of the daily maximum (which is 61 MPN) or geometric mean for bacteria, resulting in three closures. One of those closures lasted 63 days, and overall the beach was closed for about 70% of the bathing season. The bathing season ended before bacteria levels returned to a level where the beach could be open. Lake Park was not much better. It had 13 daily exceedances over the course of one 55 day closure. However, the beach was open for the last week of the summer. The increase in the number of closures at Lake Quinsigamond this year is staggering. In 2017 Regatta Point was closed for a total of 14 days, and Lake Park was closed for 18 days, and at the time this was considered to be exceptional, as there were no closures in the rest of the Worcester lakes and ponds all season. See Table 1 for bacteria results at the beaches.

<table>
<thead>
<tr>
<th><strong>Enterococcus Results at Lake Quinsigamond Beaches</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Regatta Point</strong></td>
</tr>
<tr>
<td>5/22: 6 MPN</td>
</tr>
<tr>
<td>5/29: 10 MPN</td>
</tr>
<tr>
<td>6/7: 21 MPN</td>
</tr>
<tr>
<td>6/12-6/15: 93 MPN-22 MPN</td>
</tr>
<tr>
<td>6/19-6/21: 328 MPN-43 MPN</td>
</tr>
<tr>
<td>6/26: 122 MPN</td>
</tr>
<tr>
<td>7/5: 99 MPN</td>
</tr>
<tr>
<td>7/10-7/12: 20 MPN-43 MPN</td>
</tr>
<tr>
<td>7/17-7/19: 64 MPN-123 MPN</td>
</tr>
<tr>
<td>7/24-7/26: 22 MPN-11 MPN</td>
</tr>
<tr>
<td>7/31: 16 MPN</td>
</tr>
<tr>
<td>8/7-8/8: 47 MPN-194 MPN</td>
</tr>
<tr>
<td>8/14: &gt;2420</td>
</tr>
<tr>
<td>8/21: 49 MPN</td>
</tr>
<tr>
<td>8/28: 411 MPN</td>
</tr>
<tr>
<td><strong>Lake Park</strong></td>
</tr>
<tr>
<td>5/22: 7 MPN</td>
</tr>
<tr>
<td>5/29: 5 MPN</td>
</tr>
<tr>
<td>6/7: 6 MPN</td>
</tr>
<tr>
<td>6/12: 31 MPN</td>
</tr>
<tr>
<td>6/19-6/21: 2420 MPN-2420</td>
</tr>
<tr>
<td>6/26: 1730 MPN</td>
</tr>
<tr>
<td>7/5: 228 MPN</td>
</tr>
<tr>
<td>7/10-7/12: 118 MPN-35 MPN</td>
</tr>
<tr>
<td>7/17-7/19: 63 MPN-228 MPN</td>
</tr>
<tr>
<td>7/24-7/26: 67 MPN-64 MPN</td>
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<tr>
<td>7/31: 7 MPN</td>
</tr>
<tr>
<td>8/7-8/8: 62 MPN-121 MPN</td>
</tr>
<tr>
<td>8/14: 35 MPN</td>
</tr>
<tr>
<td>8/21: 11 MPN</td>
</tr>
<tr>
<td>8/28: 16 MPN</td>
</tr>
</tbody>
</table>

**Table 1.** Regatta Point beach was closed for almost 70 days this summer due to daily and geometric exceedances, while Lake Park beach was closed for over 50 days.
Why measure water clarity? One indicator of water quality is clarity, or how transparent the water is. 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 a variety of reasons in a lake. Clear water allows light to penetrate and encourages the growth of aquatic plants, which provide food, shelter, and oxygen to aquatic organisms. Turbid waters, or water filled with particles, will warm up faster as it absorbs heat from sunlight which causes oxygen levels to fall because as 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. TSS results quantify the particles of algae or sediment in the water column.

Lake Quinsigamond was sampled for Secchi clarity and TSS at the two in-lake locations. Readings for both parameters were similar in each location. Secchi depth readings were averaged and generally graded as “good”, or above 10 feet, all season long, with the poorest clarity occurring on 11/6, when the average reading was just 7 feet. This reading occurred on a windy, cloudy day, which may have affected the perceived clarity of the water. Overall, Secchi clarity was higher this year than last year, when most of the readings were below 10 feet, and earning a “fair” rating. See Figure C for Secchi disk readings. TSS results were rated as “excellent” for the entire sampling season, in both sampling locations at the surface and at the bottom (see Figure D). Overall, results are similar to what they were last year, and considered “good” or “excellent”.

Clarity
Water Temperature and Stratification

The Importance of Water Temperature. 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, their populations may decrease. Additionally, water temperature affects the speed of chemical reactions and 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. The density of water changes with temperature, and variations in temperature can cause cold water to settle in a layer on the bottom while warm water stays on top, resulting in stratification. Stratification can prevent the replenishing of oxygen on the bottom layers of the lake, and the rise of sediment nutrients to the top, which may be detrimental for lake health. Wind plays a role in the mixing that can occur, as does overall lake depth.

Water temperature and stratification are generally normal in Lake Quinsigamond, with only a few exceptions. We measured water temperature at the surface and at the bottom of the water column at the two in-lake sites twice a month during the sampling season. We also measured the temperature profile of the entire water column monthly at the deepest point (the north site). Water temperature was similar between both sites. Temperatures at the bottom of the lake were consistently about 6 degrees throughout the sampling season. At the surface, water temperature increased throughout the season until mid-August, when it peaked at 29.1°C. While most of the season the surface temperature was rated as “excellent”, between the 7/10 and 8/28, the temperature was above 26°C, receiving ratings of “fair” and “poor”. See Figure E for temperature readings at Lake Quinsigamond.

Being very deep, Lake Quinsigamond undergoes some thermal changes that more shallow lakes and ponds in Worcester do not experience. We measure these changes with a monthly lake temperature...
profile. While the temperature of the lake is pretty consistent averaging at about 8 °C in April, the surface warms up as we enter the early summer (see Figure G). Because warmer water is less dense than colder water, the warm water will continue to float on top of the cold water. In May, the bottom temperature is fairly unchanged, but the surface temperature is around 17 °C until around 12 feet deep, when the temperature suddenly drops at what is known as the thermocline. As the summer goes on, the surface temperature increases and the thermocline becomes deeper through August, and only starts to come down in September. We see in October that the shape of the temperature curve begins to become less severe, and we expect that the temperature profile was once again uniform in November, as it was in April.

While stratification is a natural process to be expected in a deep water lake in New England such as Lake Quinsigamond, it is important to understand temperature curves have implications for other lake processes, as the warmer floating layer of water can act as a barrier for lake mixing.

**Dissolved Oxygen**

Oxygen in the water. Oxygen in the water is important to aquatic life, just like it is on land. 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 levels can be affected by temperature, pressure, rate of photosynthesis and respiration by aquatic life, decomposition, aeration, and diffusion. Low DO can lead to fish kills and may be the result of nutrient loading which stimulates algae growth, or by decomposition of organic material.

Dissolved oxygen levels have been a challenge at Lake Quinsigamond for some time now. We measured dissolved oxygen at the surface and at the bottom of the water column at the two in-lake sites twice a month. We also measured the DO profile of the entire water column monthly at the deepest point. During the entire 2018 sampling season, DO levels at the surface of the Lake were above 6 mg/l, which is considered “excellent”. The bottom of the lake, however, quickly became a low- to no-oxygen environment (see Figure F). The great depth and lack of mixing due to the lake stratification described above could be partly responsible for this phenomenon. The severity of the consequences for fish and other organisms, however,
required more resolution of the oxygen levels throughout the water column. We used the lake profiling technique we used for measuring temperature to measure DO at small increments each month (see Figure G). DO levels were fairly uniform throughout the water column in April at over 9 mg/l. In May we saw the DO decrease at depth and eventually drop to below 6 mg/l around 66 feet. In June, this drop below 6 mg/l occurred at around 44 feet. Oxygen deficiency becomes shallower throughout the season through September, when it occurs at 24 feet. By October, the severe “S” shape of the temperature curve begins to straighten, and oxygen availability begins to return at lower depths, and we expect that this trend continues through the winter months. It is important to note that no fish kills were reported to the Lakes and Ponds Program in 2018. Because of the implications of low oxygen conditions for fish and other organisms, we will continue to profile the lake monthly in 2019. Oxygen limitations created by thermal stratification have been documented in Lake Quinsigamond as far back as studies have been conducted. The speed at which a low DO occurs may be influenced by nutrient loading, and will be explained later. What is unknown is whether the lake is naturally oxygen limited as a result of its depth, shape, and sources of inflow, or whether low DO is mostly due to human alterations of the watershed and nutrient inputs. Ultimately, low oxygen levels in the lake bottom are a continued concern for wildlife.

Figure G. Temperature and dissolved oxygen profiles of Lake Quinsigamond. Thermal stratification begins in May and leads in part to oxygen deprivation in the lower portions of the water column.
**What is pH?** pH is a measure of the amount 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 neutral. As you increase from 7, the solution is more basic, and as you decrease, it becomes more acidic. It is a logarithmic scale. pH can change due to the respiration and photosynthesis of 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 our area should have a pH between 6.5 and 8.5. A low pH can be the result of external forces like acid rain.

Throughout the season the pH between the north and south site were similar. pH was generally higher at the surface of the open water than at the bottom or at the north culvert. At the surface, the pH varied between 6.8 and 7.5, and at the bottom between 6.4 and 7.0 (see Figure H). These levels are generally considered normal for lakes in our region. This slight stratification may be due in part to the increased photosynthesis occurring at the surface by algae and plants, which remove dissolved CO\(_2\) from the water, reducing acidity. High rates of decomposition on the lake bottom could result in increased dissolved CO\(_2\) and acidity, as well as a lower DO.

**Nutrients**

**How are nutrients affecting our waterways?** Nutrients, primarily nitrogen (N) and phosphorus (P), are the basic food sources of aquatic plants and algae. These organisms are the basis of the food chain, and are therefore necessary for a healthy lake ecosystem. However, an excess of either N or P can promote algal blooms and excessive plant growth. Excess nutrients have both internal and external sources in a waterbody. Externally, they can come from fertilizers, pet and goose waste, and urban and agricultural runoff that wash into the storm sewer system or over land. Additionally, under the right conditions P can be released from the lake sediments at the bottom.

Nitrate (NO\(_3\)) is a nitrogen-containing compound that is easily absorbed by plants, algae and bacteria. When nitrate levels are high, it can encourage harmful algal blooms that deplete oxygen in the water column and can cause fish kills. Ammonia (NH\(_3\)) is another nitrogen-containing compound that is also directly toxic to fish in even low quantities. P is a limiting nutrient in lakes and ponds, meaning that excess P will be used up immediately by plants and algae, and is therefore an important indicator of lake health.
The City of Worcester measured NO$_3$ and NH$_3$ on the surface and the bottom of Lake Quinsigamond, as well as at the North Culvert site, monthly during 2018. Total Phosphorus was measured twice monthly. Nitrate levels at the surface of Lake Quinsigamond at the deep holes sites were rated as “good” or better and only the first sample at the north in-lake site came back above 0.4 mg/l. In some cases, the results came back with non-detectable results. The bottom of the lake, however, seemed to have more sustained high levels of NO$_3$, especially at the north site, when three of the six samples came back above 0.4 mg/l. In general, the higher NO$_3$ results are in the beginning of the season at both sites. We will continue to observe these results as NO$_3$ is an important nutrient in the lake ecosystem. NH$_3$ results were generally rated as “excellent” (below 0.15 mg/l) or below detection limits at the surface in both in-lake locations, with only one result in the beginning of the season at the south site rated as “fair” (see Figure I for details). Levels at the bottom, however, increased throughout the season, from “good” in May through “fair” and then to “poor” (above 0.5 mg/l). This seems to be a more severe problem at the south site than at the north site. These levels are harmful to fish and other wildlife, though it is unclear at what depth the accumulation reaches critical levels. We expect that this is the result of the inability of aerobic microbes to perform recycling processes at depth due to lack of oxygen in the water. Under more oxygenated conditions, natural bacteria would convert these N compounds into less toxic forms that can be absorbed by plants and other aquatic organisms. We expect that levels of NH$_3$ return to healthy levels as the lake begins to mix again.

Generally, Total Phosphorus concentrations at the surface of Lake Quinsigamond is in the “excellent” range of below 0.025 mg/l (see Figure J). On only one occasion did the concentration reach 0.03mg/l at the north site. Concentrations were higher in the north culvert, and on one sampling event reached above 0.07 mg/l, close to a “poor” rated reading. Concentrations at the bottom of the lake were higher, though generally still in the
“excellent” range, except at the south deep hole at the end of the season, when they spiked to over
0.075 mg/l for three events. This is concerning as the temperature begins to drop in the fall and the lake
begins to mix again, as this P could be made available to algae and cyanobacteria at the lake surface.

**Cyanobacteria**

*How do we measure cyanobacteria?* Algae are simple plants that use sunlight for energy and
quickly absorb N and P for nutrients. Cyanobacteria are bacteria that use sunlight, N and P in a
similar way. While they are present in small numbers in healthy ecosystems, under warm, high
nutrient conditions they can reproduce quickly, causing a bloom. In addition to being unsightly,
and smelly, these blooms 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 know algae and cyanobacteria dynamics in our lakes and ponds.

In addition to measuring cell density directly, which can take time and is expensive, we can
measure their pigments. Algae and cyanobacteria use the pigments chlorophyll and phycocyanin
to harness the sun’s energy to convert carbon dioxide to sugars for growth and reproduction.
While both algae and cyanobacteria produce chlorophyll, only cyanobacteria produce
phycocyanin. The ratio of the concentration of these two pigments in a water sample can
therefore give us insights to the composition of the algal and cyanobacterial communities. We
use a fluorimeter to measure these concentrations and compare them between waterbodies and
over the course of the sampling season. In the future, we hope to use these pigments as
indicators for cyanobacteria blooms.

Compared to the other lakes and ponds studied, Lake Quinsigamond has low levels of the
pigments phycocyanin and chlorophyll. For most of the sampling season, there was less than 1
ug/l of phycocyanin with no spikes in concentration that have been witnessed in other
waterbodies during cyanobacteria bloom formation. Chlorophyll levels are similar to what
are seen in other Worcester lakes and ponds. Because this method of pigment analysis is
qualitative, it is difficult to make significant statements about results without more data,
and next year more pigment sampling will take place. See Figure K for Pigment results.

![Figure K. Phycocyanin concentrations were low throughout the season, and chlorophyll levels were average, relative to other Worcester lakes and ponds.](chart.png)
Invasive Aquatic Plants

What makes a plant invasive? Native aquatic plants are vital parts of any lake ecosystem, providing food, shelter and oxygen to other aquatic organisms. Their uptake of nutrients reduces the likelihood of algal blooms, and their root systems stabilize sediments. An invasive plant is a plant that is not native, or did not originally come from the area. These plants become nuisances because their natural constraints, such as predators or environmental limitations, do not exist in their new home, allowing them to multiply at a rate much more rapidly. When aquatic plants become too numerous, they can reduce our ability to enjoy our lakes and ponds. Invasive aquatic plants can arrive by hitching rides on boats, pets, or boots to get from place to place. Some are released with good intentions as a beautiful addition to a landscape.

Lake Quinsigamond has been listed by the Massachusetts Department of Environmental Protection as impaired for aquatic plants. While the City of Worcester Lakes and Ponds Program did not conduct an official plant survey this season, The Lake Quinsigamond Commission contracted an environmental consulting group to produce an Aquatic Plant Mapping Survey of both Lake Quinsigamond and Flint Pond, and subsequently treated the lake in the late summer of 2018 with herbicides. Prior to the treatment, they concluded that aquatic vegetation was present in approximately 310 acres of the lakes, most extensively in the southern portions. The densest patches of aquatic plants were along the shoreline in coves. Six invasive aquatic plants were identified: Fanwort (Cabomba caroliniana), Brittle Naiad (Najas minor), Sacred Lotus (Nelumbo nucifera), Variable-leaf Milfoil (Myriophyllum heterophyllum), Curly-leaf Pondweed (Potamogeton crispus), and Eurasian Milfoil (Myrophyllum spicatum) (see Figure L).

While addressing the full extent of invasive weeds in the entire lake was complicated by the presence of an endangered plant species, the Lake Quinsigamond Commission was able to successfully treat 158 acres of beds of aquatic plants. Following the treatment, weed surveys confirmed that there were significant decreases in dense aquatic plant volume, and an

Figure L. Invasive aquatic plants identified in 2018 in Lake Quinsigamond.
especially significant reduction of the extent of fanwort and the milfoils. An aquatic plant management plan on the scale of Lake Quinsigamond is a huge undertaking, and will require the cooperation of all the surrounding municipalities to complete.

Invasive Aquatic Animals

Much like invasive plants, invasive animals can severely alter the aesthetics and functioning of a lake. Recently, the Asian clam (*Corbicula fluminca*) has been sighted in several areas of the lake. The Asian clam has a small light brown or green shell, and is native to South East Asia (see *Figure M*). It is an aggressive invasive that has been known to proliferate to the exclusion of other shellfish, altering the terrain by coating the lake bottom with sharp jagged shells. They are efficient filter feeders that can reduce the food available to juvenile fish. They can also clog water intake valves.

Asian clams can spread from one waterbody to another when they are attached to boats or equipment, but also via the bilge water of boats in their larval stage. Over the past few years, residents have found the shells of the Asian clam and have plotted their location in order to better understand the extent of the problem (see *Figure N*). However, to date, no live specimen has been collected. More information is needed to determine the threat level of the infestation.

Trash/Litter

*Why is trash such a problem?* Litter, or inappropriately disposed wastes, is harmful to the ecology, 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, they look 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.

While litter was less a conspicuous problem at Lake Quinsigamond than some of the other lakes and ponds in Worcester, the area still faces some challenges. The boat ramp on Lake Ave North near the mouth of Coal Mine Brook is the launching place for the north site in-lake sampling station.
typically left full of debris from people eating or preparing food. The informal parking lot and trail along Coal Mine Brook from this area often had trash, including used hypodermic needles. The western shore of the lake abutting the outlet of the northern culvert consistently contained plastic and fishing debris. This area has been the site of a number of watershed and community sponsored cleanups.

The sampling site at Billings Brook seems to also be a dumping spot for used tires. The least affected sampling spots seem to be those that are less accessible to people. There was little litter observed at the Poor Farm Brook site, which is located beneath a steep and wooded ridge behind a privately owned complex. The boat launch used to access the south in-lake sampling location is also used by the Worcester Fire Department and blocked off from public access, contained less litter. Finally, the Irish Dam, the spillway located below Flint Pond through an easement in a residential complex, had little debris.

Recently, the Towns of Shrewsbury and Grafton, along with tens of other communities in MA, have adopted bans on non-compostable and non-marine biodegradable single-use plastic bags for environmental concerns. In the coming years, it will be interesting to see how this legislation affects overall plastic contamination in our waterways.

Tributaries and Outlets

Why study tributaries and outlets? 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 greater waterbody. In some cases, tributaries make up a large portion of the water going into the lake, and the quality of the water in these tributaries can give us hints about where certain impairments in the lake are coming from. Outlets are the major exits for water in the lake. We measure most of the abovementioned water quality parameters at the major natural tributaries and outlets of the lakes in the Worcester Lakes and Ponds Water Quality Monitoring Program.

Lake Quinsigamond has a number of natural and stormwater tributaries throughout Worcester and Shrewsbury. As a part of this monitoring program, we 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 entering Lake Quinsigamond during storm events, as described in the documentation supporting the development of

![Figure O. Dissolved oxygen at the tributaries of Lake Quinsigamond. Coal Mine Brook and Poor Farm Brook have “excellent” levels of DO all season long.](image_url)
the 2002 TMDL. The main outlet of the pond, 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.

Tributaries and the outlet were visited 14 times during the sampling season. Poor Farm Brook was dry for three of these events, on 7/10, 8/8, and 8/28, and samples were therefore not taken. Probe measurements were taken during all events; however chemistry samples were taken on only a monthly basis.

Reviewing the data from sampling the tributaries, there were several noteworthy patterns. Dissolved oxygen was above 6 mg/l ("excellent") at Poor Farm Brook and Coal Mine Brook on all days sampled. DO at Billings Brook was low, almost anoxic, for 10 of the 14 sampling events, generally in the hottest months of the season. The DO at the spillway was generally considered “good” or “excellent”, however, it did drop in to the “fair” and “poor” category during the month of August. See Figure O for tributary dissolved oxygen.

Ammonia (NH₃) levels in the tributaries were generally below 0.3 mg/l (“excellent”), often times below detection limits. They tended to be slightly higher in Billings Brook than in the other tributaries and at the outlet. Billings Brook also experienced the only spike in NH₃ above 0.5 mg/l, which is considered a “poor” reading. See Figure P for NH₃ results.

TP levels in Coal Mine, Poor Farm Brook and at the Spillway were generally between “excellent” and “good. Billings Brook, however, had TP levels above 0.05 mg/l ("fair") for 3 of the 6 sampling events, and above 0.075 mg/l ("poor") for 2 of the 6. See Figure Q for TP results. Billings Brook is therefore the most impaired of the three sampled tributaries. This may in part be due to the impoundment of the water behind the culvert due to the accumulation of brush and debris.
Conclusions

State of the Lake

Water quality at Lake Quinsigamond is threatened for several reasons: (1) beach bacteria exceedances, (2) invasive plants and animals, and (3) nutrients. Beach closures directly affect the public’s ability to recreate on the water and cause local businesses that rely on water access to be negatively impacted. The extent and cause of the contamination is still unknown, and should be a priority to identify in the coming year. Invasive plants threaten the habitat of local species of fish and other wildlife, as well as inhibit the use of the lake by watercraft, which negatively impacts recreation. A plan has been created through the Lake Quinsigamond Commission to begin to address this challenge, and local municipalities should try to support it. While the extent of the invasive plant infestation has been well documented, less understood is the threat of the Asian clam. The Lake Quinsigamond Watershed Association has begun to document the occurrence of these mollusks, but more research is necessary to know the best management options for controlling and/or eradicating the current population. Finally, nutrients are a threat to Lake Quinsigamond. The depth of the lake contributes to its sensitivity to the effects of nutrient enrichment because of the lack of summer mixing that occurs with stratification and oxygen depletion in the bottom portions. Nutrients contribute to algal blooms and plant growth. In addition to being problems themselves, when plants and algae die and decompose they bring N and P to the bottom of the lake, and decomposing bacteria consume O$_2$ and prevent nitrification, or the transformation of NH$_3$ to a usable form by plants. This is a threat to fish populations since they rely on oxygen to survive and are sensitive to the high NH$_3$ concentrations developing on the lake bottom. Phosphorus is also documented to be accumulating in the depths of some portions of the lake, which could lead to fall algal blooms when the lake begins to mix again and bring the P to the surface. The source of this P may be the bottom sediments or external inputs. Data collected by the Lakes and Ponds Program shows that of the three tributaries samples, Billings Brook seems to be contributing significant amounts of P to the lake. However, there are many more natural tributaries and stormwater outfalls that are not currently sampled. Regardless of the source, the depth of Lake Quinsigamond facilitates processes that make nutrients a challenge for the lake.

Priorities for 2019

Monitoring priorities. Changes to the frequency of sampling for certain water quality parameters following the 2017 season seem to be effective. In 2019, we will attempt to take even more lake profile measurements. We will also attempt to discern the type of animal responsible for the increased number of bacteria exceedances at the beaches. In addition, we will do a comprehensive industrial contaminants test on the water.

Figure R. An engineered biofiltration unit resembling a rain garden will be installed along Coal Mine Brook to address stormwater contamination.
a minimum of two times during next sampling season. In doing so we hope to assess how legacy contamination from previous industrial uses of the area, as well as the threat other pesticides, metals, and petroleum products, have affected water quality.

The Lakes and Ponds Program has submitted an application to the Massachusetts Department of Environmental Protection to perform an analysis of fish tissues for potential contaminants, in order to determine if fish caught in Lake Quinsigamond are safe for human consumption.

*Continue stormwater best management practices.* In order to address concerns of nutrient and sediment loading, the City of Worcester will install a stormwater treatment best management practice (BMP) near the lake. The city has identified a site on the banks of Coal Mine Brook along Lake Ave North to construct an engineered biofiltration system that will mitigate the impacts of stormwater on nutrient and sediment loading (see *Figure R* and *Figure S*). Water will enter what on the surface looks like a traditional rain garden, but is built on top of an underdrain system and with substrates to improve filtration of the stormwater before it enters Coal mine Brook. Additionally, the system will include an insert for the catch basin on the other side of the street that will filter sediments or phosphorus from entering water before it is released into the stream. An educational sign will be posted near the site so that hikers on the East-West Trail, which begins at the site, will be able to learn more about the system. We hope that this will be another step to address nutrient loading and sedimentation issues from stormwater at this site, and raise awareness about these issues throughout the watershed.

*Establish a volunteer-led bacteria source tracking program.* Finding the source and extent of bacteria exceedances will be a priority in 2019. In addition to attempting to determine the type of animal causing the exceedances as described above, the Lakes and Ponds Program will team up with the Lake Quinsigamond Commission and the Lake Quinsigamond Watershed Association to develop a volunteer monitoring program with a special focus on *E. coli*, another fecal bacteria indicator. With the help of a volunteer monitoring team, we will be able to more effectively track and understand bacteria dynamics, as well as other contaminants of concern, in such a large lake with so many tributaries. The program will also help to increase the visibility and expand the mission of the watershed association.
Control invasive aquatic plants and animals. The City of Worcester will continue to collaborate with the Lake Quinsigamond Commission and neighboring municipalities to implement a long-term comprehensive aquatic vegetation management plan. This plan will include the drawdown, harvesting, and herbicide control of vegetation. It will also include the annual mapping of aquatic vegetation to track the progress of the program. The program will stress the importance of the prevention of the introduction of new invasive species, including plants and animals, via the implementation of educational programs and boat washing stations. The city will continue to provide courses on invasive weed identification and management, and encourage communication about the reporting of the sightings of invasive species. To address the Asian Clam, the City will work with the Lake Quinsigamond Watershed Association to continue to map shell findings, search for live specimens, and research relevant management techniques.