Indian Lake has had a long history of management to control excessive native and invasive plants, as well as algal and cyanobacteria blooms. The Lakes and Ponds Water Quality Monitoring Program, initiated in 2017, created a baseline for measuring progress on these challenges. Sampling in the 2018 season suggests that these challenges are ongoing, stemming in part from an excess of the nutrient phosphorus in the water column. Cyanobacteria dynamics in the lake are still poorly understood, and even with multiple algae treatments and consistent monitoring, a high cyanobacteria density caused an advisory to be put into effect in August of 2018, although happily, no toxins were detected in the water column. Treatment of cyanobacteria tends to clarify the lake, causing it to be more susceptible to invasive aquatic plants. This sampling season, Eurasian milfoil was found in the eastern portion of the lake, and continued management of this plant will be a part of the 2019 lake management plan. The Lake and Ponds Program continues to work with local residents and watershed associations to create more long term solutions to these challenges.

Background

Indian Lake was originally a 100-acre natural lake called North Pond. It was dammed and expanded to 220 acres in the 1800s to supply water to the Blackstone Canal. After the closure of the canal, the more recent construction of I-190 caused the reduction of the size of the water body to its current acreage of 190. Indian Lake’s main tributary is Ararat Brook, which enters from the north. The lake empties over a spillway into a culvert on the eastern side of the lake, and eventually flows into Salisbury Pond to the south. In the southern portion is a small residential island, called Sears Island, connected by a causeway to the mainland. To the south is a small pond called Little Indian Lake, which is connected to the main lake by a small culvert under Grove Street. Indian Lake has a maximum depth of about 17 feet, with the deepest point being in the north-eastern portion.

Besides the interstate, which is zoned for limited manufacturing, the majority of the lake perimeter is zoned for residential use. The eastern shore of the lake is zoned as general residential while the island
area around counterclockwise through the western shore of the Lake is zoned primarily as single family residential.

Indian Lake is a well-used urban lake, supporting swimming, fishing, motorized and non-motorized boating, jet skiing and water skiing. White perch, yellow perch, largemouth bass, golden shiners, black crappies, bluegills, pumpkinseeds, yellow bullhead, brown bullhead, carp, white suckers, and northern pike have been observed in its waters. Two city-maintained beaches, Clason Beach and Shore Park, as well as a city-maintained boat ramp at Morgan Park are bustling all summer long. The lake is considered a great pond, meaning that it is larger than 10 acres in its natural state, and within the jurisdiction of MA Chapter 91.

**Current Management**

Indian Lake is listed on the Massachusetts Impaired Waters 303d List as Category 4a for low dissolved oxygen and non-native plants and received a TDML, or a nutrient budget, for phosphorus in 2002. Nuisance plants have included European Naiad (*Najas minor*), *Elodea*, pondweed (*Potamogeton pusillus*) and common reed (*Phragmites australis*). Algal blooms have also historically been a problem. In the summer of 2014, Indian Lake turned a vile shade of green overnight. When tested, the water contained a high density of cyanobacteria cells, which are harmful toxin-producing bacteria, and prompted the state to shut down the lake for the remainder of the summer, seriously disrupting local programming. Since that time, the local watershed association and the city have worked together to test and treat cyanobacteria before it becomes a public health issue.

For many years, the Indian Lake Watershed Association has worked with the City of Worcester and Commonwealth of Massachusetts to manage water quality and other challenges at the lake. For the aquatic plants, management has included annual drawdowns, or the lowering of the lake water level in the winter to expose the roots of plants to freezing temperatures and kill them. The lake has been treated with copper sulfate to control algae and cyanobacteria. In addition, fluridone, diquat dibromide, and glyphosate have been applied to control nuisance aquatic plants. More recently, aluminum sulfate (“alum”) has been used as a preventative measure for algal and cyanobacterial blooms. Alum is a coagulant that will strip phosphorus, a major food source for algae and cyanobacteria, from the water column and make it unavailable to them.

Per the new management plan created by the Lakes and Ponds program in 2017, in 2018, alum was applied to the lake on 5/24, and copper sulfate was applied on 8/6 in response to indicators suggesting that cyanobacteria may rise above advisory levels. The Commonwealth of Massachusetts recommends issuing a “no primary contact advisory” for cyanobacteria when cell density levels rise above 70,000 cells/ml. In the short term, the treatments were successful in lowering cyanobacteria density, however, density then rose past advisory levels very quickly with few other indicators, and the lake needed to be closed to recreational activity on 8/31. At this time, algaeicide treatments are also determined to be unsafe due to their ability to cause dissolved oxygen levels to fall dramatically. While beaches were technically already closed for the season, DPW&P continued to take density samples until two
consecutive readings were below advisory levels. This occurred on 9/20. Concurrent cyanotoxin analysis indicated that no toxins were being produced at this time.

After the 2017 monitoring season, the Lakes and Ponds Program had intended to continue the existing weed management program, which includes a winter drawdown and the application of glyphosate to stands of common reed. However, during the course of the 2018 season, residents reported sightings of Eurasian milfoil in the northeastern portion of the lake. In order to contain the infestation, a treatment dose of diquat dibromide was applied to the affected area with immediate success in plant suppression. Glyphosate was applied to approximately 10 stands of the invasive common reed along the shoreline on 8/28. The effects of this treatment will be best seen in the summer of 2019.

While all of these methods were permitted by the Conservation Commission and are considered safe for the local ecology and human health, they are mostly short term solutions that do not address the root cause of the impairments. In 2019, the City of Worcester Lakes and Ponds Water Quality Monitoring Program aims to explore more fully the root causes and develop long term, sustainable management plants for Indian Lake. Read on to learn more about the details of the lake monitoring as well as the exciting initiatives we have in store.

**Sampling Analysis and Overview**

Indian Lake was visited semimonthly from the end of April through mid-November and sampled at four locations: The major aboveground tributary, Ararat Brook; the middle of the two basins of the lake (the north “deep” hole is about 17 feet deep and the south hole is about 5 feet deep); and the outlet at the spillway, located in the eastern part of the lake (see Figure A). The in-lake locations were sampled at the surface of the water (1 foot underwater), and the bottom (2 feet from the lake floor). Delaney Brook, a minor tributary that brings flow from stormwater and Kiver Pond, was periodically sampled. 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, and performed monthly lake profiles for temperature and dissolved oxygen. Additionally, the Worcester Department of Inspectional Services tested the beach area for *E. coli* as an indicator for harmful bacteria on a weekly basis during the summer months. Altogether, there were 14 sampling events. For the first 9 of these events, there had been no rainfall 24 hours prior to data collection. However, on 9/18, 10/2, 10/16, 10/28/, and 11/13 there were .4, .7, .22, .26 and 1 inches of rain having fallen within 24 hours of sample collection.
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. *Escherichia coli*, or *E. coli*, are 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 from illicit sewer connections to the storm water system, or from leaking septic tanks. The Commonwealth of Massachusetts has strict water quality standards for public bathing beaches, and Worcester Inspectional Services tests the water for *E. coli* on a weekly basis during the summer months. If the readings are too high, the city is required to close the beach until readings return to safe levels.

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Table 1. There were no beach closures at Indian Lake, and *E. coli* levels were rated as “excellent” (blue) or “good” (green) for all sampling events.

There were no beach closures at Indian Lake for the summer of 2018. In fact, results from *E. coli* tests all ranked as “excellent” or “good”. One test result on 8/7 was so low that it was undetectable by our analysis methodology (see Table 1). While these results are slightly elevated over the raw numbers that we experienced at Indian Lake in 2017, they are still very good, and fecal bacteria pose no danger to public health.

**Clarity**

**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.
Indian Lake was sampled for Secchi clarity and TSS in the two in-lake locations. Secchi readings were higher in the northern deep hole, which is the deeper portion of the lake. Average secchi depth in the north deep hole was about 5.5 feet over the course of the sampling season, which gives it a rating of “fair”. Readings were above 4 feet for 10 of the 14 sampling events throughout the season, with the highest reading being after the aluminum sulfate treatment on 5/29, when it was measured at 10 feet, the highest recorded secchi depth since monitoring began in 2017. Even though these depths are slightly better than last year’s readings, they are still on the lower end of what is considered safe and healthy. Local sources imply that clarity has been in this range for many years. Noticeable are the increases in clarity following lake treatments. While lake treatments seem to temporarily mitigate the problem, they are not able to solve it permanently. See Figure B for the season’s Secchi depth readings.

TSS was measured at the surface and near the bottom of Indian Lake at the two in-lake locations. Generally, there were higher concentrations of TSS on the bottom of the lake than at the surface, but surface results were similar in both locations. Results can be seen in Figure B. All but one bottom result was rated as “excellent”; and no single result reading above 12 mg/l. It should be noted that these results are generally higher than any other TSS results in the City of Worcester, and it is possible that TSS is contributing to the low Secchi depth, in addition to colored dissolved organic matter (CDOM) coming from the decay of plants and leaves underwater, which releases tannins that turn the water a tea-color.

Figure B. (Top) Secchi clarity at the north deep hole of Indian Lake was rated as “fair” for 10 of the 14 sampling events in 2018. (Bottom) TSS was rated as “excellent” on the surface and for all but one bottom sample.
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 was measured twice monthly at the surface at the two in lake locations, as well as at the bottom of the north deep hole location. We also measured the temperature profile of the entire water column in 1 foot intervals monthly at north site. In general, the surface temperatures in both locations of the lake were comparable. The lake was not stratified, and the maximum temperature difference between the surface and bottom temperature was 3.3 degrees on 7/17 (see Figure C for temperature and stratification data). Profiling data supports the hypothesis that water temperature varies little throughout the water column (See Figure D for summer lake profiles). Surface temperatures were rated as “excellent” or “good” for 11 of the 14 sampling events, and for all of the bottom readings. The high temperature on the surface this year was 27.4°C (“fair”), which is several degrees higher than it was last year, as was overall average summer temperature. Higher temperature may be related to higher algal and cyanobacteria densities in lakes and ponds, as well as heat stress for fish. Given these implications, we will continue to track temperature closely in the future at Indian Lake.

Figure C. Surface water temperature rated “fair” at Indian Lake on two occasions during the summer. Temperature peaked on 7/17. The lake is not highly thermally stratified.
Dissolved Oxygen

**Oxygen in the water.** Oxygen levels in the water are important to aquatic life, just like they are on land. Algae, plants, fish, and other aquatic organisms require a certain amount of oxygen to survive. Dissolved oxygen (DO) is therefore 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.

*Figure D.* Profiles at Indian Lake suggest that the water column is well mixed thermally in the summer months. Noteworthy, however, is a sharp drop in DO below 10 feet between July and September.
Dissolved oxygen (DO) was measured twice monthly at the surface at the two in lake locations, as well as at the bottom of the north deep hole location. We also measured the DO profile of the entire water column in 1 foot increments monthly at the north site. DO levels at the surface of Indian Lake rated as “excellent” for the entire sampling season (see Figure E). The elevated water temperature mid-summer coupled with such high DO readings indicated that there was a lot of oxygen production during the day. The bottom of the lake, however, had very low DO, and was often anoxic, for 6 of the 14 sampling events. Five of these were consecutive events between mid-July and mid-September. Profiles of the water column suggest that there is some oxygen stratification occurring in the lake between July and September, when oxygen levels begin to drop dramatically around 8 to 10 feet below the surface (see Figure D). While the wind seems to be enough to keep the lake thermally mixed, there seems to be a lack of DO getting to the bottom portion during the summer months, even while the photic zone is very productive. Several small-scale overnight fish kills in the beginning of August support this hypothesis; while algae and other primary producers are actively photosynthesizing and creating oxygen during the day. But when the sun goes down, they only consume $O_2$, leading to a net deficit in the lake and a challenge for fish. In 2019, in addition to continuing normal testing, we will attempt to confirm this theory by testing DO at the surface of Indian Lake during the night. For now, we know that we have less-than-ideal oxygen conditions at the bottom of Indian Lake, and we will continue to monitor accordingly.

$pH$

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.
We sampled pH at the north deep hole twice monthly at the surface and bottom, as well as at the surface of the south site. Generally, pH is in the normal range in the north deep hole at Indian Lake. Throughout the season the pH at the surface of Indian Lake varied between 7.0 and 8.7, and between 6.3 and 7.7 at the bottom (see Figure F). These results are not indicative of the results at the south surface location, which had a high reading of 8.9 units on 6/12. While a large variation in pH may be detrimental to fish and aquatic life, we do not have enough temporal resolution to know how quickly these shifts are occurring. Daytime pH during the periods when small-scale fish kills occurred at the lake were relatively normal. However, in 2019 we will investigate nighttime pH on occasion, in addition to routine water quality monitoring.

**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\textsubscript{3} and NH\textsubscript{3} on the surface and the bottom of Indian Lake monthly during the summer. In general, the results from both the north and south site were comparable. NO\textsubscript{3} levels were below detection limit of 0.050 mg/l for most of the sampling season, and never rose above 0.24 mg/l. These results are similar to the results we observed in 2017. NH\textsubscript{3} results were rated as “good” or “excellent” at the surface for the entire sampling season in both locations. On only one occasion did the NH\textsubscript{3} reading at the bottom rate as “fair”. These readings are comparable, if not slightly better, than those in 2017. See Figure G for N data.

Indian Lake has a state-mandated budget for phosphorus loading in order to bring concentrations in the lake down to 0.027 mg/l from the 2002 estimate of 0.044 mg/l. In 2017, the average concentration of TP at the surface of Indian Lake was 0.043 mg/l. In 2018, TP was measured at the surface in both in-lake locations and at the bottom in the north site every other week throughout the sampling season, for a total of 14 sampling events. In the north site surface TP levels were rated as “excellent” for 11 of the 14 events, “good” for 2 events, and “fair” for one event. Results were similar in the south sampling location, where all but one event was rated as “good” or “excellent”. However, there was one occasion, on 7/31, when TP at the south site was 0.109 mg/l. On this day, TP was...
high in all locations. TP was slightly elevated at the bottom of the north deep hole, with two “poor” ratings on 5/15 and 7/31. However, field notes from 5/15 indicate that the sample may have been contaminated by bottom sediments, which are suspected to be high in P. The average surface TP reading for the season was 0.028 mg/l, which can be interpreted as “very good”. See Figure H for TP results. However, readings too far above these, combined with other factors like elevated temperatures, may be sufficient to trigger an algal or cyanobacteria bloom, such as that which occurred at the end of the sampling season. Phosphorus is still a concern in Indian Lake. In order to reduce the possibility of harmful algal blooms from occurring, the City of Worcester contracted the application of aluminum sulfate, or “alum”, a coagulant that strips phosphorus out of the water column and sinks it to the bottom of the lake, making it unavailable to algae and cyanobacteria. The application seems to have temporarily lowered the TP concentration, but continued inputs of TP to the lake via Ararat Brook during a rainy July brought in-lake concentrations back up quickly. Continued monitoring and control of TP is necessary in conjunction with other factors that predict and cause algal blooms.

Cyanobacteria

What do pigments tell us about algae and 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.

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.

In 2017 the Lakes and Ponds Program began to collect semi-monthly cyanobacteria cell density samples at Indian Lake. While the production of cyanotoxins is poorly understood, the Massachusetts Department of Public Health has determined that the risk of exposure is low to non-existent if the density of cyanobacteria cells in the water is below 70,000 cells/ml. If a beach’s cell density results reach this level, it must be closed, and treatment can no longer occur. With this in mind, we created a monitoring and management plan to track and treat cyanobacteria before they reach densities harmful to public health. This year, DPW&P began collecting these samples in May (see Figure I). Between May and mid-July results remained far below action levels. A preventative treatment of aluminum sulfate was applied on May 24th to reduce the likelihood of bloom development. This may have been responsible in-part for continued low densities. Other parameters pointed to a relatively healthy lake: *Secchi clarity*, was as high as 8 feet in June, and average around 4 feet during this time.
Early July was hot and rainy. Over a short period of time, Secchi clarity decreased to an average of 3 feet in both surface locations. On July 31st, daytime oxygen levels were reported very high and overnight fish-kills suggested high rates of respiration by photosynthetic organisms, such as cyanobacteria. Residents complained of the lake smelling “funky”. On August 2nd, DPW&P received the cyanobacteria density results taken on July 28th to be 50,000 cells/ml. DPW&P called in a contractor to treat the lake with copper sulfate on August 6th so as to prevent the density to reach advisory levels. Post-treatment sampling suggested success, with Secchi clarity readings at an average of 4 feet again, and normal oxygen levels. Cyanobacteria density was reported to be 10,500 cells/ml on August 14th.

After the 14th, there was continued hot weather and rain, however, clarity remained the same and there were no other visual or olfactory indicators of bloom formation. All parties were surprised to receive the result of 188,000 cells/ml on sample date August 28th, indicating a 177,500 cell/ml spike in density over just 14 days. Because the density result was above advisory level, DPW&P had no option to treat the lake, but collected a sample for overnight toxin analysis to determine if the cyanobacteria were harmful to human health. See Figure J for toxin analysis results. Additionally a sample was collected for a repeat density analysis to confirm the spike. The repeat sample confirmed the bloom with a result of 101,000 cells/ml.

During this time, water samples were collected to test for cyanotoxin levels. Results found only trace levels of toxins, far below any advisory threshold established by EPA or the Department of Public Health.
(see Figure J). The city continued to collect cell density samples, despite the beaches already being closed for the season. As the summer came to a close and temperatures decreased, cell density samples came back under the threshold. Around September 20th the lake was reopened.

Currently, testing for cell density directly is our most accurate method to determine the threat of cyanobacteria to residents, and we will test even more often for this indicator in 2019. While we know that there are other indicators such as Secchi clarity, and causes, such as high temperatures and nutrient content, the relationship between the factors is not clear. Increases in lake TP throughout the summer seemed to be halted by chemical treatments, but concentrations were still very high prior to the July 26th cyanobacteria population spike. Noteworthy is the relatively low TP concentration prior to the late August spike (see Figure H).

Throughout the sampling season we also collected water samples to analyze for the cyanobacteria pigments, chlorophyll and phycocyanin. These samples were not processed until the end of the season, and the results can be found in Figure K. We see that around the time of the first increase in cyanobacteria cell density there was an increase in both pigments. While the algaecide treatment did seem to bring the levels of pigments down, they were still elevated to levels seen earlier in the season.

Compared to other lakes and ponds in Worcester, Indian Lake had high concentrations of chlorophyll and phycocyanin. Both pigments seemed to generally become more abundant throughout the season, despite being seemingly affected by alum and copper sulfate treatments. Both pigments peak in concentration right around the first spike in cyanobacteria density, however are not quite so high around the second, much more severe spike in density. Curiously, the second peak in pigments occurs in early October, when lake temperatures are much lower, albeit more uniform throughout the water column. We do not have density data for the October months. 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.

**Figure J.** Throughout the bloom, there has been little toxin production by the cyanobacteria. All three samples collect have read for microcystin levels below 0.4 ng/ml. This level is well EPA and MDPH guidelines for an advisory.

**Figure K.** Pigments associated with cyanobacteria generally increased in concentration throughout the summer, though it seemed to respond to lake treatments.
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.

In its long management history, Indian Lake has oscillated between periods of dominance by aquatic plants and algae. Previously, native waterweed (Elodea) and pondweed had been a recurring problem, until the annual drawdown was initiated. Today, Indian Lake is listed on the 2016 Integrated List of Waters for invasive aquatic macrophytes including Eurasian Milfoil (Myriophyllum spicatum). During the 2017 season, little nuisance aquatic vegetation was observed apart from the Common Reed, which was treated with glyphosate. Common Reed was treated again in the fall of 2018, in order to ensure that the remaining stands were completely eradicated. During the early summer of 2018, there were some complaints by residents of Milfoil confirmed in the eastern portion of the lake, above Sears Island. The Lakes and Pond Program responded quickly with a diquat dibromide treatment, in order to ensure that the plant did not spread. The treatment was immediately successful, and the milfoil was suppressed. It is suspected that the recurrence of this weed is due in part to the earlier-than-usual aluminum sulfate application, allowing greater light penetration earlier in the season to this portion of the lake. Most growth was observed in areas that were not exposed during the drawdown. The drawdown will continue to occur, and the lake was brought down 5 vertical feet for the winter of 2018-2019. In 2019, we will continue to closely monitor aquatic vegetation as well. The case of milfoil identification in 2018 is a reminder of the value of environmental education in stopping invasive plant infestations before they become unmanageable.

Figure L. Eurasian milfoil found at Indian Lake.
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.

Litter was less a conspicuous problem at the Indian Lake sampling sites than some of the other lakes and ponds in Worcester. Morgan Park, where the program launches to collect the in-lake water samples, is well-maintained by the Parks Department and local residents, and little litter or debris was found there or spotted along the shoreline of that area of the lake. The entrance to the spillway sampling station was also generally free of debris, however, it is not accessible by the public. The only area that consistently had litter or dumped materials was the entrance to the Ararat Brook tributary sampling site, a small dirt parking lot at the corner of Shore Drive and Holden Street. This seems to be an area frequented by people trying to get rid of furniture, as well as litter. Residents report that this is also a problem in the area around Clason Beach.

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 lake or pond. 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.

Indian Lake has several natural tributaries. As a part of this monitoring program, we measured the parameters described above in the major natural tributary, Ararat Brook, at the spillway, and on several occasions, at the smaller tributary Delaney Brook. Ararat Brook was visited 14 times, the spillway was visited 13 times, and Delaney Brook was visited 7 times. Probe measurements were taken on all occasions, while other parameters were taken on a semi-monthly basis.

**Figure M.** DO is generally considered “excellent” in Ararat and Delaney Brook.
Dissolved oxygen levels in Ararat and Delaney Brook was rated as “excellent” on all dates sampled (see Figure M). However, DO readings at the spillway, or outlet, did enter the “good” and “fair” category on 8/16 and 9/4 respectively. These lower readings reflect the overall in-lake DO levels, and return to “excellent” the following sampling date. In general, DO is lowest mid-summer. TSS readings in the tributaries and at the outlet were also very low, rated as “excellent” or “good”. The highest TSS ratings were seen in Ararat Brook. See Figure N for TSS results.

NO₃ levels in Ararat Brook were higher in the beginning of the season, but with the final 3 of the 6 readings below detection limits. The two samples taken for NO₃ at Delaney Brook (7/17 and 8/16) have similar results to those of Ararat Brook. The concentration of NO₃ leaving the lake at the spillway was consistently low, much of the time below the detection limit for the test. NH₃ appears to be generally undetectable in all locations. See Figure O for N results.

TP levels in Ararat Brook were above 0.075 mg/l (“poor”) for 4 of the 7 sample events and for 2 of the 2 sample events in Delaney Brook. Even while base flows into the lake may be rated as “excellent” for TP, it is apparent that P load increases during rain events. This is a significant source of P to Indian Lake. At the spillway, TP levels were “good” throughout the sampling season (see Figure P).
Conclusions

State of the Lake

Water quality at Indian Lake remains highly threatened. Even with intensive monitoring and preventative measures, the lake suffered a cyanobacteria advisory, closing the Lake for about two seeks in August and September of 2018. It is suspected that a bloom would have occurred earlier without intervention. Indian Lake experienced small-scale fish kills during the summer, perhaps due to overnight drops in DO from algal activity or high surface temperatures. It is likely that high nutrient levels are in part causing these impairments, and average phosphorus levels in the lake and tributaries is higher than desired. As water clarity is reduced, lake warms up faster, and it is predicted that these warmer waters are promoting the reproduction of algae and bacteria. Finding and mitigating the source of these nutrients may be a long term solution to this issue. Ararat Brook is suspected to be one of those sources, which is not surprising, given that 51% of stormwater flow and 77% of dry weather baseflow enter the Lake through this tributary. This year the lake also saw a return of Eurasian milfoil. While treated successfully this year, it is is suspected to return in 2019.

There is some good news. This year, like in 2017, there were no closures due to E. coli, the indicator of human waste. While cyanobacteria were present, they did not produce any toxins, meaning that the water was never unsafe for humans to recreate in. However, due to the limited knowledge that we have of how and when toxins are produced, we must continue to close beaches when if cyanobacteria density reaches advisory thresholds. We have also come a long way in mitigating the threat of the invasive aquatic plant the common reed, and it is suspected that 2019 will be the last year we will need to treat to that species.

Priorities for 2019

Monitoring priorities. Changes to the frequency of sampling for certain water quality parameters following the 2017 season seem to be effective. However, the sudden increase in cyanobacteria density this summer at Indian Lake suggests that we will consider adding more cyanobacteria density samples in the summer months. In this way, we will be able to more quickly respond to any threat of a cyanobacteria bloom. In 2019, we will also add several new parameters to those collected currently in order to gain a more holistic understanding of water chemistry and lake dynamics. Among these are an indicator for water color, in order to better understand how Secchi clarity is related to cyanobacteria density. In addition, we will do a comprehensive industrial contaminants test on the water 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 Indian Lake are safe for human consumption.
In order to better understand the phosphorus loading into Indian Lake from tributaries, this spring we will commission a study of wet weather flow monitoring. Water samples will be taken in short intervals after a rain event begins to better understand at what point during a storm that the most phosphorus is entering the lake from Ararat Brook. This will help us to better understand how weather affects TP in the lake as a whole.

*Nuisance aquatic plants.* The city will continue to take an active role in the control of invasive aquatic plants at Indian Lake. As of November 2018, the drawdown has commenced to tackle the shallow water weeds. We will evaluate the results of the most recent common reed treatment and consider applying a final treatment this year. Additionally, we are considering using Diver Assisted Suction Harvesting (DASH) to remediate the Eurasian Milfoil in the northeastern portion of the lake. Divers are able to remove the plants by the roots in order to ensure that they are not able to reproduce in the following year. In this way, we are taking a more proactive, sustainable approach to eliminating this invasive species.

*Shore Park Rain Garden.* Using money allocated to the City of Worcester through a state earmark, Worcester DPW&P contacted the design and construction of a rain garden to treat stormwater coming off of the parking lot at Shore Park. Previously, this water would come over the parking lot in a sheet during rain event, causing erosion to the beach and sedimentation to the lake itself. The project will divert the rain water to natural rain garden a biofiltration unit, where it will be treated before being slowly released into the lake. The project will include a kiosk to educate park visitors on stormwater and how the system works. See Figure Q for a diagram of the rain garden location. The rain garden will be constructed in the spring of 2019.

*Figure Q.* Location of the Shore Park rain garden to be constructed in 2019.