Improving Water Quality of Green Hill Park Ponds and Investigating the Feasibility of an Irrigation System Using Pond Water

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Abstract

Water pollution in surface water is attributed to stormwater runoff, introducing nutrients and sediment into waterbodies. This project researched the historical and current conditions impacting the Green Hill Park Ponds, as well as researched the feasibility of using Pond water to irrigate the adjacent golf course. Samples of the water from both ponds were collected and analyzed. The results helped determine the conditions negatively impacting the ponds and create mitigation strategies, which we recommended to the City of Worcester and the Green Hill Park Coalition. The mitigation strategies we recommended were planting vegetative buffer strips around the perimeter of the main pond, using chemical treatment to reduce algae bloom, and not implementing the irrigation system.

Figure 1: Small Pond in the Vietnam Memorial (Daily woot, 2016)

Acknowledgements

We want to thank the following people from the City of Worcester Department of Public Works and Parks for their contributions to the completion of this project: Jacquelyn Burmeister, Robert Antonelli, David Harris, and Ian Weyburne. We also want to thank the following people at Worcester Polytechnic Institute for their contributions to the completion of this project: Professor Laura Roberts, Professor Harold Walker, Professor Aaron Sakulich, Professor Paul Mathisen, and Donald Pellegrino. Finally, we want to thank the following people from the Green Hill Park Coalition: Michael Comer, and our fantastic sponsor, Brian McCarthy.

The Executive Summary

This project seeks to understand and develop solutions to the water quality issues in Green Hill Park, Worcester Massachusetts.

Green Hill Park is one of Worcester's oldest and largest Parks. Its history spans back to the 1700s, when it served as an estate to the Adams family, and later the Green family. The Green family would pass the estate down through generations, who expanded it until 1902, when it was purchased by the City of Worcester. It is currently almost 500 acres, with many amenities such as a golf course, a skateboard Park, a Vietnam Memorial, and a small farm. However, one of the biggest attractions is the aptly named Green Hill Pond, which is a 30-acre Pond often used for fishing and rowing.

Figure 2: View of the Golf Course from the Pond

Prior to starting this project, we identified our two main goals, each with a set of objectives to better accomplish those goals. Our first goal was to understand the conditions of the Pond and create a mitigation plan to help remedy these issues even after the completion of this project. To achieve this, we tested the water in April, prior to the project, to create a baseline for the Ponds so we can understand what the Ponds are like at their healthiest and to give us data to compare against past and future tests. When we received these results, we analyzed them to determine the harmful and current pollutants. Once we determined the Ponds' key issues, we created a set of mitigation strategies to tackle each problem.

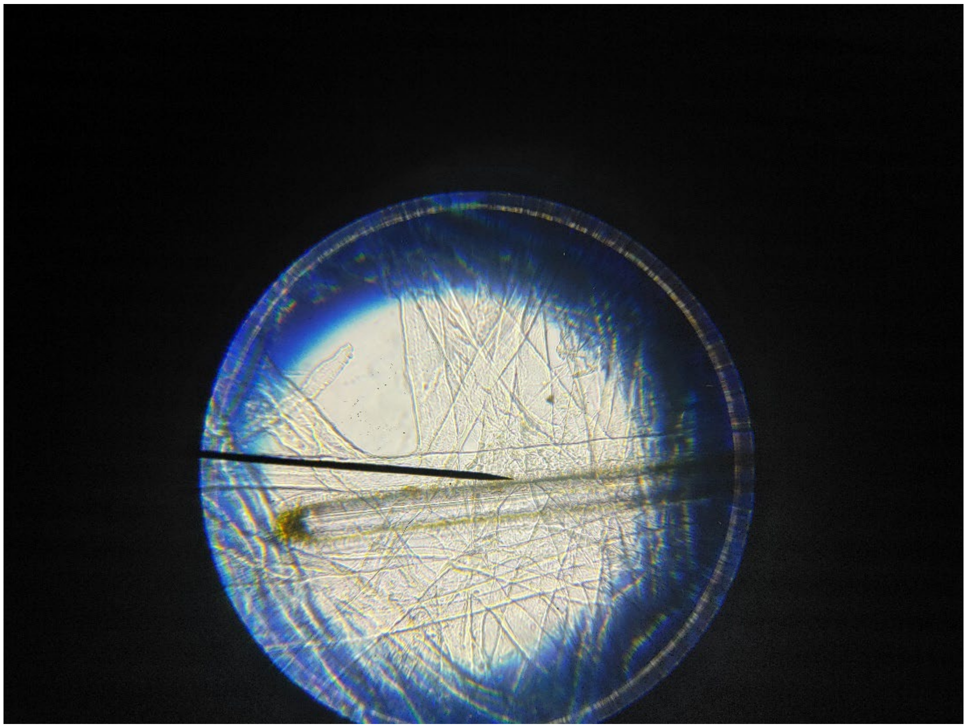

Figure 3: Cyanobacteria found under a microscope

In this project, we had three groups to analyze our water samples. The first group was Nashoba Analytical, a company that the Coalition uses for water tests. The second group was the Worcester Cyanobacteria Monitoring Collaborative, a program run by Jacquelyn Burmeister, who is the City of Worcester Department of Public Works and Parks' Senior Environmental Analyst, who monitors the level of Cyanobacteria in ponds and lakes across the City of Worcester. The final group was us at the Worcester Polytechnic Institute Civil and Environmental Engineering Laboratory, with help from Lab Manager Donald Pellegrino and Professor Paul Mathisen while our WPI tests did not show any problems concerns, these tests did confirm the results from Nashoba Analytical. The Nashoba Analytical test results (Appendix IV) told us a lot about the overall quality of the water. The key issues in the ponds that we found with these tests were the Iron, Manganese, and Total Coliform counts.

The Iron and Manganese counts both exceeded Nashoba's major contaminant level in the small pond, based off the EPA's drinking water standards (Figures 14 & 15 respectively). While this is a noticeable issue, there is no correlation between any of our tests to suggest that this is an overarching issue for recreational use.

One microbiological issue the Nashoba tests showed was the Total Coliform levels. Total Coliform bacteria is a group of bacteria that enters the water through animal waste. A well-known bacterium in this group is E. Coli. The results (Figure 19) showed a spike in the May and June tests. When we asked Jacquelyn Burmeister about this trend, she explained that coliform bacteria often do not live long in ponds unless it is entering the water from a constant source, which means it can vary between tests. She also said that total coliform is only a concern in drinking water, not recreational water, and E. Coli levels are not high enough to suggest a health concern for any citizens. However, even though the elevated coliform count is not an issue for recreational water use, it does indicate that the ponds are primed for an algae bloom. The high coliform count suggests animal waste is entering the ponds, and the nutrients in the waste promote algae growth.

The other microbiological issue is cyanobacteria. Cyanobacteria are groups of blue green algae that are the primary culprits behind the yearly algae bloom. The Worcester Cyanobacteria Monitoring Collaborative's test results (Table 5) showed that the Pond is usually at an elevated risk for an algae bloom during June and July, with our test in late May confirming this trend.

To finish this goal, we researched two mitigation strategies that we think the Green Hill Park Coalition and the City of Worcester should consider. The first strategy is to plant vegetative buffer strips. These are different types of vegetation that are planted around water bodies, reducing erosion and contaminants from storm water runoff. Planting a strip of Vetiver, Switch, Side Oats Grama, Big Bluestem, or Little Bluestem grass around the perimeter of the pond will reduce the number of sediments entering the pond by 70%-90% (Table 7). Our second strategy is for the Coalition and the City to do regular treatment to the Pond. There are several ways to treat the Pond such as using Copper Sulfate and Cutrine Plus, antimicrobial solutions that bind to phosphate and sulfur groups of a microorganism, damaging major cell functions and Aluminum Sulfate to decrease the turbidity of the pond. Antimicrobials can target a wide range of microorganisms, including bacteria, fungi, algae, and viruses. These treatments can help prevent and manage the yearly algae bloom. Another treatment option is through Solitude Lake

Management, a professional water treatment company that is often used by Indian Lake. This solution was recommended to us by Professor Sakulich.

Figure 4: Image of the former drain of the pond

The second goal of our project was to research how feasible implementing an irrigation system would be. The City of Worcester is interested in using water from the Green Hill Pond to irrigate the adjacent golf course. Our first objective was to determine the volume of the Pond. We got data from the City about the area of the Pond, and we used a depth finder to plot the depth. Once we calculated the average depth, we found the volume. Then, we had to find the average rainfall and the average water use for irrigation over the summer months. We were able to get the irrigation data from the past four years, but we had to calculate the average rainfall data by multiplying the monthly rainfall by the area of the Pond (Table 6). Once we did that, we calculated the average evaporation that occurs per foot based on the average depth, the total volume of the Pond, and how many feet (or inches) were lost. During our research, we were concerned that the Pond water being contaminated with cyanobacteria would affect the irrigation system, which led us to suggesting that further testing and solutions were needed. Because of the high loss of water due to evaporation, we concluded that the irrigation system should not be implemented until further research of the water level in the summer months.

We have provided the City of Worcester and the Green Hill Park Coalition with helpful solutions for them to make the best choices for the Green Hill Ponds. We are eager to see how the park will change after implementing our recommendations.

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Chapter 4: Research Findings	Aaron Swann, Cyril Ogbebor, Gabriel Buziba	Aaron Swann, Cyril Ogbebor, Gabriel Buziba
Chapter 5: Recommendations	Aaron Swann, Cyril Ogbebor, Gabriel Buziba	Aaron Swann, Cyril Ogbebor, Gabriel Buziba
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Chapter 1: Welcome to Green Hill Park

In today's world, our water quality has begun to deteriorate due to the modernization of our cities, which includes building roads, bridges, and landfills to create more infrastructure. Roads and paved surfaces reduce the soil's ability to soak up water, causing stormwater runoffs and introducing non-point source pollutants to a water body. Landfilling can also impact water quality if leaching occurs.

Local communities are also affected by this issue. Green Hill Park (GHP) is one of the largest Parks in Worcester, Massachusetts. It is a 500-acre Park that has served the community for decades. There are two Ponds at Green Hill Park which suffer from water pollution, Green Hill Pond, and Duck Pond. The water quality noticeably deteriorates every summer, getting worse with each passing year. If this continues, it poses a significant danger to citizens enjoying the Park, and the animals who live there.

Thus, this project aimed to determine the probable cause of the Ponds' degrading water quality and suggest mitigation strategies on how to improve the water quality of the Ponds. We also researched the effects of using the Pond water to irrigate the golf course and how this would impact the Pond over time.

We conducted this research by investigating the current baseline of the water and studying how it changes over time. We investigated the source of the Pond contaminants to determine the best mitigation strategy.

Figure 5: Green Hill Park drone view (Blk Supra, 2018)

Chapter 2: Background

This chapter introduces the project and the project goal. It also provides a brief history of Green Hill Park, Green Hill Park Coalition, and Green Hill Pond. It provides information needed to understand the project and the Ponds' water quality.

2.1: History of Green Hill Park

Figure 6: Picture of the Vietnam Memorial at Green Hill Park

Green Hill Park is the largest Park in the City of Worcester. The Green Hill Park Coalition website states that the Park is almost 500 acres. According to the Coalition, Martin Green was part of the Green Family, who bought the land from the original owners. The website states that he undertook many landscaping and engineering projects throughout the estate, including damming the Bear Brook Valley to form an extensive body of water (present-day

Green Hill Pond) in 1878. In 1903, Martin's brother, Andrew Green, died and left his estate of 549 acres to his nieces and nephews, who then sold the Parkland to the City of Worcester in 1905 (Green Hill Park Coalition, 2015).

2.2: Green Hill Park Coalition

Figure 7: Image of Green Hill Park Coalition Logo (Green Hill Park Coalition, 2015)

The Green Hill Park Coalition is a non-profit citizen group established in 2000 with the goals of preserving the remaining acreage of Green Hill Park, enhancing the Park's natural and cultural resources, and protecting the Park through conservation restrictions. The Green Hill Park Coalition comprises of citizens, primarily neighbors of the Park, who come together to make sure the Park is kept clean. The Coalition also partakes in some volunteer projects around the Park.

2.3: Green Hill Pond

According to the history of Green Hill Park as told by the Green Hill Park Coalition, Green Hill Pond is an artificial Pond created in 1878 by Martin Green when he dammed the Bear

Brook valley and formed an extensive water body. It is a thirty-acre Pond surrounded by a Golf course and a Park, which is used by the community for various outdoor activities. The Pond has two outlets and drains into Lake Quinsigamond.

Figure 8: Image of Dam at Green Hill Pond

2.4: Current Conditions of the Green Hill Pond

The Green Hill Park Coalition noticed the Ponds' water quality degrades in the summer months, citing significant algae bloom, causing the Pond to turn green in the summer months. The Green Hill Park Coalition participates in the City of Worcester Cyanobacteria Monitoring Collaborative to monitor the changes in the Pond's water quality. The Coalition has also been doing independent water testing for the past three years to further understand the changes in water quality.

Figure 9: Image of early Algae bloom in Green Hill Pond

2.5: Water Quality Standards

To understand the water quality test results given to us by Green Hill Park Coalition, we researched the laws enacted in the United States to prevent water pollution. The Clean Water Act (CWA) is a law that was passed in 1972, it regulated pollutant discharge into the United States waters and gave the Federal Government greater ability to enforce the new regulations by creating the United States Environmental Protection Agency (US EPA, n.d.). The US EPA laws helped to reduce point source pollution and set water quality standards for contaminants (Cohen, 1999).

2.6: Current Water Quality of the Ponds

The Clean Water Act has a set water quality standard for Ponds, lakes, or any water body that is to be used for recreational activities such as swimming, fishing, or any other activity that involves human contact with the water. The Pond must meet the water quality standards set by the United States Environmental Protection Agency. The current water quality of Green Hill

Ponds will be discussed below. Each test parameter will also be briefly introduced in the following subsections, as well as their impact on the usability of the Pond water.

2.6.1: Escherichia Coli

Escherichia coli (E. coli) is a bacterium commonly found in the digestive system of humans and animals. E. coli in a water body is used as an indicator to monitor the possible presence of other more harmful microbes such as Cryptosporidium, Giardia, and norovirus (Lewis, 2003). Human contact with contaminated water can cause gastrointestinal illness and wound infections (Lewis, 2003). E. coli present in the water should be less than 235 colonies/100ml; otherwise, the body of water must be closed until the E. coli level reduces (MDPH, n.d.).

2.6.2: Ammonia

Ammonia is a toxicant that is derived from wastes, fertilizers, and natural processes. Ammonia increases plant growth and algae in the Pond, and consumes the dissolved oxygen in the water, thereby causing the death of aquatic organisms (US EPA, n.d.). High ammonia levels impact the aquatic life in the Pond. The amount of Ammonia present in the water should be less than 0.1 mg/L (Swistock, 2022).

2.6.3: Nitrogen/Nitrate

Nitrogen is a nutrient essential for plant growth, it is naturally abundant in the environment, but it is also introduced through sewage and fertilizers. The abundance of nitrogen in a water body promotes plant growth and algae bloom. Nitrate is an inorganic compound made of nitrogen and oxygen. It can get into the water because of runoff from fertilizer. It also promotes plant growth and algae bloom. The amount of Nitrate-Nitrogen found in the water should be less than 3 mg/L (Swistock, 2022).

2.6.4: pH

pH affects the aquatic life of a Pond; it affects the solubility and the toxicity of chemicals in the water. It is the measure of the acidity of Pond water. The pH of the water should remain near 7.0 (Swistock, 2022).

2.6.5: Metals

Metals such as Iron, Manganese, and Copper are pollutants that produce foul tastes that may affect animal intake. They may cause offensive tastes and adversely affect the aesthetics of the Pond by precipitating an orange coating on the bottom of the Pond (SWISTOCK, 2022). Iron should be below 0.3 mg/L, Manganese should be under 0.05 mg/L, and Copper should be less than 1.0 mg/L (Swistock, 2022).

2.6.6: Turbidity

Turbidity is caused by erosion, runoff or debris, wastewater with residual particles, and plant or animal decay. It affects the aesthetic of the Pond (SWISTOCK, 2022). The level of turbidity should remain under 5 NTU (Swistock, 2022).

2.7: Project Goal

This project worked with the Green Hill Park Coalition to address the first goal of this project which is to research the history and current conditions of the Ponds at Green Hill Park to determine the conditions negatively affecting the Pond. In addition, the second goal, to research the effects of using Pond water to irrigate the golf course during the summer months. To achieve these goals, we created five objectives which will be discussed in the next chapter.

Chapter 3: Methods of Research

This chapter discusses our goals and objectives in-depth, what methods we used to achieve these goals, and the ethical considerations we had to be aware of during the project.

3.1: Our Goals

We had two goals for this project. The first goal of this project was to determine what conditions of the Ponds at Green Hill Park were negatively impacting the water quality and develop a mitigation strategy. To achieve this goal, we took a baseline test of the water quality before the seasonal changes between spring and summer. This first test was only meant to tell us the concentration of contaminants in the water during spring, when the water was cleaner, based on visual record. The following tests were conducted during the summer. These water tests told us about the changes in the concentration of the contaminants, so we could identify where they were coming from. We also looked at past test results to see what contaminants were affecting the Ponds, and how they compare to current test results to see what had changed. The second goal of this project was to research the effects of a potential irrigation system for the adjacent golf course sourced by the Pond in the summer. The City of Worcester wanted to know if using the Pond as the source for an irrigation system is practical, so that they could limit the drinking water use on the golf course. To help us determine the feasibility of this goal, we researched how the irrigation system would affect the Pond.

3.2: Understanding and Mitigating

Most of our research was focused on our first goal. Since it was a bigger and more complex issue, we created a list of objectives to help us break down this problem into manageable pieces.

3.2.1: The Baseline

For us to understand what was affecting the Ponds, we had to determine the baseline water quality. Before our research began, we collected water samples from both Ponds with assistance from our sponsor. The water samples were analyzed by Nashoba Analytical, a lab who analyzed previous water samples for the Green Hill Park Coalition (GHPC). This first water test was conducted before the water usually deteriorates, so we knew the qualities of the Ponds before the summer. While Nashoba Analytical primarily tests for drinking water, we were able to use the Worcester Blue Space and the EPA guidelines for recreational water quality to create standards for our end goal.

Figure 10: Baseline Water Test

3.2.2: Investigating Contaminants

Next, we started deepening our understanding of the contaminants. We began by comparing the results and interviewing a Senior Environmental Analyst who works for the City of Worcester to discuss those results. We also visited the Park multiple times to better understand where the contaminants were coming from. We saw how the landscape of the Park could contribute to certain pollutants entering the Pond and saw where some storm drains and waste drains could lead to. Thanks to our prior research, we were able to start testing for more specific issues. Our team started participating in the City's cyanobacteria testing after talking about it being a contaminant after our interview with Jacquelyn Burmeister. On May 24th we conducted another water test by Nashoba Analytical to see how certain contaminants have changed.

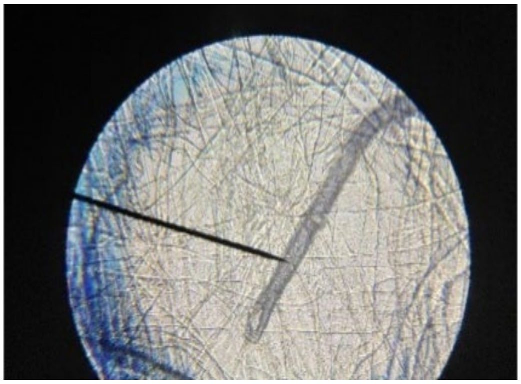


Figure 11: Cyanobacteria from Green Hill Pond

3.2.3: Mitigation

After completing the last two objectives and meeting with the Assistant Commissioner of the Worcester Department of Public Works, we had enough information to start developing a mitigation plan.

The plan showed the feasibility, sustainability, and benefits of each solution, so that both the Green Hill Park Coalition and the City of Worcester have options to choose from. At the end of our project, we presented a list of options to the City of Worcester and Green Hill Park Coalition where we introduced different water treatment methods, their sustainability, and how long the treatment method would last.

3.3: Irrigation Feasibility

The second goal of our project was to determine the impact of using the Pond water in place of drinking water to irrigate the adjacent golf course during the summer months. In line with our first goal, we wanted to break down our second goal into objectives.

3.3.1: Determining the Volume

The first objective that we focused on was finding the volume of the Pond. To do this, we plotted the depth of the Pond using a depth finder and canoe. We canoed around the lake, using a map and the depth finder to plot the depth of the lake. Then, we multiplied the depth by the area, which is 30 acres, to get the volume.

3.3.2: Flow System of the Pond

After plotting the depth and finding the volume, we wanted to find the flow of water in and out of the Pond. We considered many factors while doing this. The Pond is fed by springs, so we calculated the amount of water flowing into the Pond. We also estimated the amount of water coming into the Pond via rain and runoff. For water exiting the Pond, we considered evaporation and the water that drains out. This is important because we got a sense of how the irrigation system would affect the Pond's water flow.

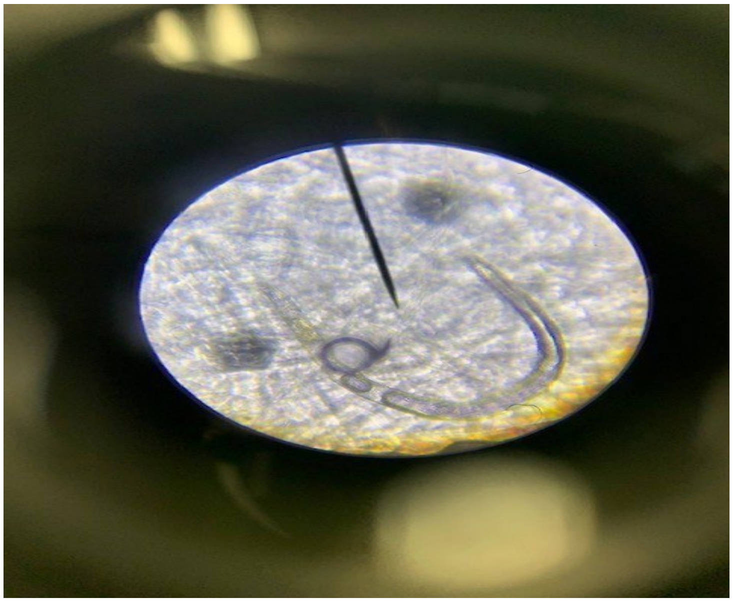


Figure 12: Microscopic Organism from water at Green Hill Pond

3.4: Ethical Considerations

Before starting, this project was reviewed by the Institutional Review Board. The Protocol Number is IRB-22-0651. The FWA and HHS are 00030698 and 00007374, respectively.

Chapter 4: Findings

In this chapter we will discuss the results of the Pond water quality test done by Nashoba Analytical, a water analysis company based in Ayer, Massachusetts. It also includes cyanobacteria test results obtained from the City of Worcester Cyanobacteria Monitoring Collaborative, a program within the City of Worcester Water Department dedicated to monitoring the Cyanobacteria level in Ponds and lakes in the City of Worcester. The depth of the Pond, the volume of water in the Pond, and rainfall data for the past five years will be discussed in the later parts of this chapter.

4.1: Pond Water Quality Results and Analysis

The pollutants we found to be of concern were Total Coliform, Iron, Cyanobacteria, and Manganese. The four main pollutants of concern were determined using the standard for recreational water set by the United States Environmental Protection Agency. Table 1 shows the water quality test results for Green Hill Ponds including the Minimum Reporting Level (MRL) and the Maximum Contaminant Level (MCL). The MCL is set to the EPA's drinking water standards.

Parameters & Units	May 24th 2022		April 28th 2022		June 15th 2021		October 19th 2020		MCL
	GHPL	GHPO	GHPL	GHPO	GHPL	GHPO	GHPL	GHPO	
E. Coli, /100ml	-	-	3	8	58	58	PRESENT	PRESENT	-
Total Coliform Bacteria, /100ml	>2420	1120	727	517	440	260	PRESENT	PRESENT	Absent
Iron, MG/L	0.102	0.314	0.076	0.405	0.154	0.135	0.158	0.291	0.3
Manganese, MG/L	0.095	0.068	0.052	0.065	0.041	0.038	0.101	0.019	0.05
Chloride, MG/L	71.1	46.6	68.2	39.8	68.1	67.3	75.8	20	250
Color Apparent, CU	15	30	8	18	35	35	5	25	15
Odor, TON	3	4	1	1	0	0	1	2	3
Ph, pH AT 25C	6.6	6	6.6	6.1	8.6	8.9	6.7	6.5	6.5-8.5
Sulfate, MG/L	7.3	7.1	7.4	7.4	7.8	8	9.1	8.3	250

Table 1: Shortened Nashoba Analytical Water Test Results (Full table can be found on Appendix IV).

4.2: Contaminants of Concern

Iron is a contaminant of concern that is found at higher levels in the smaller Pond than the bigger Pond. The iron level of the smaller Pond increased this year compared to the last two years. Manganese is also high in both Ponds; the two water test results show a spike in Manganese level this year. Although the health impact of high Iron and Manganese is low, it can affect the aesthetics of the Pond by causing orange-brown coating on the bottom of the Pond (SWISTOCK, 2022).

Figures 11 and 12 show the plots of Iron and Manganese for the large and small Ponds, they also show the minimum reporting level and the maximum contaminant level.

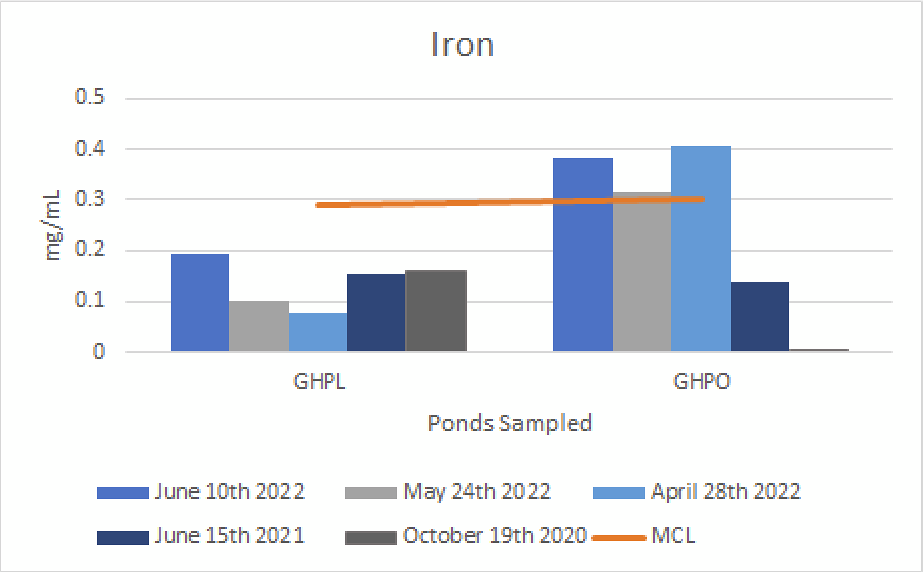


Figure 13: Iron levels in the large (GHPL) and small Pond (GHPO)

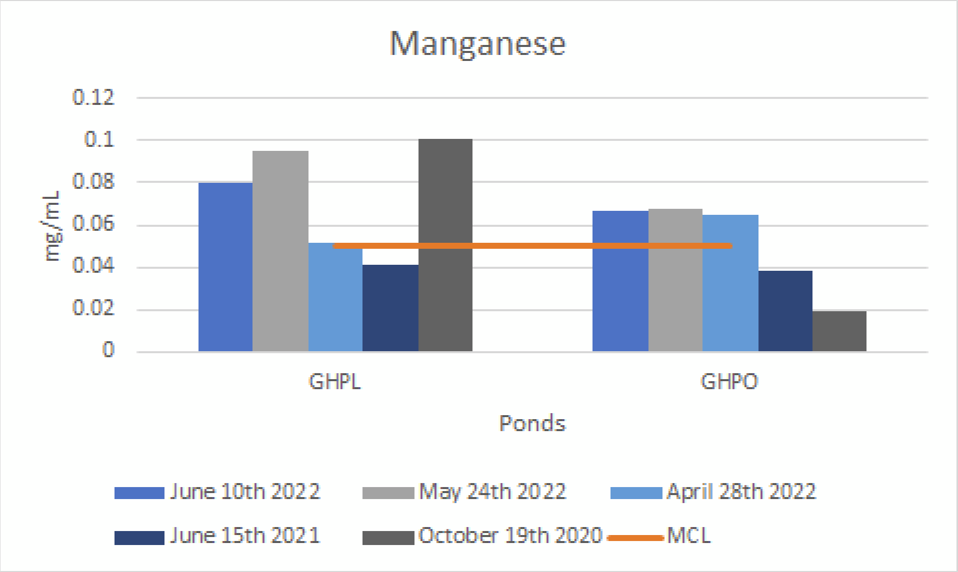


Figure 14: Manganese levels in the large and small Pond

4.3: Pond Water Analysis Results from Worcester Polytechnic Institute Laboratory

In addition to the water test done at Nashoba Analytical, water samples were taken from the Green Hill Ponds to be analyzed at the Civil and Environmental Engineering laboratory at Worcester Polytechnic Institute (WPI). We went out to the park to collect five samples (Figures 13 and 14).

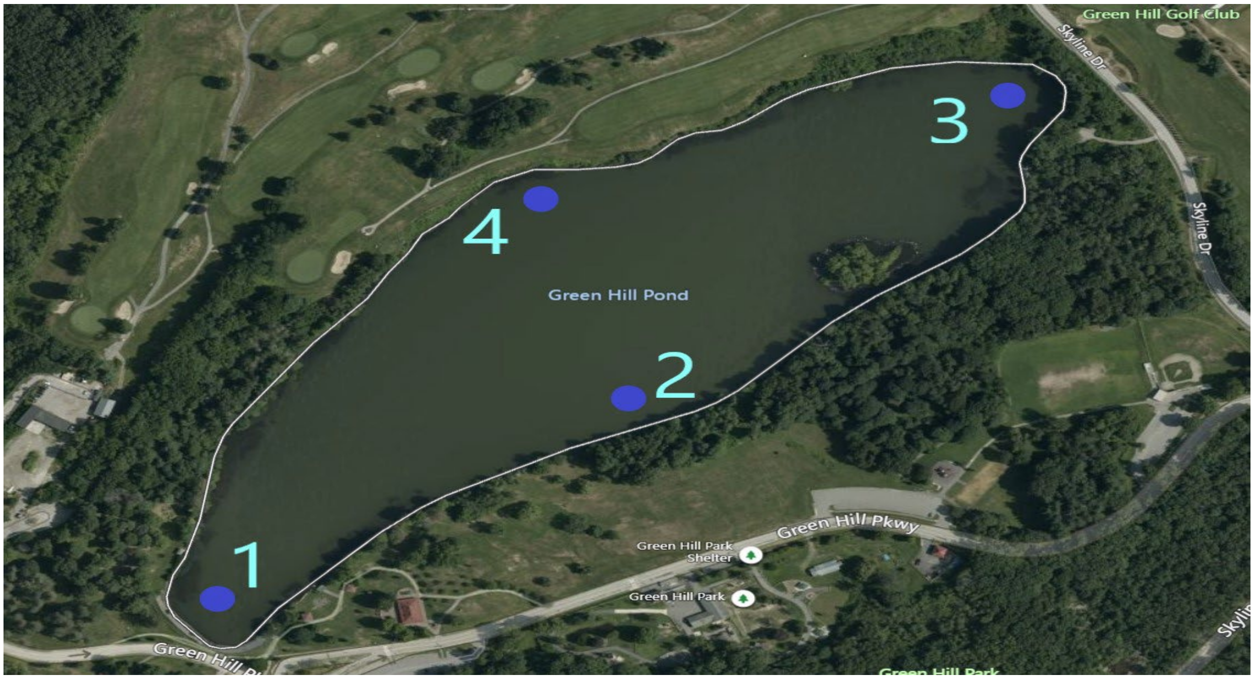


Figure 15: water sample location for the large Pond

Figure 16: water sample location from the small Pond

The water samples taken from locations 1, 3, and 5 were tested for Dissolved Oxygen (DO). The levels shown in table 2.

4.3.1: Dissolved Oxygen (DO)

Dissolved oxygen level in a water body impacts aquatic life in the Pond. The current dissolved oxygen level of Green Hill Pond is above the minimum dissolved oxygen level required to sustain aquatic life in the Pond. The required dissolved oxygen level for trout and bass fish is above six mg/L and five mg/L, respectively (Swistock, 2022).

GHP-1	11.2 MG/L
GHP-3	11.55 MG/L
GHP-5	12.25 MG/L

Table 2: Dissolved Oxygen Levels in the Pond

4.3.2: Total Phosphorus

In addition to the dissolved oxygen test, we also tested water samples from all locations shown in figures 15 & 16 for total phosphorus concentrations. Phosphorus is a nutrient that is essential for plant growth. It is crucial to test the Pond water periodically to monitor the phosphorus concentration in the Pond water because phosphorus in the water can be used by aquatic plants and algae, which can lead to eutrophication. The current water test results show that the Phosphorus concentration in the Ponds is low. It is recommended that Phosphorus concentration in the Pond is as low as 0.01 ppm (Swistock, 2022).

The water samples were also tested for chloride and nitrate. The complete water analysis result from WPI lab can be found in Appendix VII. The result of the water test done at WPI lab validates the water test result from Nashoba Analytical, showing low concentrations of Nitrate and Total Phosphorus in the Ponds.

Abs.	Conc. Stds.
0	0
0.052	0.2 ppm
0.132	0.5 ppm
0.687	3 ppm

Table 3: Absorbance and Concentration Standards used to measure Total Phosphorus

Sample Location	Absorbance	Concentration
1	0.034	.115ppm
2	0.039	.137ppm
3	0.069	.27ppm
4	0.026	.081ppm
5	0.032	.11ppm

Table 4: Total Phosphorus Concentration in the Ponds

4.4: Microbiological Issues

Cyanobacteria is a group of bacteria that form blue-green algae. They primarily live in aquatic environments and can have adverse effects on the water body when they start to peak. For an algae bloom to occur, there is a period where the Pond has an overabundance of nutrients. This could be from fertilizers, animal manure, or from sediments in the ground. These excessive nutrients encourage an algae bloom to occur. When the bloom occurs, the algae turn the water into a thick green mucus, releasing harmful cyanotoxins into the water (NIEHS, 2021).

When we interviewed Jacquelyn Burmeister, she helped us better understand the severity of cyanobacteria in the Pond. Green Hill Park only joined the program in 2021, however, the data (Table 4.1) matches with the seasonal algae blooms.

Risk for Bloom	Phycoyanin Concentration (ug/l)	Particle Concentration (#/ml)	Cyanobacteria Presence	Cyanobacteria Character
June 2021	-	3786	-	Trichrome, Ceratium
Jul 2021	21	1792	-	Microcystis, Anabaena
Oct 2021	-	-	Low	Woronichinia, Dolichospermum
May 21st, 2022	10	3367	Some	Aphanizomenon
Almost None	0-15	0-1000	None	-
Low	15-20	1000-5000	Low	-
Elevated	20-50	5000-10000	Some	-
Blooming	>50	>10000	High	-

Table 5: Worcester Cyanobacteria Monitoring Collaborative Test Results

The main thing that caught our attention was the Risk for Bloom. The Risk for Bloom May 21st test was recorded as Low, but even then, it was still close to particle count for the June 21st test. These tests also showed us some of the bacteria in the samples, which gave us a glimpse of health issues. The Environmental Protection Agency divides cyanobacteria into three distinct categories, based on the toxins they create that affect humans. These are Cylindrospermopsin, Anatoxin-a Group, and Microcystin-LR. Most of the bacteria, Aphanizomenon, Dolichospermum, Woronichinia, and Microcystis, were in the Anatoxin-a Group (Figure 15). Research done by the EPA concludes that these bacteria target the nervous system, causing numbness, tingling, burning, and, in some cases, respiratory paralysis leading to death (EPA, 2021). There have also been cases where these toxins have affected other animals, like dogs or birds.

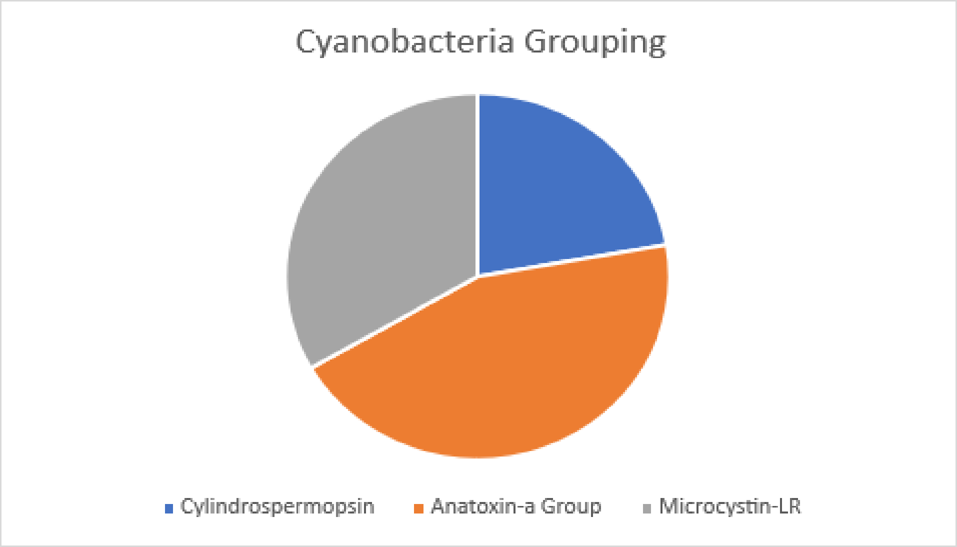


Figure 17: Distribution of Cyanobacteria

Another microbiological issue we found in our Nashoba Analytical tests was the amount of E. Coli and Total Coliform Levels (Table 5 & Figure 16). Total Coliform bacteria is a group of diverse types of bacteria, which includes E. Coli. Coliform Bacteria enters the surface water through animal feces.

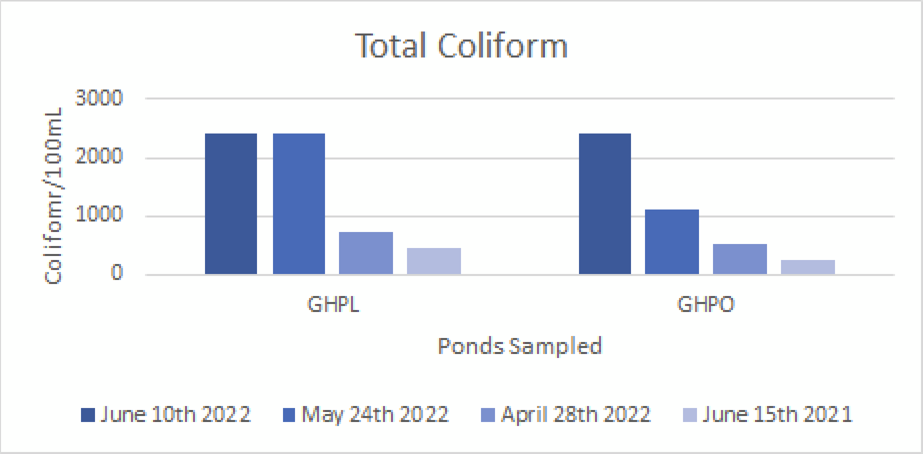


Figure 18: Total Coliform level in the large and small Pond.

As seen in Figure 16, we found that there is no real correlation between the month and the Total Coliform count. When we interviewed Ms. Burmeister later in the project, she explained that bacteria like E. Coli do not survive long in water bodies without being continuously added in. This can explain why the 2021 June test does not match our predictions for bacteria count in the summer. Coliform bacteria tend to be random based on the amount of animal waste that would be around the Pond on a given day. In addition, we learned that Total Coliform only matters for drinking water standards, which is not what this project is focused on. Our team wanted to improve the quality to match the EPA's recreational water standards.

4.4.1: Treatment Research

To combat the seasonal blooms, we investigated a few methods that the Green Hill Park Coalition can use to proactively manage the algae blooms. Antimicrobials are types of agents that attach to phosphate and sulfur groups that are part of the phospholipid cell membrane or to membranal proteins, and severely damage the cell and its major functions, such as permeability, regulation of enzymatic signaling activity, and cellular oxidation and respiratory processes (Dror-Ehre, et al. 2009). Antimicrobial agents can focus on all types of microbes, including bacteria, fungi, and viruses. Common antimicrobials are Aluminum Sulfate, and the cheaper alternative Copper Sulfate.

Aluminum Sulfate, also known as alum, are white, lustrous crystals, granules, or powder. When it is added to water, Alum causes microscopic particles to clump together and descend to the bottom of the Pond. This helps to reduce the turbidity and phosphorus in the water, removing the source for algae to grow. Copper Sulfate are small, blue crystals also used for water treatment as antimicrobials. However, both can have their downsides, Alum can reduce the pH of the Pond, which can harm fish. A key reason we are worried about a pH is because of our Alkalinity levels in the Green Hill Pond (Appendix IV) average around 20ppm. Alkalinity levels show how well the Pond can handle pH drops, and since it is recommended that we keep the alkalinity around 50-200ppm before adding Alum, we recommend the Coalition to either consult a professional for applying Alum or use aluminum sulfate carefully. Copper Sulfate tends to not be effective long term, usually needing to be reapplied every 2 weeks to stay effective (Bioworld USA, 2017). However, research also shows that Copper sulfate can easily be overused, leaving a copper buildup, which can cause oxygen levels and pH to drop in the water. Using copper sulfate after an algae bloom begins means you will need a higher dosage, which will stress, and kill any fish in the Pond (SouthernAG, n.d.).

As we researched a safer alternative to the prior chemicals, we came to a product called Cutrine Plus, a chelated copper solution that can be used as a safer substitute for Copper Sulfate (Applied Biochemists, n.d.). The chemical process better targets algae and some of the cyanobacteria we have seen (Table 4.2) such as Microytis, Anabaena, and Aphanizomenon. It lasts longer and cleans the Pond faster than copper sulfate (EPA, n.d.). Cutrine Plus also does not cause as much of a copper buildup in the Pond due to the chelation process. However, trout and other species of fish are still at risk of dying if the water becomes too acidic (EPA, n.d.). Like the Alum and Copper Sulfate, there is a fine line between treatment and overdosing, so we again recommend that the Coalition consult with a professional to apply these chemicals.

We also contacted Aaron Sakulich, a WPI professor and contributor to Indian Lake, about how they solved Indian Lake's seasonal algae bloom. He recommended using Solitude Lake Management, a professional lake management agency that would regularly come and clean their lake every summer. Professor Sakulich made it clear that their services tend to be expensive.

4.5: Introduction to Irrigation Feasibility

In response to our second goal, which was to research whether an irrigation system is feasible, we wanted to find out how an irrigation system would affect the Pond. Initially, our concern was that too much water would leave the Pond, lowering the water level and creating issues for the Pond's wildlife. We found that there are two equally important conditions that must be met to implement the irrigation system safely. The first condition is that the irrigation system cannot be implemented unless adjustments are made to the current flow of water in Pond. The second condition is that the irrigation system cannot be implemented until the cyanobacteria issue is addressed. Finally, we found that there could be benefits if the system is implemented.

4.6: Research for Condition 1: Flow

The next few sections detail our findings about how we calculated the flow system of the Pond, and how factors within that system such as volume, evaporation, rainfall, springs, and the drain affect the Pond and its wildlife.

4.6.1: Finding the Volume

The first thing we did to research the irrigation issue was find the volume of the Pond. To do that, we needed the area and the depth of the Pond. Finding the area was the easier of the two tasks. The City records indicate that the area of the Pond is 30 acres. We verified the area using an estimation on Google Earth, where we found the Pond area to be 29.6 acres.

The second task to find the volume was to find the depth. We used a canoe and a depth finder to calculate the average depth of the Pond. We started on the southwest end of the Pond and paddled around the shoreline. Then, we paddled in the middle of the Pond. While we paddled, we took measurements at certain points using a depth finder and tracked where we took them on a map. Using the map and the depth points, we calculated the average depth, which came out to be 7.32 feet. Once we had the area and average depth, we found the volume by multiplying the area and depth. We found the volume to be 219.54 acre-feet or 71,537,316.1 gallons.

Unfortunately, the average was skewed because we took significantly more measurements around the shore than we did in the middle, where the Pond is deeper. The depth finder was also very erratic, as it would adjust the depth at random. We knew some of these were incorrect because, for example, it would show two feet at the shoreline, and then jump to 10 feet. We adjusted by using the first measurement shown, as that was consistently more accurate. Because the average depth is likely deeper than calculated, the volume is also likely greater than calculated.

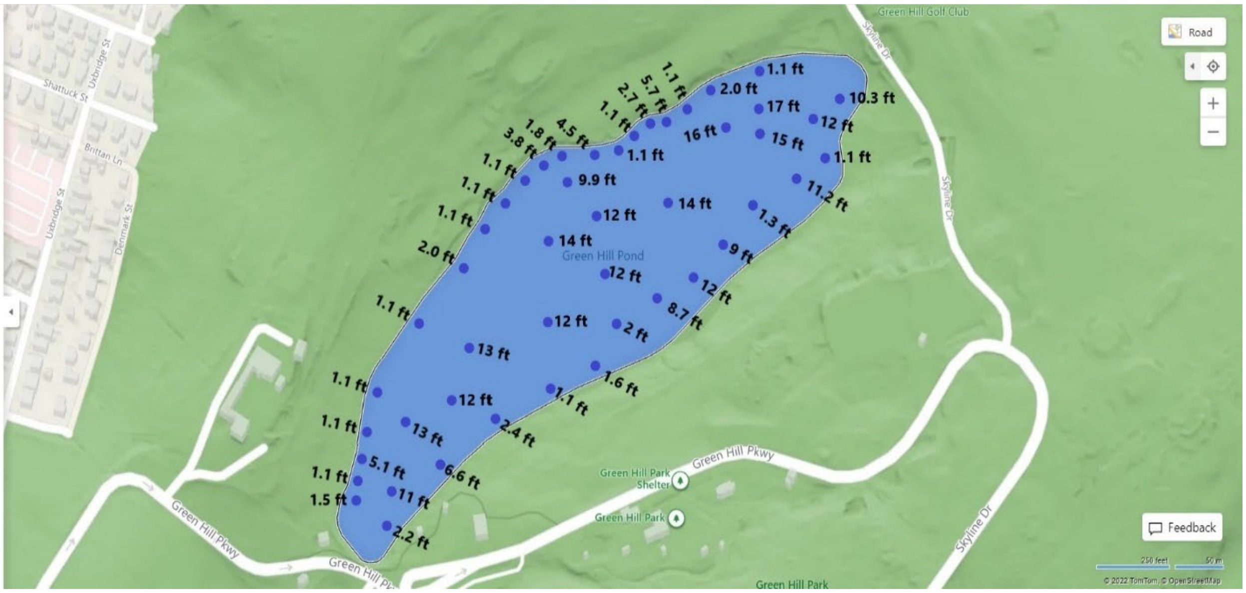


Figure 19: Green Hill Pond Mapped Depth

4.6.2: Comparing the Current Water Entering Against the Water Exiting

The next step in determining if the irrigation system would hurt the Pond or not was comparing how much water was coming into the Pond against how much water was leaving. For this, we considered four factors, which were split into water entering and water exiting. The factors were springs and rainwater for water entering and drainage and evaporation for water exiting. We had to make a necessary assumption, which was that the water entering via the springs and rainwater and the water exiting via the drain and evaporation must be in equilibrium during the fall, winter, and spring months.

$$\text{Springs} + \text{Rainwater} = \text{Drain} + \text{Evaporation}$$

However, we recognized that during the summer months, evaporation played a greater role in the equation, based on the water level decreasing. This threw off the equation, making the amount of water exiting the Pond greater than the amount of water entering.

$$\text{Springs} + \text{Rainwater} < \text{Drain} + \text{Evaporation}$$

After running into this conundrum, we decided to start researching irrigation and rainwater by using the amount of water produced or used. Thanks to the Parks Assistant Commissioner, we were able to get the records of the water used for irrigating the golf course. Over the past four years, 2018, 2019, 2020, and 2021, in the summer, the City used 12,713,592 gallons, 14,649,708 gallons, 10,690,008 gallons, and 9,062,788 gallons, respectively, for an average of 11,779,024 gallons of drinking water. However, we also calculated the amount of rainwater entering the Pond during the months of June, July, August, and September, which we found to be 12,789,677.33 gallons using a rainfall calculator. This was done by multiplying the amount of rainwater in inches by the area of 30 acres. We repeated this process for each month and added them together. In the table below, there are two categories of rainfall data called “actual” and “normal.” We used the 2020 “normal” category because we considered it to be a more accurate representation of the average rainfall over a longer time. Another reason we used the 2020 “normal” data is because the “actual” data diverged from the pre-established average. In 2018 and 2019, the rainfall followed the average much more closely and was closer to each other. The difference category was also consistent between 2018 and 2019 as opposed to 2020, so we determined that the 2020 “actual” data was an outlier. Once we found the rainwater, we compared it to the volume of drinking water used, and the difference came out to be 1,010,653.33 gallons. After adding the difference to the original Pond volume, the new volume came out to be 72,547,969.43 gallons of water.

Summer Rainfall in Worcester (Inches)									
Parameters	2020			2019			2018		
	Actual	Normal	Difference	Actual	Normal	Difference	Actual	Normal	Difference
June	2.46	4.03	-1.57	4.03	3.77	0.26	4.02	3.76	0.26
July	3.07	3.77	-0.7	5.13	3.83	1.3	5.71	3.81	1.9
Aug.	3.31	4.02	-0.71	4.12	4.08	0.04	7.85	4.06	3.79
Sept.	1.59	3.88	-2.29	1.61	3.82	-2.21	8.44	3.79	4.65

Table 6: Summer Rainfall in Worcester

4.6.3: Volume Lost Due to Evaporation

Based on rough estimates, we found that the difference of 1,010,653.33 gallons between rainwater and current irrigated drinking water was not enough to make up for increased evaporation during the summer. Since we calculated the average depth as 7.32 feet, we associated each foot with a volume to find out how much water has left the Pond due to evaporation. We wanted to find the associated volume for each foot because our sponsor said that he estimates that the Pond's water level dropped one foot during the month of June. Using this method, we estimated that the Pond loses anywhere from 9.5 to 10 million gallons per foot due to evaporation, as of mid-June.

What we did not account for was the water level dropping below the belly of the north end drain. The drain sits at one of the higher points of the shore, where the depth is only about 18 inches. This revelation made us reconsider the effect of evaporation in the flow equation.

$$\text{Springs} + \text{Rainfall} < \text{Evaporation}$$

The fact that we had to consider evaporation as a greater variable than both springs and rainfall made us reconsider the feasibility of the irrigation system, given that there would not be enough water entering the Pond through springs or rainfall to match the evaporation or supply the irrigation system.

4.7: Research for Condition 2: Cyanobacteria

We mentioned in previous sections that Cyanobacteria is an issue for the Pond. However, it also poses a danger if the irrigation system is implemented without the cyanobacteria issue being solved first. In our research, we found that humans and animals can be affected by ingestion of or contact with algae caused by cyanobacteria (NSW, 2013). The effects include skin problems such as eczema and other health issues such as asthma attacks (NSW, 2013). The research also states that about 30% of the population suffers from these conditions, so irrigating with water contaminated by cyanobacteria would cause greater health issues to about one-third of golfers, by percentage (NSW, 2013).

4.8: Benefits of the Irrigation System

Despite the concerns in our previous findings, there are potential benefits if the Pond water is an irrigation source. Because the City wants to use the Pond water in place of drinking water, it will lessen the amount of drinking water the City must use. It will also lessen the associated cost. The last benefit of using the Pond water is that the chemicals that are commonly found in drinking water for treatment purposes will be reduced in the Pond such as Iron and Manganese (USEPA, 2022). Presently, neither of these chemicals are at a high enough concentration in the Pond to be considered harmful for recreational use. However, they can be harmful to fish at a high enough concentration because the chemicals build up and clog the fishes' gills, killing them. Reducing the amount of these chemicals will help ensure that build up does not occur, lowering the risk of killing the fish and upsetting the local food cycles.

4.9: Summary of Findings Regarding the Irrigation System

To summarize our findings regarding the irrigation system: if the irrigation system is implemented, it must be done with adjustments to the current Pond system and only after the cyanobacteria issue is under control. The reason the irrigation system will not work without adjustments is because the 1,010,653.33-gallon difference is not enough to counteract the 9.5 to 10 million gallons of evaporated water per foot. The left-over volume from evaporation in the first month of summer will continue to lower the water level, which will harm the Pond's wildlife by increasing the concentration of harmful substances. We also concluded that if the irrigation system is to be implemented, it must be done after the cyanobacteria issue is solved. Cyanobacteria pose too many health concerns for humans and animals, including eczema, asthma attacks, and lack of oxygen, to safely irrigate as the Pond is currently. Finally, despite the difficulties in implementing the irrigation system, there are potential benefits to implementing the system, which are saving resources and money and lowering the chemical impact on the Pond.

4.10: Summary of All Findings

Both our Nashoba Analytical and WPI water tests showed no major concerns in any test that was not biological. The main contaminants that stood out on the Nashoba Analytical tests were Iron and Manganese. These were both above the maximum containment level, especially in the smaller pond. The WPI tests focused on some of the same contaminants, like nitrate and nitrite, and other factors like Dissolved Oxygen and Total Phosphorus. Dissolved Oxygen and Total Phosphorus levels were at healthy levels for a pond with aquatic life and other contaminants that were already previously tested, confirmed the Nashoba Analytical tests.

The microbiological issues in the pond are at risk of causing harm to citizens during the summer months, when Total Coliform and Cyanobacteria start growing at an accelerated rate. The algae blooms that occur during the latter half of the summer are caused by cyanobacteria growth. This can be minimized by using antimicrobial agents. While Coliform bacteria, and other fecal bacteria like E. Coli, do not last long without a constant source, we still feel that using antimicrobial agents would be a promising idea to treat the pond. These can be treated by the Coalition and the City of Worcester, or by Solitude Lake Management. This is a water treatment company used by Indian Lake that offers professional treatment using many of the antimicrobial agent we will be suggesting.

As it pertains to the irrigation system, we found that it must be done with two conditions, which are that modifications to the current flow system are necessary, and that it cannot be implemented until after the cyanobacteria issue is solved. The modifications will be discussed in the Recommendations chapter below, but as we learned in our research, if an irrigation system is implemented without adjustments, it will not work due to evaporation. The added water leaving via irrigation will further drop the water level, increasing the concentration of harmful chemicals, endangering the wildlife. Because of the danger that cyanobacteria pose, the irrigation system cannot be used until after the cyanobacteria issue is solved.

Chapter 5: Mitigation Recommendations

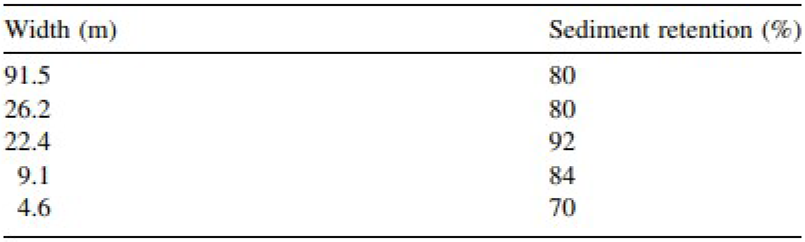
This chapter discusses our recommendations of mitigation strategies, how to implement them, and whether to implement the irrigation system sourced from the Pond to the City of Worcester and the Green Hill Park Coalition.

5.1: Introduction to the Recommendations

There are three recommendations we would like to present to the City of Worcester and the Green Hill Park Coalition. The first recommendation is to plant buffer grass around certain portions of the Pond to reduce the amount of nutrients entering the Pond through stormwater runoff. The second recommendation is to use chemicals to treat polluted Pond water. The third recommendation is to not implement an irrigation system using Pond water. These recommendations were thoroughly contemplated while considering cost efficiency, aesthetics, and preserving the wildlife population.

5.2: Recommendation 1: Vegetative Buffer Strips

Vegetative buffer strip is a strip of vegetation planted around a waterbody to control erosion and filter pollutants entering the waterbody through stormwater runoff. One of the conditions negatively affecting the Pond is Eutrophication. Eutrophication is caused by excess nutrients like nitrogen and phosphorus in a waterbody. Research shows that grass buffer strips can significantly limit the transfer to surface water of sediment and total phosphorus due to diffuse flow (Dorioz et al., 2006).



Width (m)	Sediment retention (%)
91.5	80
26.2	80
22.4	92
9.1	84
4.6	70

Table 7: Width of grass buffer and sediment retention (Castelle et al., 1994)

The table above shows sediment retention percent of buffer strips. The effectiveness of the buffer strips depends on the width. We recommend the City and the Green Hill Park

Coalition to plant any of the following grass as vegetated buffer strips around the Green Hill Pond.

1. Vetiver Grass
2. Switch Grass
3. Side Oats Grama Grass
4. Big Bluestem Grass
5. Little Bluestem Grass

The grasses mentioned above are good for erosion control and would help reduce the amount of sediment and nutrients getting into the Pond from stormwater runoffs.

The effectiveness of buffer grass to continue preventing runoff over an extended period depends on biogeochemical transformations. Nitrogen and most pesticide retention in a grass strip is accompanied by biogeochemical transformations that reduce the quantities present over time through denitrification, degradation, and decomposition (Dorioz et al., 2006).

5.3: Recommendation 2: Anti-Microbial Solutions

Antimicrobials are commonly used to treat public water bodies. We have determined the following treatments would help clean the Pond.

- Aluminum Sulfate
- Copper Sulfate
- Cutrine Plus

Aluminum sulfate is a coagulant, which means it will handle the turbidity problems of the Pond. Copper sulfate and Cutrine Plus are both antimicrobials, which will handle algae blooms, as well as any bacteria issues, that affect the Pond at any point through the summer season.

These treatments can be added to the Pond by either the Coalition or by Solitude Lake Management, a water treatment company that provides many of these services already. They are also used by Indian Lake to handle their yearly algae blooms.

5.4: Recommendation 3: Do Not Implement the Irrigation System

Our third and final recommendation is that the City should not implement an irrigation system using Pond water as a source. Despite the possibility of the system working with modifications and waiting until the cyanobacteria issue is solved, we concluded that evaporation is too great an unknown variable to confidently suggest implementing the irrigation system, based on evolving information. However, we will still explain the possibilities of implementation for future consideration by the City of Worcester and the Green Hill Park Coalition.

5.4.1: Modifications to the Flow System

As currently constructed, the south end dam stops most of the water from getting out (outside of a small discharge), while the north end drain is the only significant escape for the water. During the summer, the water level lowers by multiple feet due to increased evaporation, and an irrigation system would exasperate the water level dropping if implemented as the drain and dam currently are. We estimated that for each foot of depth, about 9.5-10 million gallons of water are lost per month, while the difference between rainwater and the average water use for the current irrigation system is only 1,010,653.33 gallons. This discrepancy would significantly lower the water level even further, but there is a potential way to counteract that. Options for implementation include raising the dam slightly and modifying the drain to be at a deeper part of the Pond floor. The modified drain should include a gate or door, which would allow the City and the Coalition to control the outflow via the drain so that the Pond has enough water to support the irrigation system. Raising the dam is mostly a precaution in the unlikely event that the water level rises, alleviating the risk of overflow.

5.4.2: Cyanobacteria Issues Affecting Implementation

As stated in the Findings chapter, cyanobacteria pose too many health risks including eczema and asthma attacks to implement the irrigation system without first solving the cyanobacteria issue. To combat this issue, we suggest the water treatment with Copper Sulfate described in the previous sections, and that Green Hill Pond participates in the weekly or bi-weekly testing with the Worcester Cyanobacteria Monitoring Collaborative.

5.4.3: Record Data on Water Level Fluctuations

Finally, we would also like to suggest that the City of Worcester and the Green Hill Park Coalition keep an accurate record of the Pond's depth, how much the water level drops or rises each month, and how much water is leaving and entering via the drain and the springs, if it is decided that the irrigation system will be implemented. We suggest at least a year be taken to do this; however, it can be done during the participation in the Worcester Cyanobacteria Monitoring Collaborative, as it will take time to solve the cyanobacteria issue. The data kept will help give an idea of how much water is evaporated and how adding an irrigation system could affect the water levels. The data will also help alleviate the impact of any other error created by the assumptions and limitations of our project and ensure that the Pond and its wildlife will be protected.

Chapter 6: Conclusion

This project is the culmination of much research from various sources and meetings with experts in the field. We addressed the Green Hill Park Coalition’s concerns about the Pond’s seasonal degradation, as well as considering the City of Worcester’s needs. Treating the Pond will help the Coalition stave off algae bloom and weaken any future resurgences. Vegetative buffers allow for a barrier around the Pond to prevent contaminants from entering the Pond, slowing the Pond’s runoff pollution. Finally, we are confident that the mitigation strategies provided will solve the Cyanobacteria issue, however, we do not recommend implementing an irrigation system, as we were not confident about the unknown variable of evaporation.

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APPENDIX

Appendix I: Professor Walker Interview Questions, April 7, 2022

- What do you think are the key causes of the Pond's poor water quality?
- What are some treatment methods we should investigate?
- What should we be testing for?
- What are some case studies we should be looking into?
- Should we be using the Pond for an irrigation source?

Appendix II: Brian McCarthy (Sponsor) Interview Questions, April 9, 2022

1. How long have you been working at Green Hill Park?
2. What made you decide to join the Green Hill Park Coalition?
3. What do you enjoy about being part of the Green Hill Park Coalition?
4. What are your main concerns about the Park?
5. When did your concerns about the "Great Pond" become noticeable?
6. In your opinion, what do you think is the cause of the Pond's poor water quality?
7. What has the Coalition already done to slow down the decrease in water quality?
8. What is your end goal for the Pond?
9. Is there anything you want us to know before we start our research into the Pond?

Appendix III: City Official Interview Questions

Worcester Department of Public Works and Parks

We are a group of students from Worcester Polytechnic Institute in Massachusetts. We are conducting interviews about the Green Hill Pond to learn more about the current condition of the Pond. This research will be used by Green Hill Park Coalition to enhance the Green Hill Pond.

Your participation in this interview is completely voluntary and you may withdraw at any time. Please remember that your answers will remain anonymous. No names or identifying information will appear on the questionnaires or in any of the projects or publications.

Interview questions

1. How long have you worked for the City of Worcester?
2. What is the City doing to prevent water pollution at Green Hill Park?

3. How long ago did the City start water testing of Ponds and lakes? Are those results available? Can we access them?
4. In your opinion, what do you think attributed to the poor water quality of Green Hill Pond?
5. Does the City have any plans to help improve Green Hill Pond's water quality?
6. What do the numbers in the test results mean?
7. Can we have the wetland map / where water drains to? |

Appendix IV: Jacquelyn Burmeister Interview, May 17, 2022

1. How long have you worked for the City of Worcester?
2. What is the City doing to prevent water pollution at Green Hill Park?
3. How long ago did the City start water testing of Ponds and lakes? Are those results available? Can we access them?
4. In your opinion, what do you think attributed to the poor water quality of Green Hill Pond?
5. Does the City have any plans to help improve Green Hill Pond's water quality?
6. What does the numbers in the test results mean?
7. How much do you think littering impacts water quality?
8. Can we have the wetland map / where water drains to?

Appendix V: Robert Antonelli Interview, May 25, 2022

- How long have you worked for the City of Worcester?
- What is the City's history with the Park?
- What is the City doing to prevent water pollution at Green Hill Ponds?
- How long ago did the City start water testing of Ponds and lakes? Are those results available? Can we access them?
- Does the City test the Park's water?
    - What are some reoccurring concerns you see during testing?
- In your opinion, what do you think attributed to the poor water quality of Green Hill Pond?
- Does the City have any plans to help improve Green Hill Pond's water quality?
- Can we interview the golf course and the farm director?

- Does the City know what fertilizers the golf course uses?
- We are thinking of putting up QR codes across the Park, is it ok?
- Can we have access to the drainage map for Green Hill Park, the underground pipe routes?
- What type of feedback do you get from the public?
- Does the City factor the use of Ponds into recreational development?
- Do you have the water bill for the irrigation of the golf course? We want to figure out the water flow
- Tell him about our TIMELINE/deadlines

Appendix VI: Full Nashoba Analytical Water Testing Results

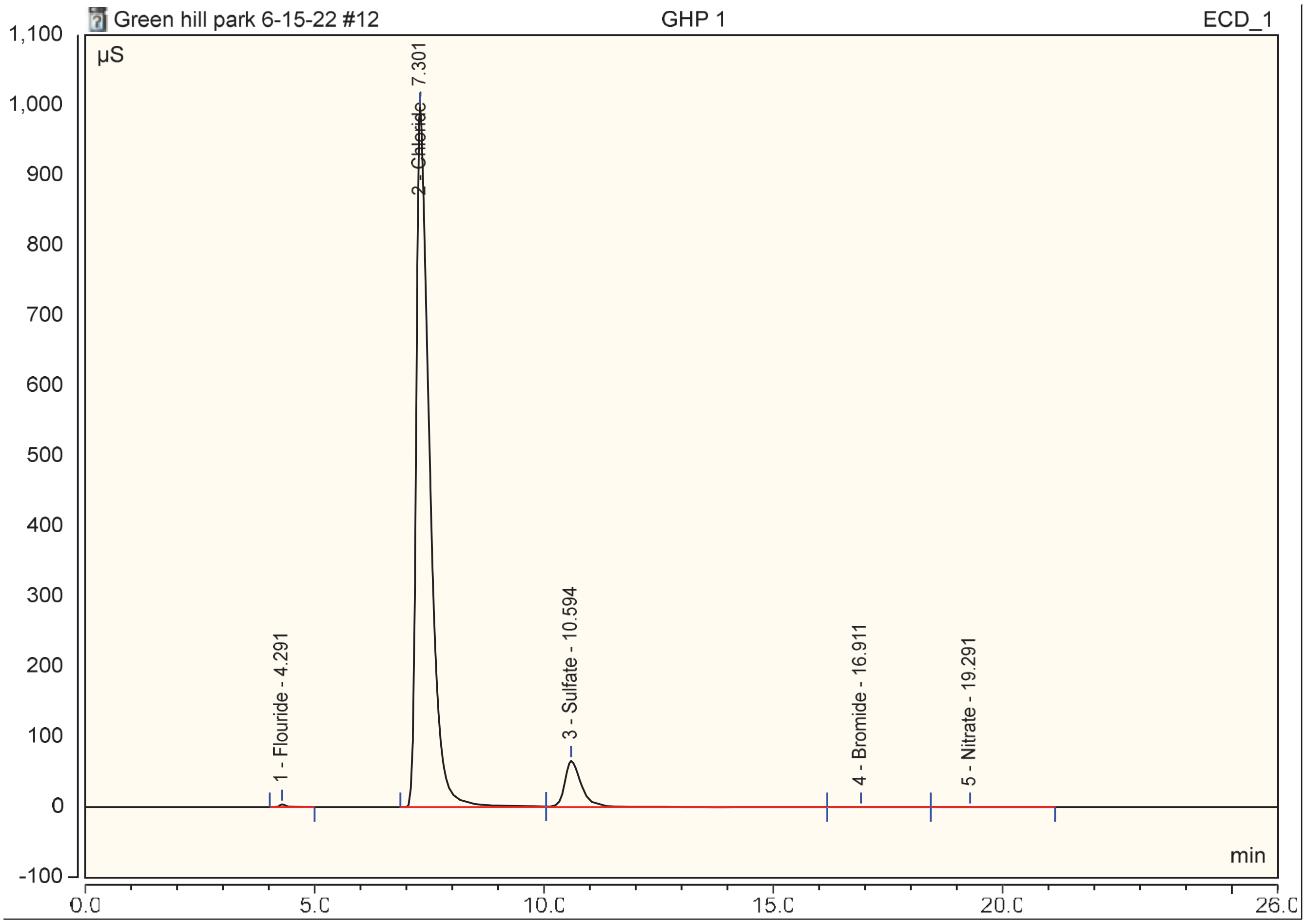
Parameters & Units	June 10th 2022		May 24th 2022		April 28th 2022		June 15th 2021		October 19th 2020		MRL	MCL
	GHPL	GHPO	GHPL	GHPO	GHPL	GHPO	GHPL	GHPO	GHPL	GHPO		
E. Coli, /100ml	-	-	-	-	3	8	58	58	PRESENT	PRESENT	1	-
Total Coliform Bacteria, /100ml	>2420	>2420	>2420	1120	727	517	440	260	PRESENT	PRESENT	1	Absent
Calcium, MG/L	12.2	11.9	11.9	11.8	11.1	10.7	13.1	13.2	13.9	6.7	0.2	Not Spec
Copper, MG/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.004	1.3
Iron, MG/L	0.191	0.382	0.102	0.314	0.076	0.405	0.154	0.135	0.158	0.291	0.004	0.3
Magnesium, MG/L	2.3	1.9	2.3	2	2.3	2	2.5	2.5	2.8	0.9	0.1	Not Spec
Manganese, MG/L	0.08	0.067	0.095	0.068	0.052	0.065	0.041	0.038	0.101	0.019	0.004	0.05
Sodium, MG/L	36.7	16.6	36.5	16.8	34	14.2	36.5	36	39	10.9	0.2	250
Alkalinity, MG/L	24	7	23	4	22	6	21	22	22	8	1	Not Spec
Ammonia as N, MG/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.1	Not Spec
Chloride, MG/L	67.5	44.7	71.1	46.6	68.2	39.8	68.1	67.3	75.8	20	1	250
Chlorine, free Residual, MG/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.02	4
Color Apparent, CU	25	30	15	30	8	18	35	35	5	25	0	15
Conductivity,	303	200	305	199	300	183	299	301	324	116	1	Not Spec

UMHOS/CM											
Hardness, Total, MG/L	40	38	39	38	37	35	43	43	46	20	1	Not Spec
Nitrate as N, MG/L	ND	ND	ND	ND	ND	ND	ND	ND	0.05	ND	0.05	10
Nitrite as N, MG/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.02	1
Odor, TON	1	2	3	4	1	1	0	0	1	2	0	3
pH at 25C	7.7	6.3	6.6	6	6.6	6.1	8.6	8.9	6.7	6.5	NA	6.5-8.5
Phosphorus-ortha as P, MG/L	ND	ND	-	-	-	-	-	-	-	-	0.1	-
Sediment, pos/neg	POS	NEG	NEG	NEG	NEG	NEG	NEG	POS	POS	POS	NEG	-
Sulfate, MG/L	7.4	6.4	7.3	7.1	7.4	7.4	7.8	8	9.1	8.3	1	250
Turbidity, NTU	7.6	8.8	1.4	6.9	1.6	4.8	1.7	1.5	3.2	6.5	0.1	Not Spec

Appendix VII: Water Test Result from Worcester Polytechnic Institute Laboratory

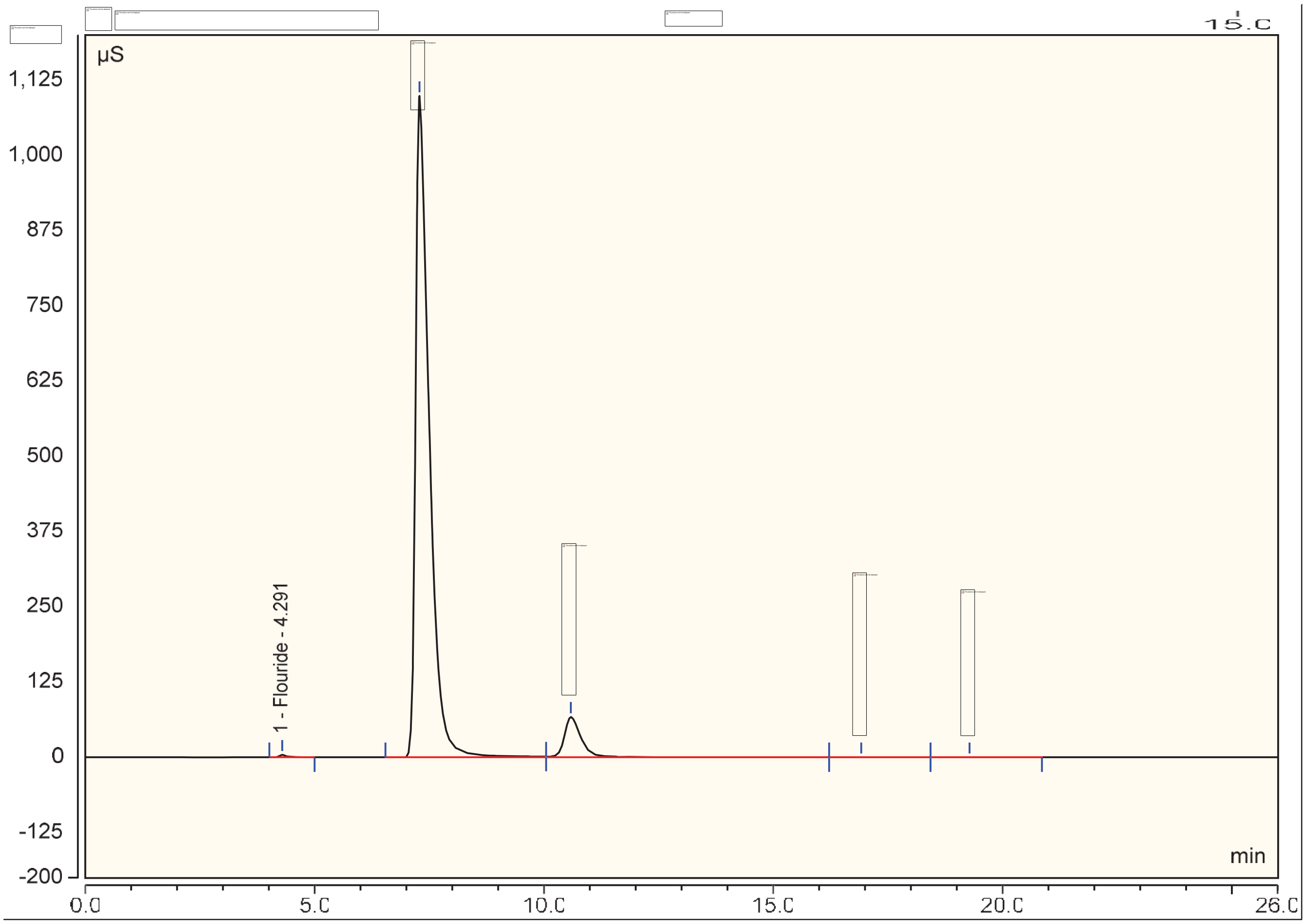
Sample Name:	**GHP 1**	*Inj. Vol.:*	**100.00**
Injection Type:	**Unknown**	*Dilution Factor:*	**1.0000**
Instrument Method:	**Anions_IM**	*Operator:*	**User1**
Inj. Date / Time:	**15-Jun-2022 / 17:27**	*Run Time:*	**26.00**

No.	Time min	Peak Name	Peak Type	Area µS*min	Height µS	Amount
1	4.29	**Fluoride**	BMB	0.784	4.129	101.2632
2	7.30	**Chloride**	BM	337.325	996.790	65916.9746
3	10.59	**Sulfate**	M	27.984	65.947	7321.0234
4	16.91	**Bromide**	M	0.101	0.094	47.9303
5	19.29	**Nitrate**	MB	0.100	0.114	34.5368
		TOTAL:		366.29	1067.07	73421.73



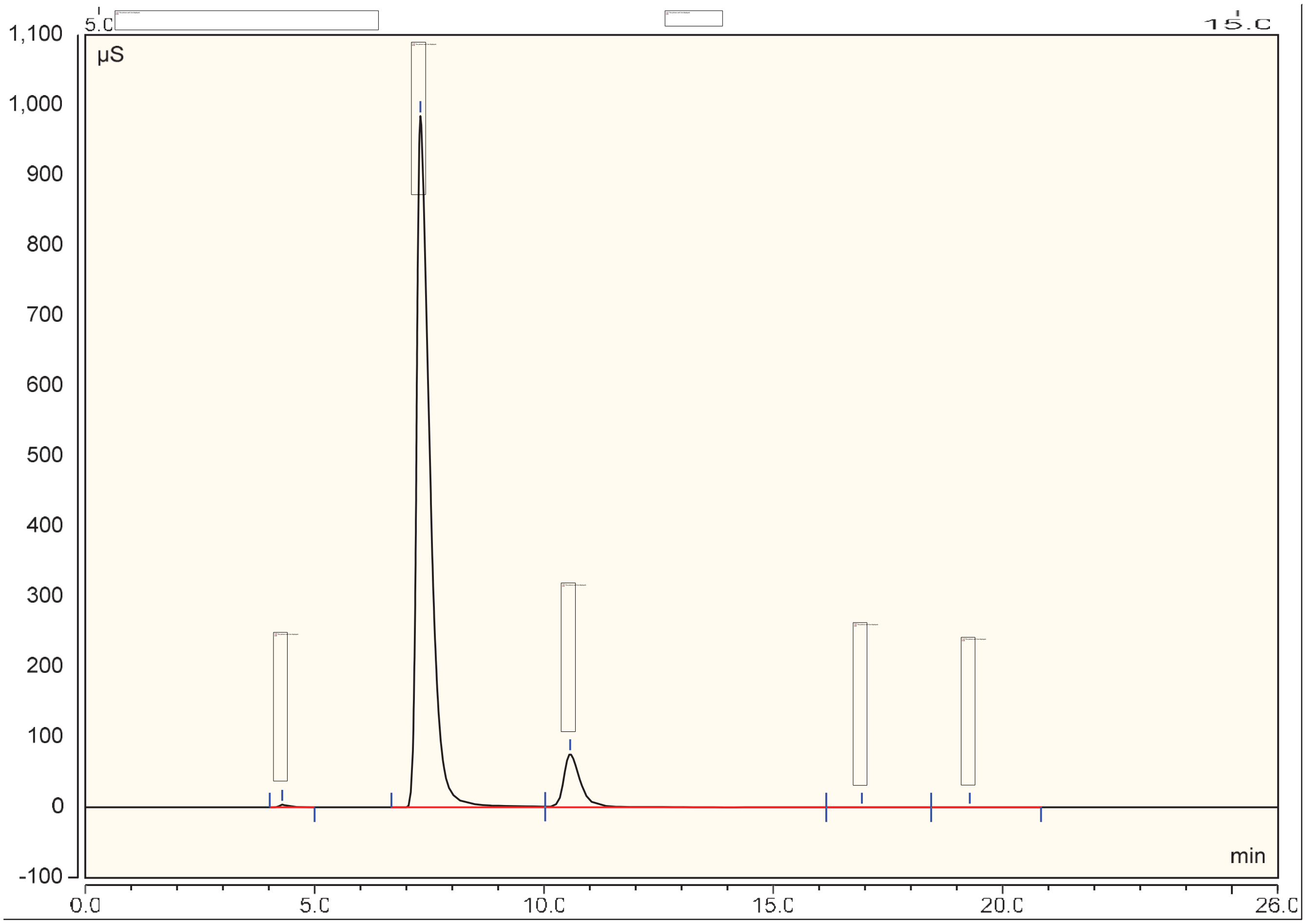
Sample Name:	**GHP2**	*Inj. Vol.:*	**100.00**
Injection Type:	**Unknown**	*Dilution Factor:*	**1.0000**
Instrument Method:	**Anions_IM**	*Operator:*	**User1**
Inj. Date / Time:	**15-Jun-2022 / 17:55**	*Run Time:*	**26.00**

No.	Time min	Peak Name	Peak Type	Area µS*min	Height µS	Amount
1	4.29	**Flouride**	BMB	0.858	4.479	110.8044
3	10.59	**Sulfate**	M	28.588	67.294	7479.2516
4	16.92	**Bromide**	M	0.101	0.103	48.1579
5	19.28	**Nitrate**	MB	0.173	0.234	59.8556
		TOTAL:		29.72	72.11	7698.07



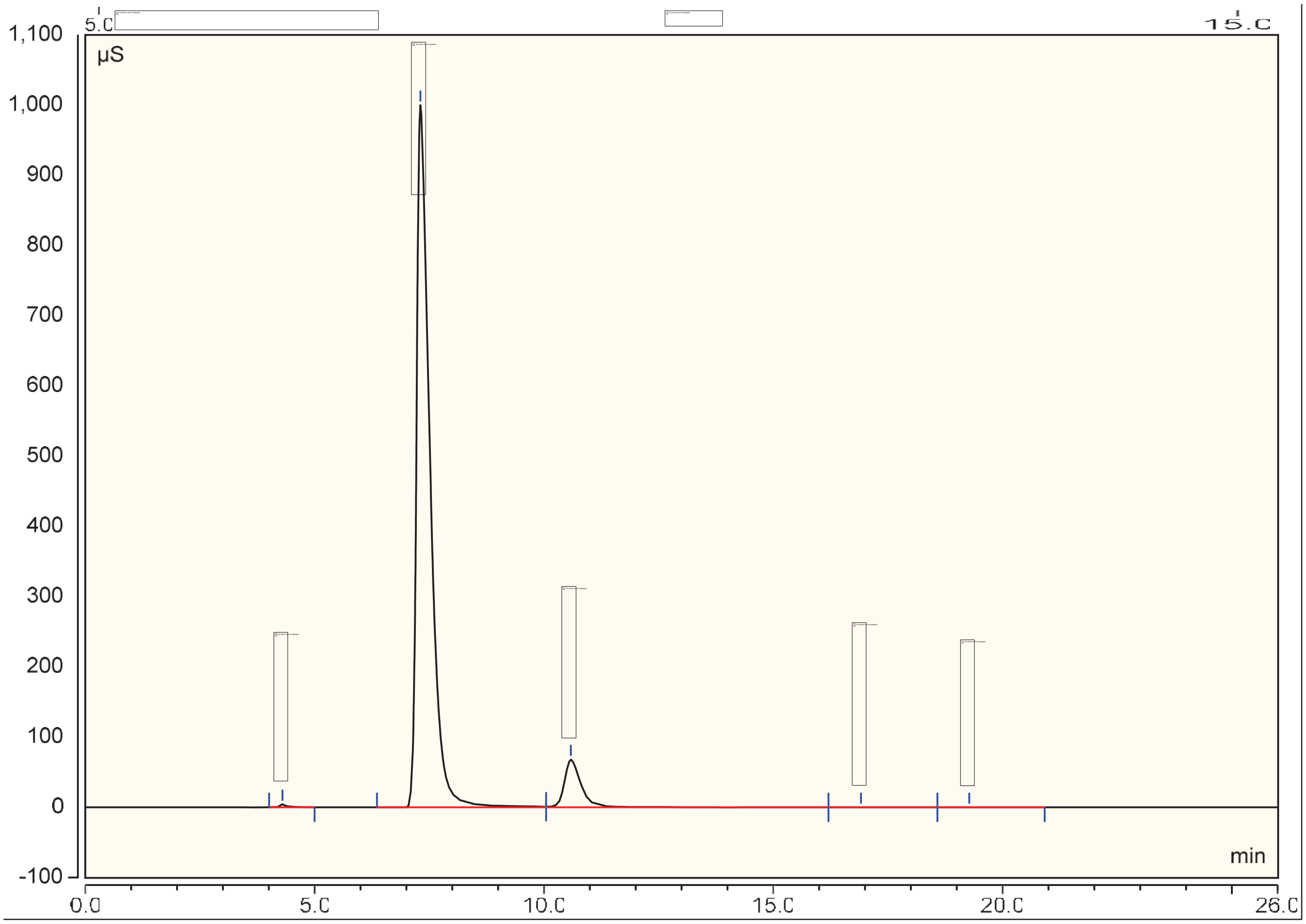
Sample Name:	**GHP3**	*Inj. Vol.:*	**100.00**
Injection Type:	**Unknown**	*Dilution Factor:*	**1.0000**
Instrument Method:	**Anions_IM**	*Operator:*	**User1**
Inj. Date / Time:	**15-Jun-2022 / 18:24**	*Run Time:*	**26.00**

No.	Time min	Peak Name	Peak Type	Area µS*min	Height µS	Amount
1	4.29	**Flouride**	BMB	0.792	4.083	102.2916
2	7.31	**Chloride**	BM	331.546	984.482	64787.6942
3	10.57	**Sulfate**	M	32.435	76.144	8485.5711
4	16.93	**Bromide**	M	0.096	0.096	45.4686
5	19.29	**Nitrate**	MB	0.110	0.142	37.9611
		TOTAL:		364.98	1064.95	73458.99



Sample Name:	**GHP4**	*Inj. Vol.:*	**100.00**
Injection Type:	**Unknown**	*Dilution Factor:*	**1.0000**
Instrument Method:	**Anions_IM**	*Operator:*	**User1**
Inj. Date / Time:	**15-Jun-2022 / 18:53**	*Run Time:*	**26.00**

No.	**Time min**	**Peak Name**	**Peak Type**	**Area µS*min**	**Height µS**	**Amount**
1	4.30	**Flouride**	BMB	0.827	4.254	106.8709
2	7.31	**Chloride**	BM	338.256	999.722	66098.9177
3	10.59	**Sulfate**	M	28.773	67.851	7527.6277
4	16.91	**Bromide**	M	0.113	0.108	53.6030
5	19.27	**Nitrate**	MB	0.069	0.082	23.9406
		TOTAL:		368.04	1072.02	73810.96



Sample Name:	**GHP5**	*Inj. Vol.:*	**100.00**
Injection Type:	**Unknown**	*Dilution Factor:*	**1.0000**
Instrument Method:	**Anions_IM**	*Operator:*	**User1**
Inj. Date / Time:	**15-Jun-2022 / 19:22**	*Run Time:*	**26.00**

No.	Time min	Peak Name	Peak Type	Area µS*min	Height µS	Amount
1	4.31	**Flouride**	BMB	3.651	18.679	471.7121
2	7.36	**Chloride**	BM	230.649	721.312	45071.3865
3	10.61	**Sulfate**	MB	23.881	57.743	6247.6594
4	16.92	**Bromide**	BMB	0.041	0.065	19.2588
TOTAL:				258.22	797.80	51810.02