Background

Coes Reservoir is a 90 acre impoundment of Tatnuck Brook, located between the Columbus Park and Webster Square neighborhoods of western Worcester. It is about 15 feet deep at the deepest point, which is located in the southern portion of the lake. Coes Reservoir is bordered on the west side by Mill Street, a highly trafficked roadway. The northern end of the lakeshore is largely residential, with commercial zoning along Mill Street on the western side. The southern portion has a public beach, playground, and access to a trail system around the eastern side of the lake.

Coes Reservoir is located at the end of a chain of mill ponds along Tatnuck Brook, which extends south from Holden. Tatnuck Brook exits Worcester's drinking water supply at the Holdern 2 Reservoir and is designated a Coldwater Fish Resource (CFR) by MassWildlife. Flowing south into Worcester, Tatnuck Brook is impounded several times as the watershed becomes more developed. Coes Reservoir was created when Tatnuck Brook was dammed in the mid 1800's in order to supply waterpower to the Coes Knife Factory. Due to its long industrial history, the area had a legacy of industrial pollutants that led to remediation and reconstruction of the dam site in 2006.

Figure 1 – *A newly constructed boardwalk provides universal access to the Eastern shore of Coes Reservoir.*

Due to efforts of the City of Worcester and various community groups, Coes Reservoir has become a valuable recreational resource. There is ample public access around much of the lake, including a public beach, a universal access park and playground, a nature viewing boardwalk (see *Figure 1*), a fishing pier, as well as a new kayak launch at the Mill Street Beach that will host kayak and paddleboard rentals. Coes

Reservoir boasts a popular fishery, where anglers can catch Largemouth Bass, Chain Pickerel, Yellow Perch, Black Crappie, Bullhead, Bluegill, and Carp.

The following report details the results of water quality monitoring programs in 2022, as well as the exciting projects and opportunities the City of Worcester's Lakes and Ponds Program (L&P) intends on implementing in 2023.

Water Quality Summary

As an urban lake, Coes Reservoir feels many of the pressures of the city. However, management by community groups, and more recently, the Lakes and Ponds Program, has led to water quality that supports a healthy ecosystem and a wide variety of recreational opportunities. In 2021, water quality at Coes Reservoir was rated by L&P as "Good". There were water quality improvements from 2020 in terms of temperature, with healthier ranges on the surface as well as on the bottom of the reservoir. Although nutrient levels are not ideal, L&P's cyanobacteria management and response plan kept potentially harmful cyanobacteria blooms at bay in 2021 leading to no lake closures. Additionally, there was a reduction in beach closures due to fecal bacteria indictor threshold exceedances. While invasive aquatic plants do exist in the waterbody, they were successfully managed and did not hinder recreation. Finally, in 2021, steps were taken to classify and quantify litter, and Coes Reservoir beach, providing a baseline for future measurement.

In 2022, Coes Reservoir received a score of "Fair" for the first time since L&P began monitoring, being downgraded from "Good". There were no beach closures due to fecal bacteria exceedances. The adaptable aquatic plant management plan has continued to be effective at keeping the reservoir generally free of invasive plants in the lower portion of the reservoir, and seasonally controlling them in the northern portion. However, surface water temperatures were considerably higher than in 2021. Because of the state-wide drought, tributary water inputs were greatly reduced, and the outlet of the reservoir stopped spilling, meaning no water was exiting the lake. Nutrients that entered the lake had a longer residence time, and nutrient sampling results indicated an increasing concentration of phosphorus in the reservoir throughout the season. In 2022, despite monitoring and management by the Lakes and Ponds Program, Coes Reservoir was closed for a total of 78 days due to cyanobacteria blooms. Luckily, only five of these days were during the swimming season. Unfortunately, this was during a heat wave when demand for swimming was high. Also during 2022, L&P did its periodic monitoring for industrial and emerging contaminants, which did not yield results that would be of concern to public health.

Management Summary

Coes Reservoir has had management plans for cyanobacteria and invasive aquatic plants since 2018. Additionally, in 2021 a plan was implemented to address the increased number of closures due to *E. coli* bacteria that the public beach experienced in 2020.

In part due to high water temperatures and elevated nutrient concentrations in 2022, there was extensive cyanobacteria activity at Coes Reservoir. In mid-July, after seeing scums along the shoreline, a treatment

of copper sulfate was applied to the reservoir, which was successful in bringing the cyanobacteria density down for some time. A bloom in mid-September also occurred, but L&P did not respond with a treatment as it was outside of the recreational swimming season and it was expected that decreasing temperatures would cause the bloom to end quickly.

Coes Reservoir's invasive aquatic plant management plan continued in 2022. On June 29 and August 24th Imazamox (trade name: Clearcast) was applied to the norther portion of the lake on to address the ongoing Water Chestnut infestation. In addition to this, a community hand pulling event was organized in mid-August.

Following high *E. coli* readings in 2020 and a suspected relation to goose activity, goose fencing was developed and installed during off-hours at the beach. This ultimately reduced goose congregation on the beach and may have contributed to fewer beach closures for fecal bacteria in 2021. In 2022 improved fencing was utilized consistently, potentially contributing to a season with no beach closures due to fecal bacteria.

Sampling Analysis and Overview

Coes Reservoir was visited semimonthly in 2022 from May through October and sampled at four locations: the major aboveground tributary, Tatnuck Brook; the two deepest parts of the reservoir (the northern is about 13 feet deep and the southern is about 15 feet deep); and the outlet at the spillway located at the southern end of the reservoir (see *Figure 2*). At the in-lake locations, probe measurements and water samples were collected one 1 foot below the surface of the water ("surface"), and two 2 feet off of the bottom of the lake ("bottom"). Parameters evaluated included: Secchi transparency, temperature, dissolved oxygen (DO), pH, total phosphorus (TP), total dissolved phosphorus (TDP), and *E. coli*. Samples analyzed for total suspended solids (TSS), ammonia (NH_3), and nitrate (NO_3) were collected on a monthly basis. This year, L&P also collected samples to be analyzed for industrial contaminants and emerging contaminants of concern on two occasions. Altogether, there were 12 sampling events. For 8 of these events, there had been no rainfall 24 hours prior to data collection. However, on 9-Jun there were 1.47 inches of rain in the 24 hours prior to sampling, on 7-Sep there were 1.23 inches of rain, on 23-Sep there were 0.61 inches of rain, and on 6-Oct there were 0.31 inches of rain. These days are categorized as "wet weather" sampling events and are denoted with the symbol on the figures.

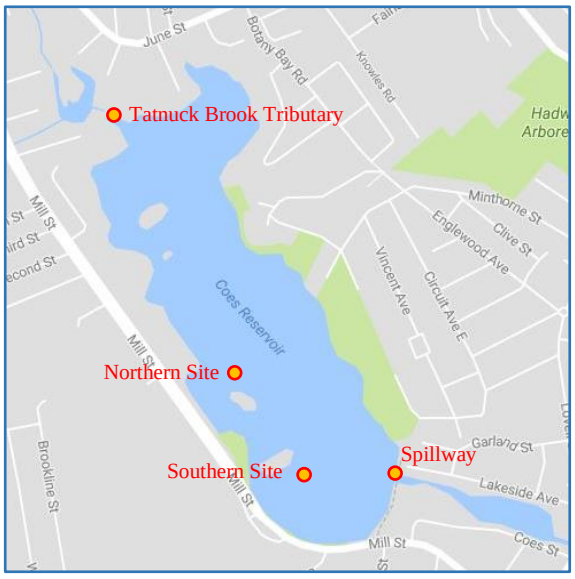

Figure 2 - Coes Reservoir map and approximate sampling locations.

Samples were collected by a contractor for cyanobacteria cell density as needed. Additionally, Worcester Department of Inspectional Services

tested for *E. coli* as an indicator for harmful bacteria on a weekly basis during the summer months at the Mill Street Beach.

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.

Quality Assurance/Quality Control

The Lakes and Ponds Program strives to have a robust data set. L&P therefore uses Quality Assurance/Quality Control checks to ensure that data are representative of local conditions and meet precision and accuracy standards. Review of QAQC check results identifies data that need to be flagged and/or censored before they are shared and can highlight issues that affect data quality. 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. For more information on L&P's data quality, please contact greenworcester@worcesterma.gov.

Fecal Bacteria

Recreational contact with water contaminated by certain fecal bacteria may cause illness. *Escherichia coli*, or *E. coli,* are a type of bacteria found in the digestive tract of warm-blooded animals including geese, pets, and humans. While most strains are harmless, some can make you very sick. These bacteria enter the water in many ways, including direct contact with animal waste, runoff from the shoreline and impervious surfaces like paved roadways during rainstorms, leaking septic tanks, and illicit sewer connections that empty sewage to the stormwater system. The Commonwealth of Massachusetts has strict regulations for bathing beaches, and Worcester Inspectional Services collected samples for *E. coli* weekly at public beaches during the swimming season to ensure that the water is safe for direct contact, closing beaches if the results were above the recreational threshold. L&P collected samples for *E. coli* at the surface of certain in-lake sites during all sampling events to assess *E. coli*

***Table 1 & 2** - There were no beach closures in 2022 due to fecal bacteria exceedances at Coes Reservoir and results from in lake testing remained low.*

2022 OPEN WATER E.COLI RESULTS	
DATE	RESULT
5/5/2022	<1
5/19/2022	7
6/9/2022	46
6/23/2022	14
7/7/2022	2
8/4/2022	5
8/18/2022	7
9/7/2022	74
10/6/2022	10
10/20/2022	9

Excellent	Good
Fair	Poor
Results in colonies/100 ml	

2022 BEACH E.COLI RESULTS	
DATE	RESULT
27-Jun	56
5-Jul	112
11-Jul	116
18-Jul	188
25-Jul	64
1-Aug	24
9-Aug	152
15-Aug	4
22-Aug	148

conditions in open water. Samples were sent to an external lab for analysis.

Fecal Bacteria at Coes Reservoir. There were no beach closures in 2022 due to fecal bacteria exceedances at Coes Reservoir. Results from beach testing conducted by Inspectional Services ranged between 4 and 188 cells/100ml, never exceeding the recreational limit *(see Tables 1 & 2).* Open water *E. coli* samples were collected at the surface of the southern site, with results ranging between undetected and 74 cells/100 ml. Most results were lower than 24 cells/100 ml, or in the range considered "Excellent". Fecal bacteria therefore were not a concern at Coes Reservoir in 2022, and L&P rated the reservoir as "Excellent" for bacteria.

Water Clarity

Water clarity is a measure of the transparency of water. Algae, microscopic organisms, eroded particles, and re-suspended bottom sediments are factors that interfere with light penetration and reduce water transparency. Clear water allows sunlight to penetrate the depths of a waterbody, supporting growth of aquatic plants, which provide food, shelter, and oxygen to aquatic organisms. Clear water is also pleasant to the eye and safer for recreational contact. Turbid water, or water filled with particles, absorbs more heat from sunlight. This reduces the water's capacity to hold oxygen, creating favorable conditions for algal and cyanobacteria blooms, which further reduce clarity. 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 were collected on each lake visit by L&P. TSS is a measure of the dry weight of suspended particles in a given amount of water. TSS samples were taken monthly and submitted to an external lab for analysis.

Water Clarity at Coes Reservoir. Secchi clarity at the two in-lake sites in Coes Reservoir ranged between 8.50 ft and 2.75 feet (see *Figure 3*). Most readings fell between 4 and 10 ft, or in the range considered "Fair" although several results were lower, especially at the end of the season when the waterbody was experiencing a cyanobacteria bloom. Surface TSS at Coes Reservoir ranged between 3 and 11 mg/l, with most results falling below 10 mg/l, or in the range considered "Excellent". Results at the bottom of the reservoir ranged between 3 and 14 mg/l, and were generally lower than 10 mg/l. Maximum TSS readings were all recorded on 23-Sep, when the lake was experiencing cyanobacteria bloom conditions. Overall, water clarity was considered "Fair" at Coes Reservoir in 2022.

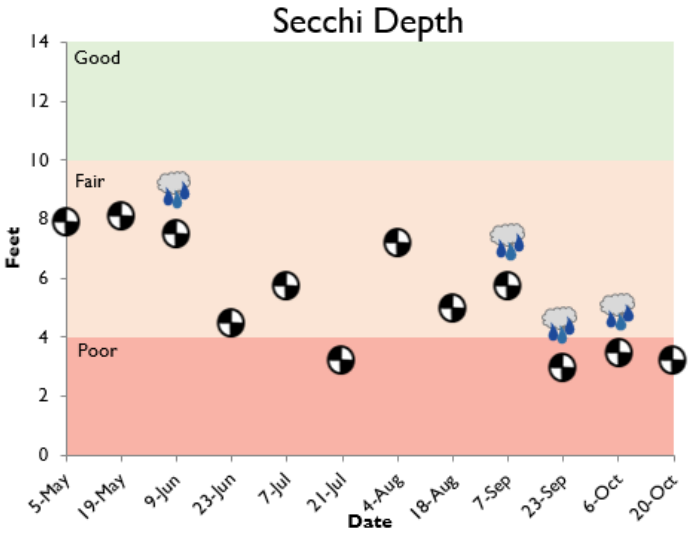

Figure 3 *- Secchi depth ranged from the "Poor" to "Fair" categories throughout the season. "Poor" secchi depth was seen generally later in the season.*

Temperature

Water temperature is important for understanding both the biology and chemistry of aquatic ecosystems. Because many organisms prefer to live in a narrow temperature range, understanding temperature across the area and depth of a water body is essential. Temperature is also a determining factor in the speed of chemical reactions and the ability of water to hold oxygen. As temperature increases, water can hold less dissolved oxygen. Temperature dynamics in lakes can also determine the level of mixing experienced throughout the water body, affecting the distribution of oxygen, nutrients, and organic matter throughout the lake. Temperature was measured using a temperature sensor on a handheld probe at the water's surface, and two feet from the bottom at the in-lake locations during every sampling event.

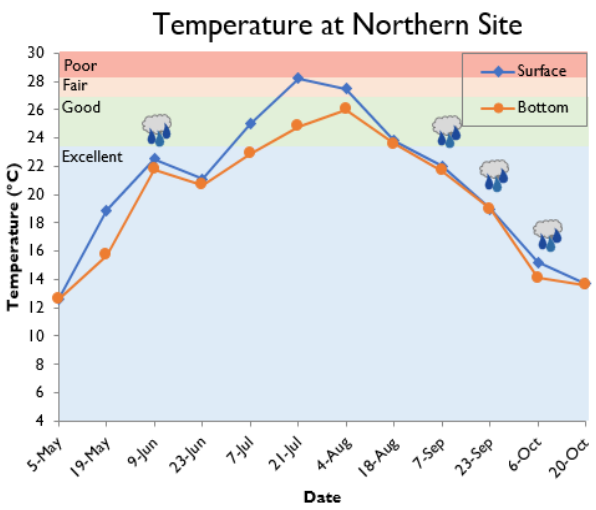

Figure 4 *- Bottom temperatures were considered "Excellent" all season. Surface temperatures were in the "Good" to "excellent" categories except for two dates that were considered "Fair".*

Temperature at Coes Reservoir. Surface water temperature at the in-lake sites began in the "Excellent" category at the beginning of the season and climbed to the maximum recorded temperature on 21-Jul before decreasing into the fall (see *Figures 4* and *5*). Maximum recorded surface temperatures in 2022 were considerably higher than in 2021, at 28.2°C at the northern site and 27.4° in the southern site compared to 24.4° and 25.0°C in 2021 respectively. As expected, bottom temperature at the northern and southern sites were always lower than the surface but followed the same seasonal fluctuations. Maximum recorded temperature on the bottom was higher at the northern site (26.0°C) than the southern site (23.5° C). Even while water temperatures were in the "Excellent" range for most of the season, because warm waters promote cyanobacteria activity, Coes Reservoir was rated "Fair" for the season for temperature.

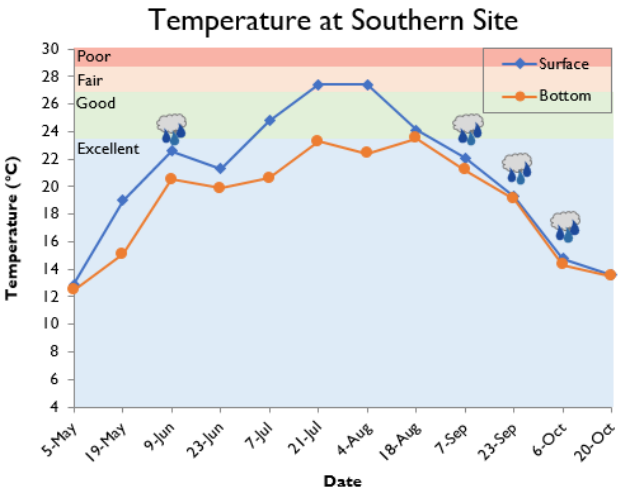

Figure 5 *- Bottom temperatures were considered "Excellent" all season. Surface temperatures were in the "Good" to "Excellent" categories except for two dates that were considered "Fair".*

Dissolved Oxygen

Oxygen dissolved in water is essential to aquatic life just as it is to life on land. Dissolved oxygen (DO) is a highly variable parameter that is controlled by many factors, including temperature, pressure, aeration, diffusion, rate of photosynthesis, rate of respiration and more. When water temperature rises, water can hold less dissolved oxygen, potentially causing stress to aquatic organisms. Thermal stratification, which is layering in the water column based on temperature, can also create a barrier to waterbody mixing, creating areas with depleted DO in some deeper portions of waterbodies. Increased algal growth followed by excessive decomposition of organic material can also lead to low oxygen conditions, and potentially causing fish kills. DO was measured using a galvanic DO sensor on a handheld probe at the water's surface, and two feet from the bottom at the in-lake locations during every sampling event.

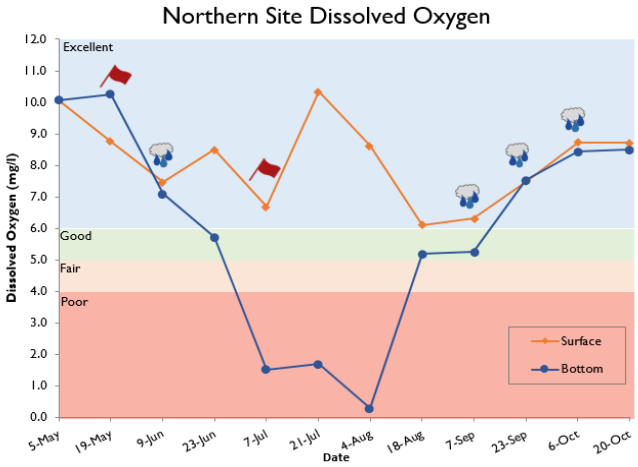

Figure 6 *- Dissolved oxygen at the surface was categorized as "Excellent" throughout the season. Bottom dissolved oxygen was considered "Good" to "Excellent" except for dates from 7-Jul through 4-Aug.*

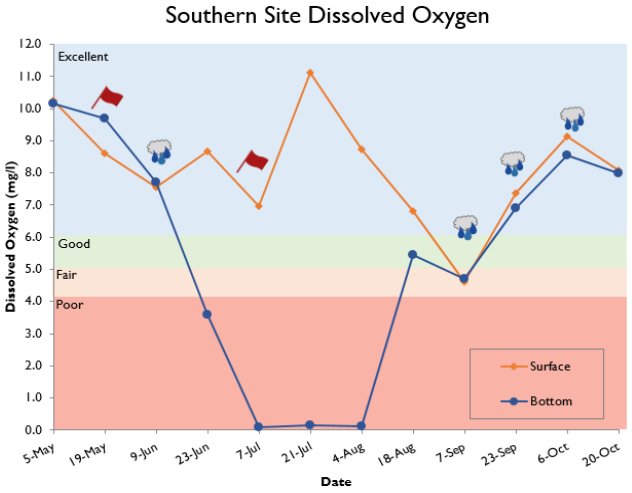

Figure 7 *- Dissolved oxygen at the surface was categorized as "Excellent" for almost every day of the season. Bottom dissolved oxygen ranged from the "Excellent" to "Poor" categories, with anoxic conditions in the middle of the season.*

Dissolved Oxygen at Coes Reservoir Surface DO at the in-lake sites was above 6 mg/l, or in the range considered "Excellent", in all but one instance (see *Figures 6* and *7*). Other than one low outlier reading on 7-Sep (4.6 mg/l), surface DO ranged between 6.1 and 11.1 mg/l and followed a similar pattern throughout the season at the northern and southern sites. DO was highest at both sites on 21-Jul, when the lake was experiencing cyanobacteria bloom conditions. As observed in past years, the bottom of the lake experienced anoxia, or no-oxygen conditions, during the middle of the summer. To better understand the extent to which oxygen depletion occurred in the water column, monthly depth profiles were taken. These included DO readings at the water's surface and at 5 ft increments until the bottom was reached. On 7-Jul and 4-Aug, while there was a healthy concentration of DO at 5 feet. However, between 5 and 10 feet, DO dropped to anoxic conditions, suggesting that the extent of the anoxia was greater than just near the bottom of the lake, which was what had been understood previously. Because of this, Coes Reservoir received a rating of "Fair" for DO in 2022.

pH

pH is the concentration of hydrogen ions (H+) in a solution. The more H+ ions that are present, the more acidic the solution. On a scale of 0-14 units, 7 is a neutral pH. As pH increases from 7, the solution is more basic, and as pH decreases from 7, it becomes more acidic. In aquatic ecosystems, pH affects most chemical and biological processes including species distribution, growth rate, reproductive success, and nutrient dynamics in lakes. A high pH can promote chemical reactions that release phosphorus from lake sediments. Healthy lakes in this area have a pH between 6.5 and 8.5. pH was measured using an ion-selective electrode (ISE) pH sensor on a handheld monitoring probe. Readings were taken at the water's surface and two feet from the bottom.

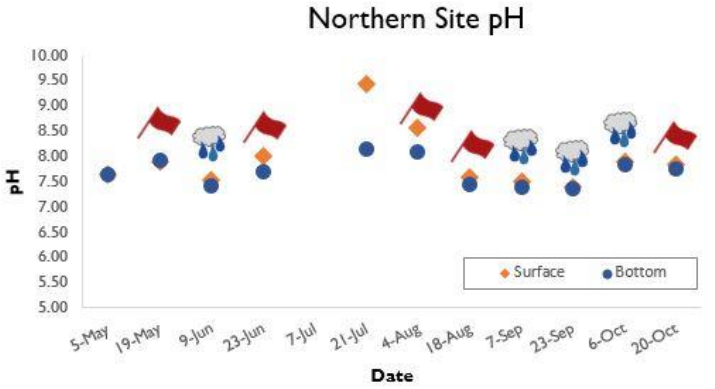

Figure 8 *- North Site: pH ranged from 7.4-9.5 at the surface and 7.4-8.2 at the bottom.*

pH at Coes Reservoir. Surface pH at the in-lake sites ranged between 7.2 and 9.5 over the course of the season (See *Figures 8* and *9*). The highest recorded pH at the reservoir was recorded on 21-Jul when the lake was experiencing cyanobacteria bloom conditions. pH readings at the bottom at each site had a smaller range, from 7.2 to 8.2, with no discernable pattern throughout the season. pH at Coes is higher than ideal, but while the range of pH throughout the reservoir was large, pH did seem to change gradually throughout the season.

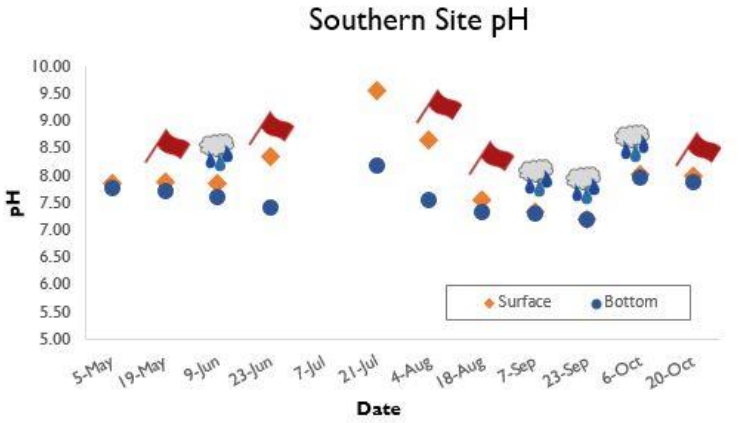

Figure 9 *- South Site: pH ranged from 7.2-9.5 at the surface and 7.2-8.2 at the bottom.*

Nutrients

Nutrients, primarily nitrogen (N) and phosphorus (P), are food sources for aquatic plants and algae. Although plants and algae are the basis of aquatic food chains, and necessary for a healthy lake ecosystem, an overabundance of nutrients can lead to issues such as harmful algal blooms and excessive plant growth. Common nutrient inputs to urban lakes and ponds include fertilizers, pet and goose waste, illicit sewer connections to the stormwater system, and runoff that flows over land into the stormwater 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. To examine the nutrients present in program lakes, L&P collected samples for several compounds and submitted them to an external lab for analysis. To

measure N, samples were collected for nitrate (NO_3) and ammonia (NH_3) at all sites monthly. As extensive issues were noted with QAQC checks performed by the laboratory, the data collected for NH_3 were not considered suitable for inclusion in this report. To measure P, samples were collected for total phosphorus (TP) twice a month at all sites, and total dissolved phosphorus (TDP) twice a month at all bottom sites. TDP was also analyzed to understand how much P is dissolved in the water and available for use by aquatic organisms.

Nutrients at Coes Reservoir. At the in-lake sites, TP on the surface ranged from 0.016 to 0.048 mg/l, or in the ranges considered "Excellent" and "Good", however most results were in the latter category (see *Figures 10* and *11*). Recorded surface TP generally increased in concentration over the course of the season at both sites with the highest results on 23-Sep, a wet weather day. These results followed trends of past years, with an increase of nutrients over the course of the season. Bottom TP concentrations were always higher than surface TP and ranged from 0.017 to 0.054 mg/l, generally increasing as the season went on. Samples were also collected for TDP at the bottom in the northern and southern sites. Results were consistently low, either below the laboratory reporting limit or below 0.025 mg/l, the range considered "Excellent". While L&P rated phosphorus as "Good" in 2022, it is possible that Coes Reservoir is susceptible to cyanobacteria blooms at lower phosphorus concentrations.

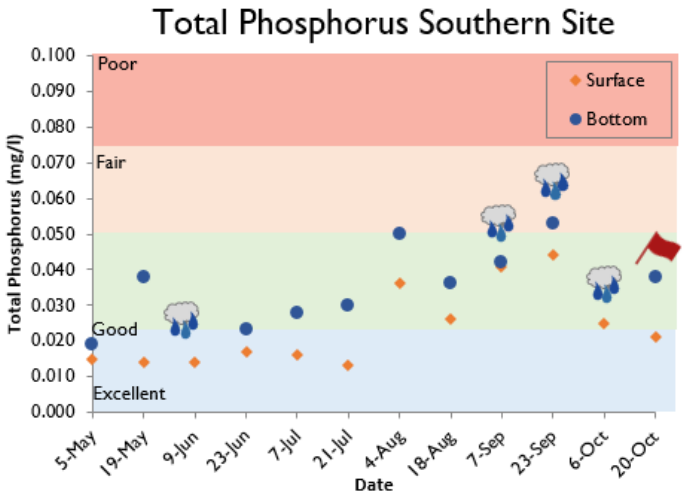

Figure 10 *- Overall total phosphorus was considered "Excellent" to "Good". Bottom total phosphorus reached the "Fair" category one day.*

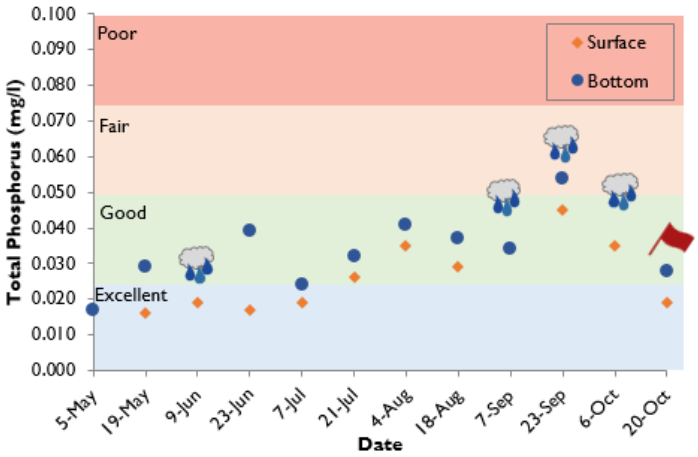

Figure 11 *- Overall total phosphorus was considered "Good" for most of the season. Surface total phosphorus was considered "Excellent" at the beginning of the season. Bottom total phosphorus reached the "Fair" category on one day.*

Cyanobacteria

Cyanobacteria are naturally occurring microorganisms in lakes and ponds. Using sunlight and nutrients such as N and P, cyanobacteria behave similarly to plants and algae. While normal at low densities in healthy ecosystems, under the right conditions, some species of cyanobacteria can reproduce quickly

causing potentially harmful blooms. Cyanobacteria blooms, in addition to being unsightly and smelly, can produce toxins that are harmful to humans and pets. Blooms also have the potential to create anoxic conditions that can cause fish kills.

To understand the abundance of cyanobacteria and make decisions regarding lake management and safe access, L&P contracted the collection of samples for cyanobacteria cell counts, or enumerations, on a weekly basis at the Mill Street Beach to determine bloom risk. When results were above the recreational threshold of 70,000 cells/ml it was considered to be blooming, and the water was closed to recreation until cell counts fell below this level naturally. During cyanobacteria blooms, L&P also contracted the collection of samples for cyanotoxin analysis to establish whether they were present in concentrations that could be harmful to humans or pets. When possible, L&P attempted to use preventative lake treatments, such as the application of algicide, to stop blooms from occurring by reducing the cell counts before they exceed the recreational threshold.

Figure 13 *– Cyanobacteria scums seen along the beach at Coes Reservoir in early July of 2022.*

Cyanobacteria at Coes Reservoir. Exceedances of the recreational threshold, as well as the appearance of scums at the beach, caused Coes Reservoir to have multiple advisories over the 2022 season. Usually at Coes Reservoir, if there are cyanobacteria blooms, they occur in the fall. However, in early July of 2022, scums seen around the shoreline triggered a proactive closure of the waterway (see *Figure 13*). The Lakes and Ponds Program worked to simultaneously procure treatment and order testing. The delay on test results meant that the exceedance of the recreational threshold was not known until after the treatment took place. Previous to the observation of scums, cyanobacteria cell counts remained characteristically low for the early season at Coes Reservoir, below 10,000 cells/ml (see *Figure 14*). However, between 12-Jul and 20-Jul, cell counts jumped from about 48,000 to 141,000 cells/ml, before returning to safe concentrations after the treatment.

Follow up test results for toxins and oxygen concentrations confirmed that the water remained safe for humans and wildlife, with no toxins detected or low-oxygen conditions observed. Unfortunately, the lake was closed for 5 days during a heat wave where there was high demand for swimming. This was the first time that a cyanobacteria bloom has closed Coes during the swimming season.

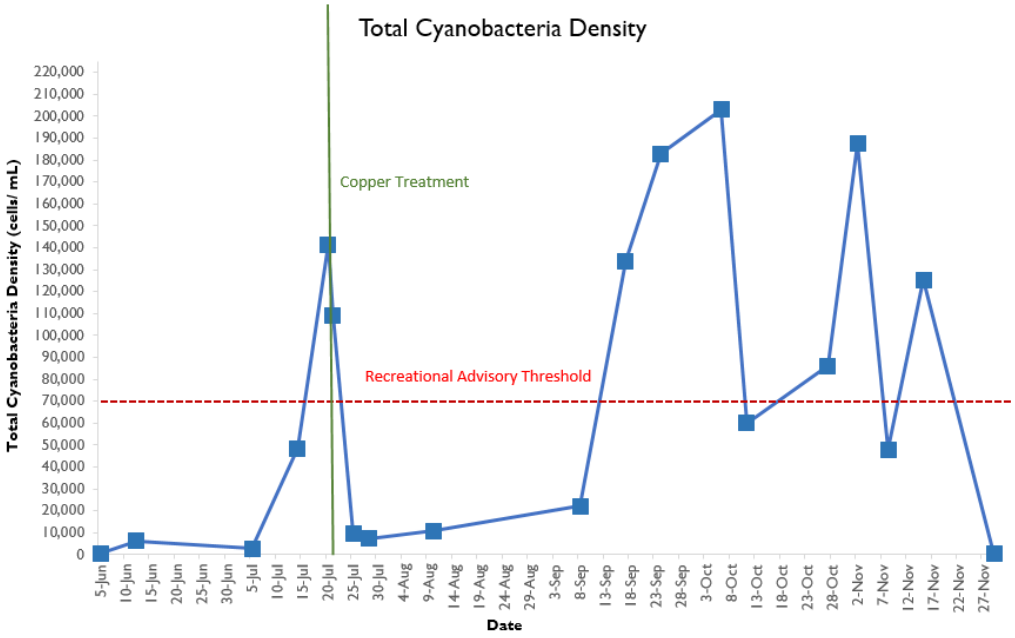

Figure 14 *– Cyanobacteria cell density over the course of 2022 at Coes Reservoir. Results over 70,000 cells/ml trigger a recreational advisory and lake closure.*

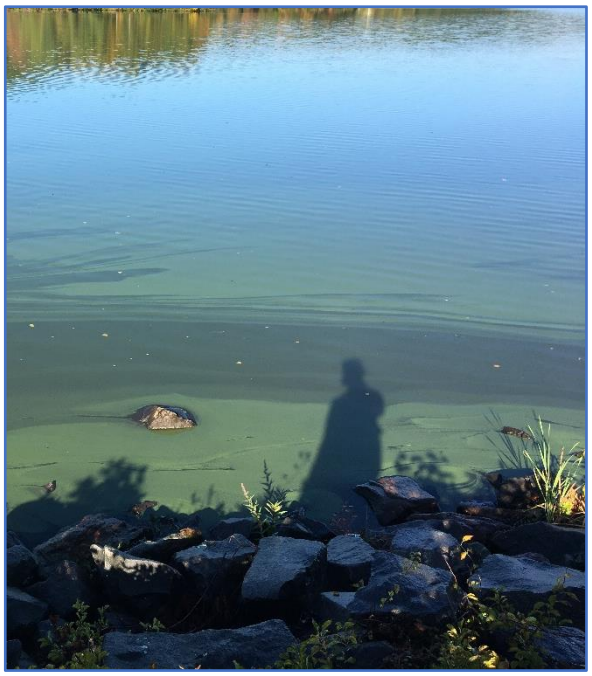

Figure 15 *– Cyanobacteria scums seen along the dam during the fall 2022 cyanobacteria bloom.*

From the end of July through the rest of the summer swimming season, cyanobacteria density remained safe for recreation. It was not until after Labor Day, in mid-September that the Program detected cyanobacteria results above the recreational threshold again. In addition, surface scums were seen across the lake (see *Figure 15*). L&P issued an advisory for the lake and continued testing, and throughout the fall, the cell count remained high. It was not until early December that the cell count was below the recreational threshold for two consecutive tests, allowing the advisory to be lifted. All in all, the advisory lasted over 70 days, the longest recorded advisory put in place for cyanobacteria at Coes Reservoir. Despite this extended period of bloom conditions, results for cyanotoxins were negative throughout. Because of these two events, L&P rated Coes Reservoir as "Fair" for cyanobacteria in 2022.

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 in these tributaries 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 were measured at the major natural tributaries and outlets of the lakes in the Worcester Lakes and Ponds Water Quality Monitoring Program.

Tributaries at Coes Reservoir. Tatnuck Brook is the major tributary to Coes Reservoir. It is a designated Coldwater Fisheries Resource, which is a special designation that is given to waterways that support cold water fish species, such as trout. These fish require higher quality water than warm water species. The outlet of Coes Reservoir is the spillway at the southern end of the of the reservoir.

Water temperature in Tatnuck Brook was warmer than ideal (see *Figure 16*). Most temperature readings were above 15°C, and during the warmest parts of summer the brook entered the "Fair" and "Poor" categories for temperature. The temperature at the lake outlet was on average 2.5°C higher than in Tatnuck Brook, demonstrating how much the brook warms after passing through Coes Reservoir.

DO in Tatnuck Brook ranged between 2.6 and 9.3 mg/l, with the lowest readings occurring when water was low during the summer months (see *Figure 17*). This is lower than ideal for a CFR, and could have detrimental effects on fish populations. DO was higher at the spillway, but still entered the "Fair" and "Poor" categories at the end of the season.

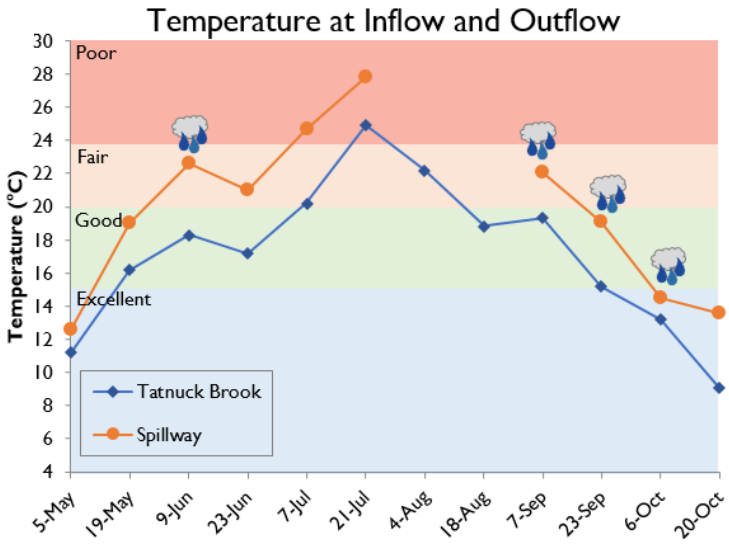

Figure 16 – *Tatnuck Brook had increasing temperatures throughout the season until mid-July, when it reached the "Poor" category, before coming back down. Temperature at the Spillway was consistently higher.*

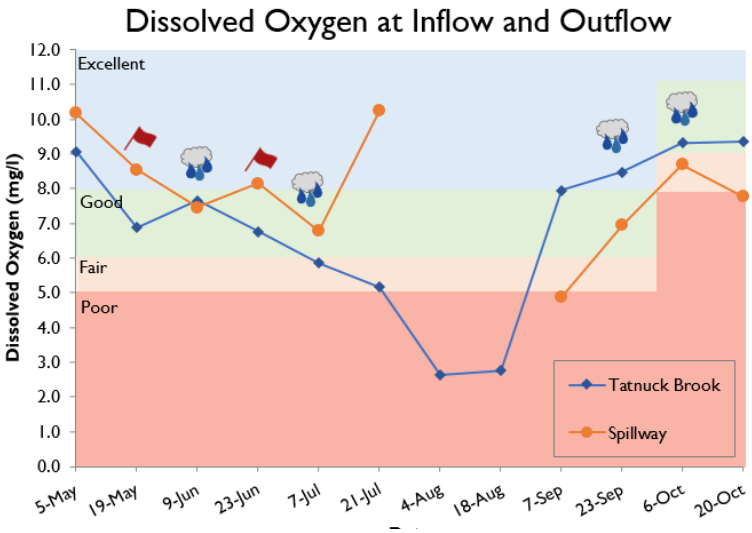

Figure 17 – *Tatnuck Brook had decreasing DO throughout the season until the end of August, when it was considered "Poor". DO was higher at the spillway, but still was lower than ideal for a CFR.*

TP results in Tatnuck Brook ranged between 0.023 and 0.082 mg/l, although most results were between 0.050 mg/l and 0.075 mg/l or in the range considered, "Fair" (see *Figure 18*). These high results were occurring even on days that were not considered wet weather. At the outflow, results were consistently lower, ranging between 0.017 and 0.050 mg/l, falling into the "Good" and "Excellent" categories, similar to the results at the southern site.

NO_3 results from Tatnuck Brook were considerably higher than the in-lake sites, ranging between 0.093 and 0.214 mg/l, though still in the ranges considered "Excellent" and "Good".

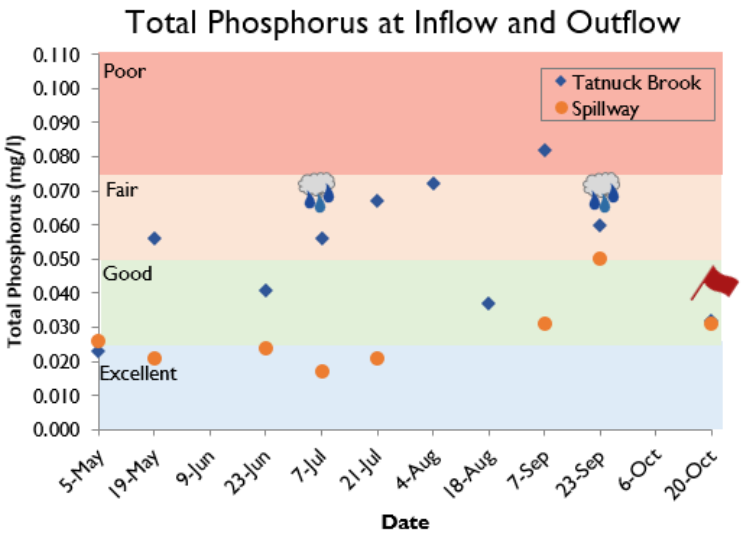

Figure 18 *- Total phosphorus was elevated in Tatnuck Brook, most sample dates were in the "Fair" category. Total phosphorus measured at the spillway was considered "Excellent" to "Good".*

At Tatnuck Brook, pH ranged between 6.1 and 8.3, not showing a pattern through the season. At the outflow, all but one sample fell between 7.0 and 8.1, with the maximum recorded reading of 9.4 taken on 21-Jul, when other high pH values were observed throughout the waterbody.

Invasive Aquatic Plants and Animals

Plants and animals are vital parts of any lake ecosystem. 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. 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 to the region and outcompetes local flora and fauna. The absence of natural constraints, like predators or environmental limitations, allows invasive plants and animals to reproduce at a rapid rate. When invasive aquatic plants and animals become too numerous or dominant, they can overtake all available space, disrupting local ecosystems and making recreation more difficult. Invasive organisms can arrive by hitching a ride on boats, pets, or boots to get to a new location. Some are released with good intentions as a beautiful addition to a landscape

Figure 19 *– Community members participated in a Water Chestnut hand pulling event in August of 2022, clearing plants remaining in the Southern portion of the lake after herbicide treatments.*

or sport fishing opportunity. Professional surveys and visual inspections from Lakes and Ponds Program staff were used to make management decisions regarding invasive species.

Invasive Aquatic Plants and Animals at Coes Reservoir. Coes Reservoir is managed for three invasive aquatic plants: Water Chestnut (*Trapa natans*), Fanwort (*Cabomba caroliniana*), and Eurasian Milfoil (*Microphyllum spicatum*). Before the utilization of chemical treatments, the Milfoil and the Water Chestnut threatened to overtake the entire reservoir. To address populations of these plants, the Lakes and Ponds Program uses a combination of physical removal and herbicide strategies. A successful systemic herbicide treatment of Fluoridone (trade name: Sonar) took place in 2019 and significantly reduced the fanwort and milfoil density through the present. In 2022, the focus was on continuing to eradicate the Water Chestnut. Imazamox (trade name: Clearcast) was applied to the norther portion of the lake on 29-Jun and 24-Aug of 2022. To address Water Chestnut plants that were not covered by herbicide treatment, a community hand pulling event was organized in mid-August (see *Figure 19*), in which 15 community members collected plants and trash in kayaks over the course of a morning. Together, these activities were successful in reducing the density of the invasive plant during the season. Unfortunately, due to its unique reproductive strategy, it will be many more years before the water chestnut will be completely eradicated.

A plant survey conducted in September of 2022 indicated Water Chestnut as the only invasive species, among a number of native aquatic plants. The survey showed the range of Water Chestnut to be generally limited to the northern end of the lake. Although it is likely that remnant populations of fanwort and Eurasian Milfoil exist, populations were small enough to evade detection by the survey.

Industrial Contaminants

As a post-industrial urban center, legacy pollutants, and emerging contaminants of concern from industrial processes may be present in Worcester's recreational waters. These contaminants may cause negative health and environmental effects. Every three years, L&P tests for a range of these compounds on both a wet and dry weather event in the lakes. In 2022, L&P tested for 74 volatile organic compounds (VOCs), 72 semi volatile organic compounds (SVOCs), 9 polychlorinated biphenyls (PCBs), petroleum hydrocarbons (TPH), 23 perfluoroalkyl substances (PFAS), 21 pesticides, 10 herbicides, and 22 heavy metals. Detected parameters are shown below. To see a full list of contaminants tested for, contact greenworcester@worcesterma.gov.

Industrial Contaminants at Coes Reservoir. All results for VOCs, SVOCs, PCBs, TPH, pesticides, and herbicides were below reporting limits, indicating an extremely low to no concentration. Eleven metals were detected including aluminum, arsenic, barium, calcium, copper, iron, magnesium, manganese, potassium, sodium, and zinc. Overall, metal results were similar to or decreased from 2019 testing (*see Table 3).* PFAS is a class of emerging contaminants of concern, however, there are no regulations on PFAS for recreational waterways. There are drinking water regulations for six species of PFAS. The PFAS drinking water limit (also known as an MCL) is total of 20 ng/l, as a sum of the 6 regulated species. The combined total of regulated PFAS species in Coes Reservoir on each sampling day was 24.63 and 20.45 ng/l (see *Table 4*). These results are lower than those of 2019. As drinking water standards are generally much

stricter than those of recreational waterways, we can assume that PFAS is not a concern for recreational users of Coes Reservoir.

Table 3 – *Eleven metals were detected in 2019 and 2022. These metals are naturally occurring in New England soils and are not present in quantities that could affect human health. "ND" signifies that the compound's concentration was not detected by the lab.*

Parameter	Wet Result	Dry Result	Wet Result	Dry Result	units
Metals	**9/7/2022**	**10/20/2022**	**7/12/2019**	**9/12/2019**	
Aluminum, Total	0.0109	0.0229	0.0118	0.011	mg/l
Arsenic, Total	0.01245	0.01338	0.00588	0.0105	mg/l
Barium, Total	0.02714	0.02033	0.01047	0.01806	mg/l
Calcium, Total	11.5	11.1	12.6	12.6	mg/l
Copper, Total	0.00463	0.00145	0.00103	0.00121	mg/l
Iron, Total	0.685	0.485	0.29	0.487	mg/l
Magnesium, Total	1.76	1.81	1.84	1.8	mg/l
Manganese, Total	0.5336	0.1859	0.05917	0.3313	mg/l
Potassium, Total	3.21	3.34	3.01	2.98	mg/l
Sodium, Total	49.7	44.4	47.3	46.8	mg/l
Zinc, Total	ND	0.01206	0.01037	ND	mg/l

Table 4 – *Several PFAS compounds were detected at Coes Reservoir in 2019 and 2022. The totals of regulated compounds were low and not of concern for recreational contact. "ND" signifies that the compound's concentration was not detected by the lab. "NT" signified that the compound was not tested for, as the analysis was not yet available.*

Parameter	Wet Result	Dry Result	Wet Result	Dry Result	Unit
Non-Regulated Perfluorinated Alkyl Acids	**9/7/2022**	**8/4/2022**	**7/12/2019**	**9/12/2019**	
Perfluorobutanoic Acid (PFBA)	7.4	5.48	NT	NT	ng/l
Perfluoropentanoic Acid (PFPeA)	25.3	21	NT	NT	ng/l
Perfluorobutanesulfonic Acid (PFBS)	2.26	1.87	2.35	2.17	ng/l
Perfluorohexanoic Acid (PFHxA)	13.6	11.5	NT	NT	ng/l
Regulated Perfluorinated Alkyl Acids	**9/7/2022**	**8/4/2022**	**7/12/2019**	**9/12/2019**	
Perfluoroheptanoic Acid (PFHpA)	7.32	6.18	12	14.8	ng/l
Perfluorohexanesulfonic Acid (PFHxS)	4.39	3.66	5.09	4.47	ng/l
Perfluorooctanoic Acid (PFOA)	4.97	4.64	6.95	8.14	ng/l
Perfluorononanoic Acid (PFNA)	2.04	ND	2.45	3.42	ng/l
Perfluorooctanesulfonic Acid (PFOS)	5.91	5.97	8.16	7.64	ng/l
Total Regulated	**24.63**	**20.45**	**34.65**	**38.47**	**ng/l**

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, 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 at Coes Reservoir. Litter is a difficult parameter to measure in a quantitative way, although litter has been determined to be a concern for lake water quality and recreational enjoyment at Coes Reservoir. A study at the Mill Street Beach in 2021 found that, of the categories examined, "small items", "tobacco products", and "food packaging and containers" were the most prominent classes of litter present. See *Figure 20* for the relative rankings of the different classes of litter examined. While trash receptacles are left out by the City, they are often overturned or not used. While litter was not formally qualified in 2022, the Lakes and Ponds Program is attempting to combat this challenge with collaborations with local organizations and an educational campaign, which you can read more about in the following section.

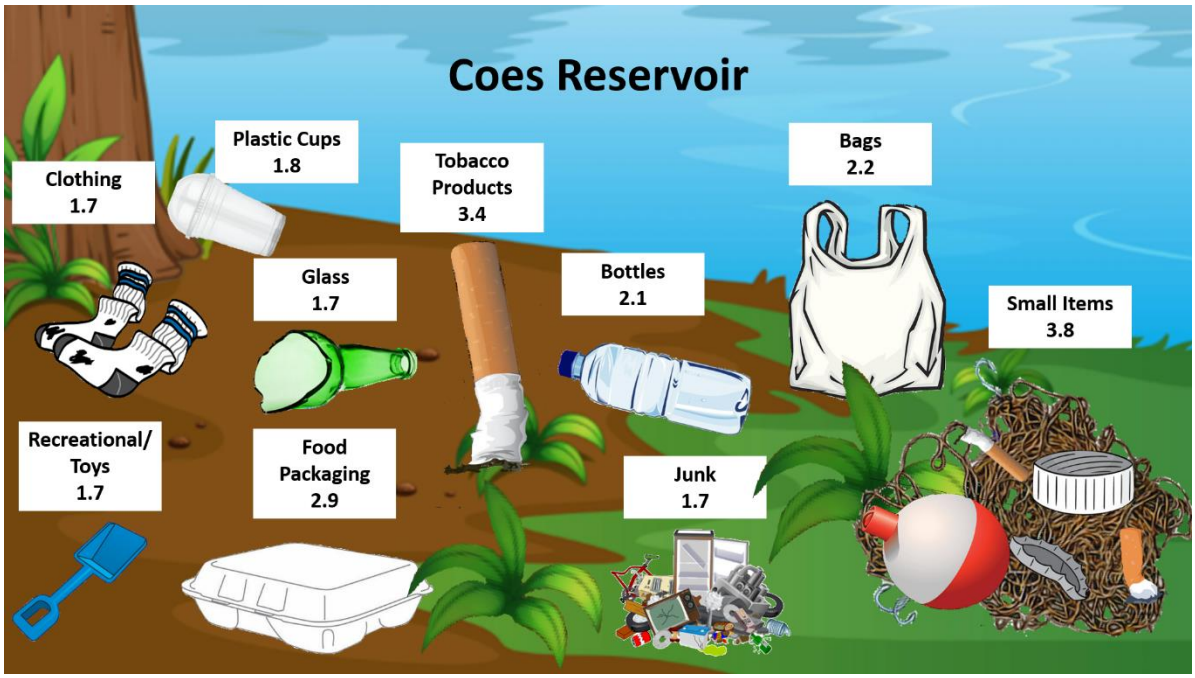

Figure 20 - *The relative abundance of different categories of litter in 2021. A rating of 1 indicates lowest abundance, and 5 is the highest.*

Ongoing Projects

Tatnuck Brook Watershed Monitoring: Collaboration with Worcester State University

Coes Reservoir is the last of a chain of lakes along Tatnuck Brook, which stretches from Holden through Western Worcester. Other lakes on the brook include Cooks Pond, Patch Reservoir, Patch Pond, and Coes Pond. Previously, consistent water quality monitoring has been restricted to Coes Reservoir due to funding and staffing constraints. However, in 2022, the Lakes and Ponds Program collaborated with Worcester State University (WSU) researchers and students to expand sampling into Patch Reservoir, Cooks Pond, and additional sections of Tatnuck Brook. Collaborators from WSU received a grant to use L&P methodologies to collect samples in these waterbodies on the same days as the Lakes and Ponds Program does in Coes Reservoir. This allows for the ability to directly compare results to better understand water quality dynamics throughout the watershed and create more informed management plans for these waterbodies in the years to come. Alongside L&P methodologies, researchers and students from WSU collected samples for aquatic macroinvertebrates to characterize communities and establish a baseline for biomonitoring in the system. Reports from these investigations have been included alongside the four program lakes and can be found at WorcesterMA.gov/bluespace.

Goose Fencing

In 2021, the Lakes and Ponds Program implemented a Goose Fencing Pilot Project that aimed to reduce the number of beach closures at Indian Lake and Coes reservoir due to fecal bacteria exceedances by humanely keeping geese away from the beach (see Figure 21). Geese usually enter the beach from the water and are not good at getting over low fences. They are uncomfortable when there are barriers between the beach and the water because the water is their escape route from land predators. After erecting a small fence between the shore and water during the evening hours, L&P found the use of the beach by the geese was significantly reduced, and beach closures due to *E. coli* also seemed to be reduced. In 2022, the Lakes and Ponds Program improved the construction of the fencing using higher quality materials to make installation easier to increase usage during the summer. Use of the beach by geese appeared to be reduced in 2022 and there were no beach closures due to fecal bacteria exceedances. L&P plans to continue the use of goose fencing at Coes Reservoir's beach and to develop an effective and easy to use solution to reduce goose congregation on the beaches and limit beach closures due to fecal bacteria exceedances.

Figure 21 – *Goose fencing at Coes Reservoir was successful in deterring geese from the beach area.*

State of the Lake

In 2022, Coes Reservoir received a score of "Fair" for the first time, being downgraded from "Good". Despite the challenges experienced at Coes reservoir in 2022, there were some successes. There were no beach closures due to fecal bacteria and open water bacteria concentrations were low. The invasive plant management plan is working, and the end-of-season aquatic plant survey showed that Fanwort and Milfoil were not a challenge, and L&P is making progress on the Water Chestnut infestation. Even with these successes, the warm, dry summer had a negative impact on the reservoir.

The lake was closed for 78 days due to cyanobacteria blooms. Five of these were in the midst of a heat wave when swimming was in high demand. Water clarity was low and pH was higher than ideal. Temperatures and TP results occasionally entered ranges that likely promoted cyanobacteria blooms as well.

Plan for 2023

Water Quality Monitoring

In 2023, the Lakes and Ponds Program will continue to monitor Coes Reservoir in order to track changes in water quality and implement its cyanobacteria and invasive aquatic plant management plans. L&P will continue to contract cyanobacteria enumeration to better understand cyanobacteria population dynamics and inform management and public health decisions.

As Coes Reservoir experienced impacts from cyanobacteria in 2022, the Lakes and Ponds Program will continue to refine its monitoring and management approach to avoid prolonged lake closures. Since 2021, the Lakes and Ponds Program has utilized solar powered continuous monitoring buoys (*see Figure 22*) at Lake Quinsigamond, with a new buoy installed at Indian Lake in 2022 These buoys contain probes that track the cyanobacteria indicators phycocyanin and chlorophyl, as well as turbidity and temperature, and remotely upload them to an online database where data can be viewed in real time. The Lakes and Ponds Program intends to install a buoy at Coes Reservoir. This should allow for improved responsiveness to mobilize management activities in the case of an oncoming bloom.

Figure 22 – A continuous monitoring buoy will be deployed at Coes Reservoir in 2023 to collect parameters associated with cyanobacteria activity.

Following the success of the collaboration with WSU to extend monitoring up the Tatnuck Brook Watershed, the Lakes and Ponds Program intends to continue to support these efforts and seek out further university research partnerships that can extend the reach of L&P's monitoring program to other waterways in Worcester.

Lake Management

Boat Decontamination Stations. The Lakes and Ponds Program is committed to monitoring and managing the invasive aquatic plants that can obstruct waterways. However, the best way to curb invasive aquatic plants' effect on lake ecosystems is to keep them out of the lakes in the first place. The most common way invasive aquatic plants are spread is the accidental introduction as hitchhikers on boats and trailers. In many cases, even a small piece of a plant can re-root and start growing in a waterbody. In the fall of 2021, the Lakes and Ponds Program was able to utilize funds from the American Rescue Plan Act (ARPA) to install solar powered boat decontamination stations at Indian Lake and Coes Reservoir (see *Figure 23)*. These stations are free to use and contain instructions on best practices for intercepting invasive aquatic plants before they can take root in Worcester's waterbodies. There are blowers and grabbers to remove weeds in hard-to-reach places, brushes to scrub algae off the sides of boats and tools to drain and dry bilge water. To learn more about invasive aquatic plants and these decontamination stations see the recent episode of "The Blue Space Minute" on the City of Worcester YouTube Channel Blue Space Minute - Boat Cleaning Stations - YouTube.

Figure 23 - *Solar powered boat decontamination stations were installed at Coes Reservoir to help enable boaters to stop invasive plants at the source by decontaminating watercraft before and after use.*

Education and Outreach

Litter. The Lakes and Ponds Program will work with its partners, including the Department of Public Works & Parks, and Worcester Green Corps, to use L&P's data to create litter reduction strategies. L&P will also try to build pride around Coes Reservoir with videos and signage related to its water quality, including the re-release of the "Blue Space Minute" Episode on Litter, which debuted in April of 2022.

Family Aquatic Science Day. As part of the 2021 Blue Space Angler Event Series, the Tatnuck Brook Watershed Association (TBWA) hosted an event at Coes Reservoir called the Family Aquatic Science Day (see *Figure 24*). In this event participants of all ages discovered the aquatic environment through a series of booths where they took measurements with water quality meters, learned about aquatic macroinvertebrates, looked at cyanobacteria under a microscope, explored a 3-D replica of a watershed, and collected fish with a large seine net.

Figure 24 –*Attendees and volunteers at the 2021 Family Aquatic Science Day collect fish and other aquatic organisms in a seine net at Coes Reservoir.*

The Lakes and Ponds Program plans on supporting the TBWA in holding the event again in 2023 and increasing participation from local young people. This will serve as an opportunity to continue to raise awareness about factors that lead to cyanobacteria blooms and how community members can support L&P's efforts to mitigate the ecological and public health concerns they create.