Analysis on Water Quality: Pharmaceutical Concentration and Community Communication

A Major Qualifying Project proposal submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfillment of the requirements for the
Degree of Bachelor of Science

May 6th, 2021

Submitted by:
Jacqueline Cardin, Chemical Engineering and Professional Writing

Advisors:
Professor Stephen Kmiotek, PhD, Worcester Polytechnic Institute
Professor Ryan Madan, PhD, Worcester Polytechnic Institute

Acknowledgements

I would like to thank the following people and organizations for their time, support, and contribution to the success of this project:

- Mark Johnson and Tim Loftus from Upper Blackstone Clean Water for the supply of wastewater samples and providing valuable insight into their wastewater treatment processes.
- Rick Wobbe for providing countless resources documenting methods of quantifying and treating pharmaceuticals in wastewater in the initial stages of this study.
- Professor Paul Mathisen, Wenwen Yao, and Rubén Bonilla-Santiago for their advice and guidance at every step of this project.
- Andrew Butler for vital assistance in the lab testing samples and providing a wealth of knowledge along the way.
- Jen Drociak, New Hampshire Department of Environmental Services, for her support and insight into the NHDES' efforts to connect and communicate with the community.
- Sara Steiner, New Hampshire Department of Environmental Services, for her insight into the Volunteer Lake Assessment Program and how water quality results are communicated to the public.
- Todd Connors for his insight into communicating technical water quality information to a nontechnical audience as a VLAP volunteer.
- Bob Corbeil and the members of the Crystal Lake Preservation Association for sharing their water quality knowledge and experiences with me.
- My team, Marina Como and Olivia Caton for their contribution and positivity throughout our chemical engineering project.

I would like to extend a special thank you to our advisor Stephen Kmiotek for providing us with continuous guidance and encouragement, especially given the restrictions of COVID-19. I would also like to express my appreciation for my Professional Writing advisor, Professor Ryan Madan, whose input and motivation was invaluable during the course of this project.

Table of Contents

List of Figures

List of Tables

Chapter 1

Pharmaceuticals Concentrations in Wastewater

Submitted by:

Jacqueline Cardin

Olivia Caton

Marina Como

Advisor:

Professor Stephen Kmiotek, PhD, Worcester Polytechnic Institute

Abstract

Pharmaceuticals are known to cause detrimental environmental effects including the increase of antibiotic resistant bacteria and development issues in animals, but research is still limited. This study aims to observe the effect current wastewater treatment methods have on three pharmaceuticals (SMZ, azithromycin, and salicylic acid) by analyzing their concentrations after seven treatment stages. Utilizing SPE and LC-MS, we determined the effluent concentrations of SMZ and azithromycin were 81 ppb and 209 ppb, respectively, with similar concentrations appearing in surface water. This study did not observe a reduction in pharmaceutical concentration with current wastewater treatment methods but noted their potential.

Capstone Design Statement

The Major Qualifying Project (MQP) at Worcester Polytechnic Institute has several requirements presented by the Accreditation Board of Engineering and Technology (ABET) to help prepare students for practical application “based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints.” These constraints depend on the economic, environmental, social, political, ethical, health and safety, manufacturable, and sustainable factors surrounding the design. Designs are often iterative, involving multiple examinations of data while forming an idea and offering areas of improvement.

Current wastewater treatment practices do not target pharmaceuticals directly, and these contaminants are often missed by general treatment processes. During our investigation of SMZ, azithromycin, and salicylic acid in Upper Blackstone’s wastewater, we found that these pharmaceuticals were present throughout the wastewater treatment process. Hence, determining a method of treating pharmaceuticals at Upper Blackstone was prudent. However, the nature of our results added an additional design constraint. UV-Vis spectrometry indicated a significant drop in detected material after aerobic treatment, at wavelengths our pharmaceuticals would be found. With LC-MS, we found all pharmaceuticals present in low concentrations, with little or no reduction from start to finish. Combined, these data indicate that aerobic treatment has the potential to treat pharmaceuticals in wastewater in Upper Blackstone’s current system. Because this design is focused on potential treatment in a pre-existing environment, it should impact the current system as little as possible. The design should also offer increased efficiency of overall treatment, in the event that the potential to treat pharmaceuticals is not reached.

To address these constraints and requirements, a second biological reactor and a recycling stream in the aerobic tank were both considered. Initial testing indicated the potential for aerobic tank treatment to effectively treat pharmaceuticals, while research also showed biological reactors had proven effective in treating salicylic acid, making both viable options. After examining potential costs, feasibility, and impact, the recycling stream option was chosen. Wastewater would travel through the aerobic tank and receive initial treatment, before exiting the tank and entering a recycling stream. Air would continuously be blown into the pipe at periodic intervals, adding oxygen necessary for aerobic treatment and thoroughly mixing the water. The wastewater would then re-enter the aerobic tank and undergo treatment a second time before flowing to primary settling. Two different dissolved oxygen values were considered for this design. The first value, 0.6 mg/L, is the average of typical values in Upper Blackstone, and focused on maintaining current levels of oxygen that appease the present bacteria. The second, higher dissolved oxygen of 1.0 mg/L is considered average wastewater treatment plant values and would provide a more complete mixing. While a higher dissolved oxygen value will ultimately reduce the aerobic treatment performed by the bacteria, this difference was found to be minimal. The focus of this design is to increase mixing, as it will allow the bacteria to better feed on pharmaceuticals and other previously untreated contaminants, especially those in low concentrations. A recycling stream has minimal impact to the current treatment system and requires limited materials, merely piping, pumps to carry the water, and air blowers to add oxygen and mix the wastewater. Recycling streams are known to be safe and non-controversial additions to a system and can easily be modified or manufactured for multiple locations. It is recommended that Upper Blackstone perform a more in-depth analysis of their aerobic tank's efficiency, bacteria conditions and reactions, and specific reactions to pharmaceuticals to determine optimal dissolved oxygen and mixing levels.

Professional Licensure Statement

Licensure is the act of distributing licenses as well as restricting practices to those who have specific licenses. Licensure is usually run by the government or a specific organization dedicated to the practice. In the United States, engineering licensure falls under the state board jurisdiction, and is represented by the National Council of Examiners for Engineering and Surveying (NCEES). There are two licenses individuals can gain for engineering: Engineering in Training (EIT) and Professional Engineering (PE).

To become a professional engineer, an individual must graduate from an accredited engineering program, then become an EIT by passing the Fundamental Engineering (FE) exam. An EIT gains experience by working under an engineer with a PE license for four years before they are eligible to take the PE exam (Doud, 2021). Becoming an EIT is traditionally a required step to becoming a professional engineer, though 15 states have begun moving away from this in the past decade (National Society of Professional Engineers, 2018). This change is intended to move engineering licensure to a more individually oriented process, where an applicant may take the PE exam as soon as they feel they are prepared. The PE exam itself is dependent on what type of engineering a person is pursuing, though exams are typically 8 to 8.5 hours long with 80 questions (NCEES, 2021). After passing the PE exam, licensed engineers maintain this status by participating in designated courses, webinars, and conferences (School of PE, 2018). The required topics of this continued education and how often they should be completed is determined state by state and can easily be found on state websites. If an engineer wishes to practice in a different state, they will need to obtain a separate PE license for that state (Blake, 2017). This process is much simpler than obtaining an individual's first PE license, as states merely need to recognize that someone has achieved the PE requisites before. At this point, obtaining the new state's PE license is simply a matter of filling out paperwork.

Regardless of engineering type or state, all PE licenses represent the legal privilege an engineer must practice engineering. They have proven they have a comprehensive understanding of the subject and can be trusted to complete their work skillfully. To the engineer themselves, engineering licensure is recognition of their hard work, and the key to open doors that otherwise may be closed. As a professional engineer, they are allowed to prepare, seal, sign, submit, and approve plans and drawings (NSPE What is a PE?, 2021). A PE license is also required for engineers who wish to work in a private practice. A license allows engineers to take higher positions in a company, often with more pay than an unlicensed engineer. All of these aspects involve a high degree of knowledge and competency, which an engineering license stands as proof of (NSPE 2021 Why Get Licensed?). It also reminds engineers of the responsibility they must use this knowledge to ensure public safety.

Licensure allows the engineering industry to preserve its integrity. Without licensure, there would be no official, definitive way of determining whether an individual has the necessary expertise to practice engineering. By setting certain goals to reach before licenses can be obtained, all professional engineers are expected to have these skills and know how to use them effectively. This helps prevent damage from inexperienced engineers, while also holding professional engineers to a strict ethical code to avoid negligence. In case of a faulty design, having a professional engineer on the design team will corroborate that an accident was beyond the industry's control, helping avoid potential lawsuits (Chinchilla, 2017). These factors ensure a group of individuals provide high quality, efficiently designed products ideal for the client's use. This is the primary meaning of "professional engineer" to the public. Most times, clients or individuals who will frequently use the final product do not have the necessary background to understand how to engineer a product. As a result, they place their trust in an engineer to not only create the product, but to do so in a way that will ensure its smooth and safe functioning. Engineering licensure acts as a way for the public to distinguish which engineers should be hired over others. They know that because the license represents extensive knowledge and skill, the engineer will use these attributes to complete projects. This results in a high-quality finish that was completed safely, efficiently, and within legal guidelines. A PE license shows an engineer can be trusted.

Executive Summary

Background

Wastewater is defined as used water including human waste, food scraps, oils, soaps, and chemicals. Originally, human waste and wastewater were disposed of directly on land surfaces, but today they are treated in specialized plants to reduce environmental impact and health risks. The major goal of wastewater treatment is to remove as many suspended solids as possible before the effluent is discharged to the environment (Cressler, 2021). Wastewater treatment plants (WWTP) are held to certain standards set by the Environmental Protection Agency (EPA), however pharmaceuticals are not currently regulated by the Safe Water Drinking Act. Thousands of tons of medicines treat both humans and animals each year. These medicines are often improperly disposed of, tossed directly into surface water or down a toilet or sink. Because of the lack of regulations, WWTPs are not currently designed to treat pharmaceuticals, so they are often redistributed into the environment by their effluent streams. Unfortunately, pharmaceuticals have many negative effects on plants and animals, such as development issues and increasing antibiotic-resistant bacteria. This is creating an urgent need to study not only their environmental impacts but also possible mitigation efforts.

This study focuses on three different pharmaceuticals: sulfamethoxazole (SMZ), azithromycin, and salicylic acid. SMZ and azithromycin are widely used antibiotics used to treat infections, while salicylic acid is a typical ingredient in acne treatments. Although research is currently focused on preventing their introduction to the environment, possible treatment methods, such as bioprocesses, show promising results. In this study, we are focused on determining the concentration of SMZ, azithromycin, and salicylic acid in surface water in Worcester, MA, and wastewater from Upper Blackstone Clean Water, one of the largest treatment plants in New England.

Methodology

Although a large portion of pollutants are removed from wastewater during treatment processes, pharmaceuticals are not directly targeted by current methods. This study aims to quantify SMZ, azithromycin, and salicylic acid in surface water samples, as well as investigate the effectiveness of current treatment methods with respect to pharmaceuticals. To accomplish this, we followed the objectives below:

1: Determine current concentration levels of SMZ, salicylic acid, and azithromycin in three different bodies of water in Worcester, MA.

2: Analyze the concentrations of these pharmaceuticals after seven major treatment stages, including the influent and effluent streams of Upper Blackstone WWTP.

3. Recommend strategies to improve the removal of pharmaceuticals in WWTPs.

First, we collected samples from three local bodies of water: Lake Quinsigamond, Green Hill Pond, and Salisbury Pond. We also collected samples from Upper Blackstone to analyze the seven major wastewater treatment methods they utilize, which includes a bioreactor process. We then created standard solutions with the pure compounds at known concentrations; this helped us identify our pharmaceuticals and quantify the samples later on. Once all the samples and standards were gathered, we used UV-Vis to confirm the presence of the selected pharmaceuticals by comparing their chemical properties to the resulting spectra. Then, we performed SPE to isolate and concentrate our samples to prepare for LC-MS. With the pharmaceuticals isolated, they were easier to detect using LC-MS, our main method of identifying and quantifying the samples. LC-MS was the ideal method based on our pharmaceutical's chemical properties, and its sensitivity allows us to detect concentrations in the parts per billion (ppb) range. By creating a serial dilution, we were able to create a calibration curve and compare the MS peak areas of our samples to find their approximate concentrations.

Results

UV-Vis Data Analysis

When UV-Vis samples have a strong signal, the absorbance can be measured, and the Lambert Beer Law is used to analyze the results. Unfortunately, the signals in our samples were too weak to definitively interpret our chosen pharmaceuticals. This is either because their concentrations are too low, or the method did not separate the signals clearly enough. Overall, our graphs showed slight differences and shifts from trial to trial, but the samples contained too many chemicals to identify our antibiotics for certain.

In both the SMZ and salicylic acid spectra, we saw the highest peaks at around 240-250 nm, which were expected as compared to literature. The next comparison we make is between the spectra of the influent and final effluent samples. The final effluent spectrum is smoother than the one of influent. This is expected because the influent is the untreated wastewater and the effluent is fully treated and leaves the WWTP as clean water. Lastly, the UV-Vis spectra between the three bodies of water were compared which can be seen in Results Section 3.1, page 17. Lake Quinsigamond and Salisbury Pond have similar graph shape and therefore may have similar concentrations, while Green Hill Pond has a steeper shape and potentially higher concentration. More details on these graphs can be seen in Appendix B.

Coliform and Bacteria Test

To investigate the presence of *E. Coli* and coliform in wastewater, the tests were performed in three composite samples (influent, primary effluent, final effluent) acquired from Upper Blackstone and in the three bodies of water (Lake Quinsigamond, Green Hill Pond, and Salisbury Pond) as shown in Appendix B. The influent color had shifted completely from yellow to dark purple, the primary effluent color was mainly yellow but with some hints of purple, while the effluent color had remained purely yellow. This color change is consistent with our expectations as influent is the raw, untreated wastewater which contains different pharmaceuticals, chemicals and effluent is the last stage of the treatment plant which is safer and well-treated for discharge.

As we can see after testing for presence of bacteria, Lake Quinsigamond and Green Hill Pond had remained yellow, while Salisbury Pond had turned slightly purple, indicating a higher level of coliform contamination. The other water quality tests included general hardness, nitrate, nitrite, free chlorine, carbonate, and pH as shown in Appendix E.

LC-MS Analysis

Since our samples contained too many chemicals to identify our pharmaceuticals in the UV-Vis spectrums, we performed SPE to isolate and concentrate our samples. This allowed for easier detection using LC-MS, and we were able to analyze all our samples at once using Single Ion Monitoring (SIM) for each pharmaceutical. Details about the optimization of the LC-MS methods can be seen in Appendix A. We had 51 total samples including 21 standards to create a calibration curve for each pharmaceutical. We then plotted the known standard concentrations against the peak area from the MS report to create a linear trendline. After retrieving the MS reports for the 30 wastewater and surface water samples, we were able to use the trendline equation to approximate their concentrations from their peak areas. A complete list of these samples, their peak areas, and their concentrations can be found in Appendix C, Table 2.

Our goal was to observe the trend in SMZ, azithromycin, and salicylic acid concentrations as the treatment stages progressed. However, our LC-MS data show there is no definitive trend or reduction in any of the three pharmaceuticals as the treatment stages progress. The approximate concentration of SMZ stays between 40 and 100 ppb throughout wastewater treatment. Due to a combination of instrumental errors and unreadable wide peaks, only one concentration was approximated for salicylic acid, and that was about 50 ppb. Figure 23 in Section 3.4 shows the concentration of azithromycin stays consistently between 200 and 300 ppb throughout the wastewater treatment process, much higher than SMZ and salicylic acid concentrations as seen in Figure 19 and 22, even though we expected higher concentrations of SMZ. A more comprehensive report of our LC-MS findings can be seen on page 30.

The LC-MS results for surface water samples taken from Lake Quinsigamond, Green Hill Pond, and Salisbury Pond show similar concentration levels. We were able to plot the concentrations for each pharmaceutical at each body of water, which can be seen on page 30. The missing data for salicylic acid at Green Hill Pond and SMZ at both Green Hill Pond and Salisbury Pond resulted from either instrument error or no sample was tested due to lack of supplies. Azithromycin had the highest concentration at all three locations, with the highest at Salisbury Pond. This is more than double the concentration of salicylic acid at Salisbury Pond and Lake Quinsigamond. Surprisingly, SMZ had the lowest concentration at lake Quinsigamond, despite high concentrations in the environment reported in literature.

Part 1: Introduction

Antibiotics are one of the most significant discoveries of the last centuries, effectively treating a large array of deadly infections. This greatly increased pharmaceutical consumption in recent years which exposes bacterial communities and ecosystems to a large amount of antibiotics residues. This exposure has led to the increase in antibiotic resistance bacteria (ARB) and poses significant risk to public health and safety. There are thousands of pharmaceuticals and antibiotics that are commonly used today. These pharmaceuticals find their way in the water by excretion of active drugs, being directly discarded into the environment, or by incomplete removal during wastewater treatment. Wastewater treatment removes contaminants from sewage and wastewater then converts it into an effluent stream that returns to the environment. This effluent can be repurposed and thus creating the wastewater cycle. Currently, pharmaceuticals are not regulated in wastewater, so treatment plants are not equipped to target and remove these antibiotics. It is critical to study pharmaceutical treatment methods for the health and safety of the public and to avoid negative effects on the environment.

Our project focused on three pharmaceuticals: sulfamethoxazole (SMZ), azithromycin, and salicylic acid. These antibiotics were chosen because of their everyday use and known presence and effect on the environment. The methods used to detect and analyze the presence of antibiotics were mainly UV-Vis, LC-MS, and general water quality tests. The goal of this study was to better understand environmental effects, pollution sources, and current treatment efficiency. By knowing this, we hope to provide recommendations to improve current wastewater treatment methods in the removal of pharmaceuticals.

Background

1.1 Cycle of Wastewater

Wastewater contains human waste, food scraps, oils, and soaps, and is usually made up of 99.9% water and 0.01% organic matter, microorganisms, or inorganic compounds (Tuser, 2020). Originally, human waste and wastewater were disposed of directly on land surfaces, leading to massive sanitary problems that caused deadly illnesses and diseases. The amount of wastewater increased with the development of water supply systems, shifting the need to create wastewater treatment plants (WWTPs) to protect public health and the environment. Wastewater treatment plays an important role in fisheries, wildlife, quality of life, and other health concerns.

To address these concerns, wastewater treatment plants (WWTPs) treat industrial and residential wastewater to remove pollutants with a combination of treatment processes. The major goal of wastewater treatment is to remove as many suspended solids as possible before the effluent is discharged to the environment (Cressler, 2021). Effluent streams are any wastewater that exits a reservoir, treatment process, or industrial plant that is treated or untreated. Influent, on the other hand, is wastewater that flows into a reservoir, treatment process, or industrial plant (UFL, 2021). In general, the urban water cycle starts with water withdrawal from rivers or lakes that is delivered to the city buildings after purification. After constant use at home or industrial plants, the water is delivered to collection plants and WWTPs. After treatment, the water is returned to its original source, rivers, or lakes. A diagram showing the path of water and wastewater can be seen in Figure 1.

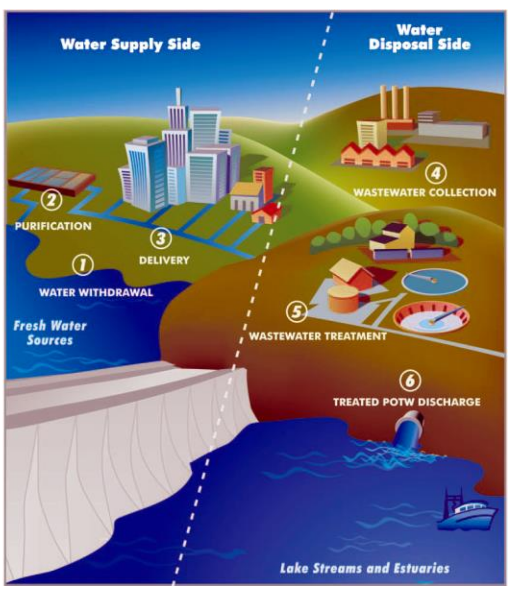


Figure 1. The cycle of wastewater starting from water withdrawals and ending as treated discharge before returning to Step 1.

A wide range of human medicines, including antibiotics, are produced and consumed in the range of thousands of tons per year (Boxall, 2004). While wastewater is processed by WWTPs, pharmaceuticals in the wastewater may not be treated at all. Many WWTPs do not currently target pharmaceuticals, so they end up recirculating in the water cycle. Additionally, some pharmaceuticals, such as veterinary medications, completely avoid WWTPs by entering the environment directly as animal waste.

Pharmaceuticals can enter the environment a multitude of ways: industrial pollution, improper disposal in sewage systems, or animal and human excrement as mentioned above. Excrement has 30% to 90% of the active chemical ingredient in it, and treatment plant removal efficiencies can be as low as 10% (Patel et al, 2019). Water bodies such as lakes are often polluted through human contact, with sweat or sunscreen products washing off skin as people swim. Though they have relatively short lifespans, pharmaceuticals' near-constant presence in effluent streams cause them to be “pseudo-persistent” in the environment.

There are several classes that categorize pharmaceuticals by function. Classes known to impact the environment include antibiotics, antidepressants, pain killers, and hormones. Antidepressants and anti-anxiety medications have led to behavior changes in birds and fish, such as increased food consumption. Additionally, synthetic hormones have caused male fish in Europe to become intersex (Nawrat, 2020). Painkillers and antibiotics commonly used to treat-cattle are linked to acute kidney failure in vultures in Asia (Pharmaceuticals Move throughout the Aquatic Environment). These studies show predators are most affected and the spread of the problem goes far beyond initial perception. Even personal care products negatively impact the environment by inhibiting vital plant growth in high concentrations. Figure 2 shows how quickly pharmaceuticals can spread through soil adsorption, water flow, and animal consumption. The figure depicts various environmental effects of pharmaceuticals, including hormone overstimulation, developmental issues, behavioral changes even death.

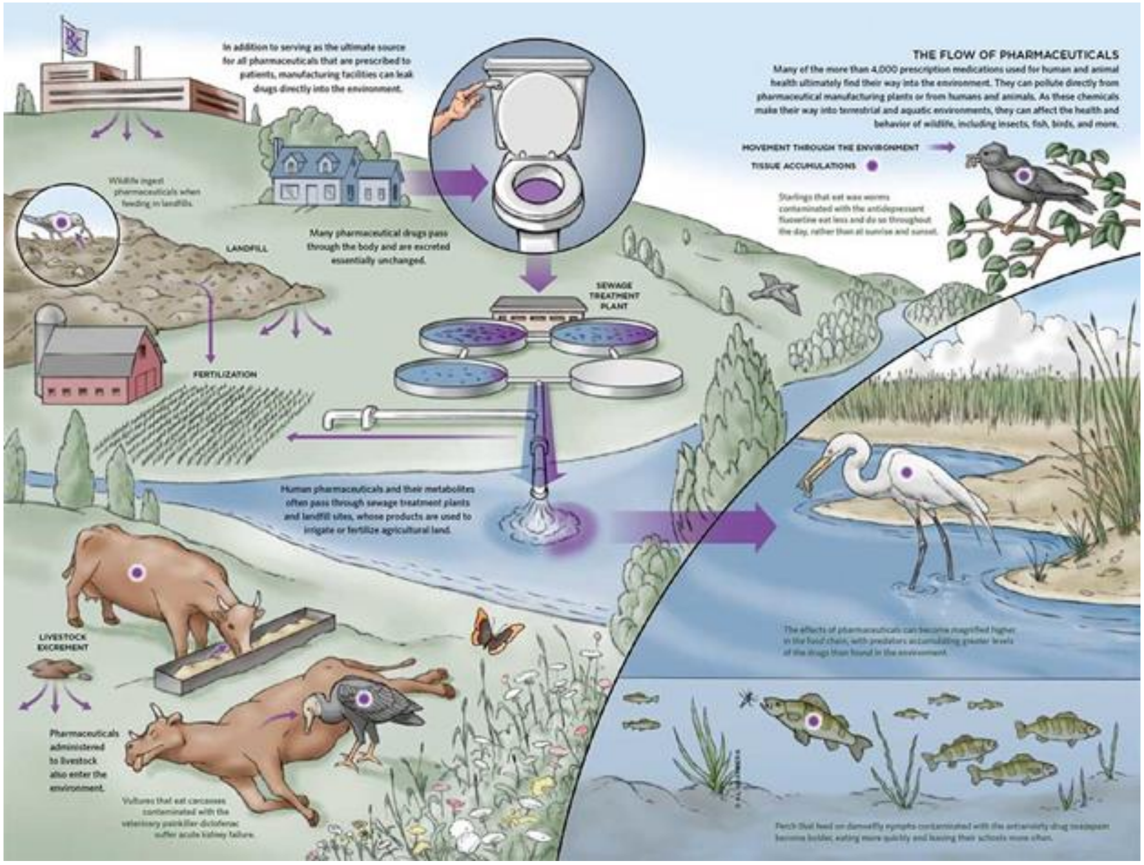


Figure 2. This flow diagram shows the possible spread of pharmaceuticals and the effects they have on flora and fauna.

One of the greatest concerns with the increasing level of pharmaceuticals in wastewater is antibiotic resistant bacteria (ARB). Even low concentrations of antibiotics can lead to antibiotic resistance in any environment. This creates a positive feed loop, where higher doses are necessary to fight infections, which increases the side effects, and ultimately creates stronger bacteria. This is particularly a problem in developing countries who have less access to medication. A recent global review reported that of 713 pharmaceuticals tested in the environment, 631 of those were found above detection limit (Thomas, 2017). Because this is an emerging issue, it is important to not only study the environmental impacts, but also any mitigation strategies that may reduce their effects.

1.2 Selected Pharmaceuticals

In the wide range of drugs, sulfamethoxazole, salicylic acid, and azithromycin have been known to have significant effects on the environment. These three pharmaceuticals are commonly used in medicine and personal care products, promoting microbial resistance that creates microbes with the potential to upend fragile systems.

Sulfamethoxazole (SMZ) is in the sulfonamide class of antibiotics that is widely effective against bacteria, including UTIs, pneumonia, and ear infections. SMZ is commonly paired with trimethoprim (TMP) to create the antibacterial products Bactrim, Bactrim DS (double strength), and Septra. It is among the top ten most common generic antibiotics and has been found in environments both near and far from hospitals and manufacturing plants, making it a prime pharmaceutical to analyze (drugs.com).

A study in a developing country found bacteria with a high resistance to TMP– SMZ (Gangcuangco, 2005). This is problematic since this antibiotic drug has been around since the 1930s and is usually the first line of treatment for infections (Huovinen, 2001). This study also showed an association between failed treatments for acute urinary tract infections (UTI) and previous UTI episodes, meaning past use of antimicrobial drugs could lead to treatment failures in the future (Gangcuangco, 2005).

There are many emerging studies attempting to treat SMZ and other antibiotics in wastewater, with varying degrees of success. Knowing this is a growing problem with no solution in sight, there should be a focus on preventing antibiotics from entering the environment as well as finding successful treatment. Recently, the Center of Disease Control issued a list of serious and concerning antibiotic resistant bacteria (ARB) afflicting the US healthcare system in hopes of doing just that, stopping the problem at the source (Ventola, 2015).

Salicylic acid is a monohydroxy benzoic acid plant hormone that plays a major role in metabolism, growth, and stress response (Hayat, 2009). It is used as a topical treatment for acne and skin conditions which cause scaling and overgrowth and is commonly found in over-the-counter skin care products such as creams or pads. The U.S. National Library of Medicine discourages pouring salicylic acid down the drain or toilet and recommends dropping the product off at a drug take-back program location (Medlineplus, 2021). However, many might not realize this common skin care product is a pharmaceutical drug that requires proper disposal to prevent negative environmental effects.

In low concentrations, exogenous salicylic acid can even be beneficial to plant health, increasing seed germination, fruit yield, and photosynthetic rate. Additionally, plants may benefit from salicylic acid in stressful situations as it naturally controls hormonal stress responses. For example, a study focusing on tobacco and cucumbers noted that salicylic acid reduced or completely eliminated oxidative stress conditions from said plants being exposed to the herbicide paraquat (Hayat, 2009). However, these effects are not consistent with all plant species; only certain strains of Rhizobia bacteria reacted to additional salicylic acid, whereas the common bean and the Asiatic dayflower did not react at all. Concentrations higher than 10^{-5} M start to have an inhibitory effect, reducing growth and increasing stress.

Salicylic acid has not been closely monitored in the past, and only recently became classified as a contaminant of emerging concerns (CEC) (Lopez-Serna, 2019). A 2019 study evaluated the effectiveness of treating several pharmaceuticals, including salicylic acid, with agal bacterial photobioreactors. Two different configurations were considered: an anoxic-aerobic photobioreactor; and an anaerobic-anoxic-aerobic photobioreactor. These types of processes have only recently been considered for treating CECs and utilize the “solar-driven conversion of carbon and nutrients from wastewater into algal-bacterial biomass” (Lopez-Serna, 2019). The first configuration had removal efficiencies between 63% and 83%, while the second varied between 34% and 97%. This may be due to the extremely high concentration of salicylic acid, roughly 10,756 ng/L, as this experiment focused on whether the configurations would remove salicylic acid rather than estimating from realistic wastewater values (Lopez-Serna, 2019). Theoretically, these photobioreactors could remove 93% to 98% of salicylic acid under average environmental conditions (Lopez-Serna, 2019). Despite this wide range of efficiency, the removal efficiency dropped after three to four days of HRT, indicating that biodegradation plays a key role in salicylic acid treatment.

Azithromycin is an acid stable, orally administered antimicrobial drug in the macrolide class used to treat different bacterial infections, especially in the lower and upper respiratory tracts (Peters, 2012). Recently, this antibiotic has been studied in combination with hydroxychloroquine and other medications to treat COVID-19. It is recommended to dispose of it through medicine take-back programs rather than flushing it down the toilet (Medlineplus, 2020).

Researchers in a YEAR study collected 72 samples from two Mid-Atlantic and two Midwest treatment plants and measured antibiotic concentrations using liquid chromatography (LC). Azithromycin had the highest concentration of all antibiotics in influent and effluent samples from both regions (Kulkarni, 2017). Other findings showed low-level antibiotic concentrations exist in reclaimed water used for irrigation. Even low concentrations of antibiotics can result in antibiotic resistance when combined with nutrients and bacteria (Kulkarni, 2017). The researchers concluded that the pharmaceuticals had entered the Mid-Atlantic wastewater treatment plant through domestic and hospital wastewater, whereas they entered the Midwest through domestic and agriculturally influenced stormwater.

Another study in Croatia investigated the effects of antibiotic-containing wastewater on bacteria, algae, and animals by analyzing river water directly downstream of pharmaceutical plants (Lehman, 2018). Azithromycin can persist in the natural environment for a long time and was one of the antibiotics detected in the river water. The study showed that fish embryos grown in this wastewater experienced development issues and they died within 24 hours of development. Additionally, the high levels of antibiotics also inhibited all algae growth. In general, discharge effluents containing pharmaceuticals, including azithromycin, alter physicochemical characteristics of receiving river sediments, which can contribute to macrolide-resistant genes (Milakovic, 2019).

1.3 Current Regulations

In the United States, the Environmental Protection Agency (EPA) is the primary governing body for effluent limitations in wastewater treatment plants (WWTP). As an extension of the Clean Water Act, the EPA publishes an annual review where these standards are evaluated and discussed for industrial categories (EPA,2018). The EPA also reviews previous Effluent Limitation Guidelines (ELGs) and publishes the Effluent Guidelines Program Plan every two years. These regulations center around current wastewater treatment technologies and are updated as needed to "restore and maintain the chemical, physical, and biological integrity of the nation's waters" (Flanders, 2021). ELGs control the discharge standards from all different kinds of industries. These nationwide regulations aim to control the largest pollutants from each industry depending on toxicity, frequency, and location (Flanders, 2021). The EPA has prioritized 126 known pollutants based on their toxicity level; however, everyday pharmaceuticals do not fall on this list (Flanders, 2021). Because knowledge of their effect on the environment is limited, pharmaceuticals are slipping through the cracks of WWTP and their effects are increasing in impact.

In 1976, the United States implemented the Resource Conservation and Recovery Act, a set of regulations meant to control hazardous wastes from cradle to grave. Frequently used medicines such as epinephrine, warfarin, and chemotherapeutic drugs are subjected to these guidelines, but WWTPs are ill-equipped to treat these chemicals. Regulations on pharmaceuticals outside of the Resource Conservation and Recovery Act are lacking worldwide; What little information is presented, comes in the form of recommended guidelines for medical centers as opposed to concrete regulations. Currently, Australia is the only country whose drinking water regulations specifically address pharmaceuticals.

Pharmaceutical treatment has become a research focus in science in recent years but overcoming years of environmental impacts is not an easy feat. While research and regulations try to catch up, actions are being taken to stop the problem at the source. Prescription Drug Take Back programs currently provide the best way to dispose of unused or expired medicine safely. The Drug Enforcement Administration (DEA) and Environmental Protection Agency (EPA) have begun regulatory proceedings on the behalf of public health and negative environment effects (Barlas, 2009). The DEA periodically hosts National Prescription Drugs Take Back events where temporary drug collection sites are set up in communities nationwide. There are also permanent collection sites that can include retail, hospital, or clinic pharmacies.

1.4 Current Treatments

Typical prescription doses have such low concentrations, at least compared to the rest of the effluent, that their impacts were historically considered negligible. As a result, current knowledge of environmental effects and effective treatment methods is growing but still underdeveloped. Because of the wide range of pharmaceutical classes and functions, chemical properties vary too much for current treatment methods or to design broad treatment methods. Despite this, some effective treatment methods for prominent pharmaceutical pollutants have been discovered through research. For example, salicylic acid has been known to degrade in bioreactors containing *C. sorokiniana*. However, bioreactors are considered a sophisticated method for WWTP and an expensive addition even if they do show promise. Fortunately, Upper Blackstone Clean Water treatment plant utilizes such treatment processes and is located nearby in Millbury, MA, allowing the opportunity to investigate the effectiveness of bioreactors in treating pharmaceuticals.

As one of the largest treatment plants in New England, Upper Blackstone treats water for over 250,000 individuals in the Greater Worcester area (UpperBlackstone, 2016). This WWTP has a multi-step treatment process, beginning with bar screens and aerated grit chambers that remove large objects and dense solids that could potentially damage more sensitive machines. Wastewater is then moved into a primary clarifier to allow organic material and suspended solids to settle, while floating matter such as grease is skimmed from the top. Through this process, roughly half of present suspended solids and one third of the organic matter is removed (UpperBlackstone, 2016). The scum and settled sludge are moved to a holding tank that will mix the material before moving it into a press to remove excess water. The dried sludge enters a scrubber, which exits to a thermal oxidizer that decomposes gases before releasing them into the environment. Some sludge does not enter the oxidizer, instead being moved to a landfill as sterile ash. Meanwhile, the wastewater moves to a biological nutrient removal system. A bioreactor and final settling tanks to remove finer solids, dissolved metals, and organic material (UpperBlackstone, 2016). The final stop before being released into the Blackstone River is the disinfection tank. Wastewater is cleansed with sodium hypochlorite, then de-chlorinated with sodium bisulfate before finally leaving as the effluent stream. A more detailed flow diagram of the wastewater treatment process can be seen in Figure 3.

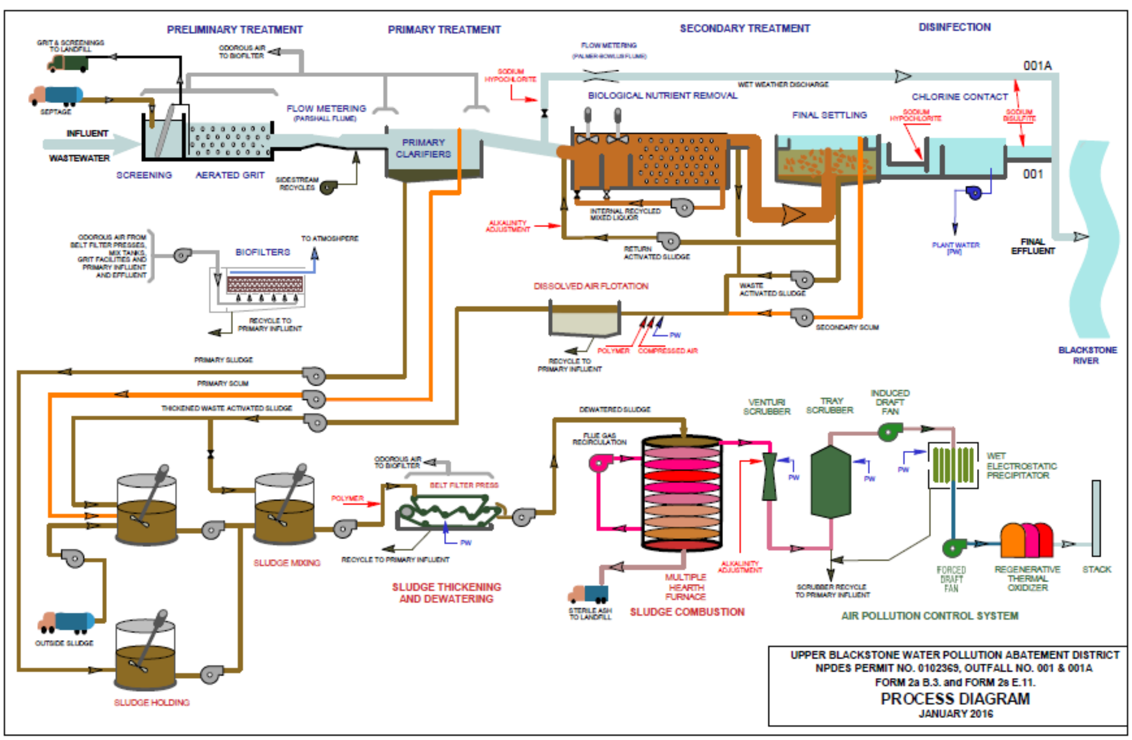


Figure 3. A visual representation of Upper Blackstone's treatment process, from Upper Blackstone's website.

The purpose of this study is to observe what effect each of these steps in Upper Blackstone's wastewater treatment process has on our selected pharmaceuticals. To achieve this, the first step is developing detection methods to identify and quantify the concentration levels of each pharmaceutical. Liquid chromatography and mass spectrometry (LC-MS) is currently the most popular detection and quantification method due to its ability to detect concentrations in the parts per billion (ppb) range. After determining the concentrations after each process, we hope to make recommendations to further improve the removal of pharmaceuticals in wastewater and analyze the concentrations of pharmaceuticals that may have leached into local bodies of water.

Methodology

The majority of micropollutants are removed from the influent stream via a variety of wastewater treatment plant processes. However, pharmaceuticals are not targeted by current treatment methods due to their low concentrations and relatively unknown impact on the environment and human health. The purpose of this study is to analyze the concentrations of select pharmaceuticals in the local Worcester county area in Massachusetts and to observe the effect that current wastewater treatment processes have on pharmaceuticals and water quality. To achieve this, the following objectives were pursued:

1: Determine current concentration levels of SMZ, salicylic acid, and azithromycin in three different bodies of water in Worcester, MA,
2: Analyze concentration of pharmaceuticals in influent and effluent streams of Upper Blackstone, as well as after each major treatment stage.
3. Recommend strategies to improve the removal of pharmaceuticals in WWTPs.

By performing solid phase extraction (SPE), we were able to isolate and analyze the pharmaceuticals. Through UV-Vis and LC-MS, the concentrations of SMZ, salicylic acid, and azithromycin were determined, as well as the overall effectiveness of Upper Blackstone's wastewater treatment process.

2.1 Sampling Scheme

Samples were collected from Upper Blackstone Clean Water treatment plant and three water bodies in Worcester, MA: Lake Quinsigamond, Green Hill Pond, and Salisbury Pond. By analyzing surface water samples, we were able to determine what concentration of pharmaceuticals were leaching into the environment and if they affected water quality. From the wastewater samples, we were able to determine if certain treatment steps were able to remove pharmaceuticals. Although the treatment process does not target pharmaceuticals directly, it is possible there may be a decrease in the concentration of pharmaceuticals during these processes as they target other pollutants.

After discussing Upper Blackstone's treatment process with several employees, we chose seven major treatment steps that potentially remove pharmaceuticals from the influent and provided glass collection bottles for each of those steps. Three composite samples were taken over a 24-hour period for the influent, primary effluent, and final effluent streams. Four grab samples were collected at some point during the 24-hour period after the anaerobic, anoxic, aerobic sections of the bioreactor, and after the final settling. Both the grab and composite samples were retrieved one day after collection. Because the composite samples consist of wastewater collected over a longer period of time, these samples were only compared to each other. Similarly, grab samples were only compared to each other. This is because the different kinds of samples, grab and composite, were collected over different amounts of time and likely have different chemical profiles.

After settling has removed suspended particles from the influent stream, the wastewater travels to the biological nutrient removal bioreactors containing the following three sections: the anaerobic section, which converts organic pollutants into biogas in an oxygen-free environment (Veolia Water, 2021); the anoxic section that removes nitrogen from wastewater; and the aerobic section, where oxygen breaks down organic contaminants and other pollutants like nitrogen and phosphorus. After the bioreactor process, the wastewater comes out as the primary effluent. Final settling is the last process separating pollutants in the wastewater, before leaving as the final effluent.

In order to better understand environmental levels of SMZ, salicylic acid, and azithromycin, we collected samples from Lake Quinsigamond, Green Hill Pond, and Salisbury Pond. As an aggregate for runoff and common recreational spot, Lake Quinsigamond makes for a representative body that has a direct impact on the surrounding community. Green Hill and Salisbury Ponds are close by and likely have different chemical profiles we were also curious to explore. All samples were collected in one-liter plastic containers and rinsed three times with the sample water before a final sample was collected. The samples were stored in a cool dark area to prevent potential degradation of the pharmaceuticals. Once all of the raw samples were collected, they were prepared for analysis.

2.2 Sample and Standard Preparation

To calibrate the equipment, we created stock standards for each of our pharmaceuticals following the procedures in Appendix A. We purchased one gram of each pharmaceutical from Sigma-Aldrich. All other chemicals were available to us in the laboratory. Since the chosen pharmaceuticals are poorly soluble in water, they were dissolved in methanol to create standards for UV-Vis. For LC-MS, we created a serial dilution by dissolving the powdered pharmaceuticals in a few drops of methanol and diluting to different concentrations with deionized water. Procedures are available in Appendix A.

Because these pharmaceuticals are present in such low quantities, it was necessary to concentrate them for detection during UV-Vis sample analysis. To accomplish this, we left the sample containers open in a fume hood over a 24-hour period at room temperature to allow excess water to evaporate. By slowly evaporating our samples at room temperature, excess water will be removed without damaging the sample, subsequently providing a better analysis. This also prevented the pharmaceuticals from possibly suffering heat degradation .

To further isolate our chosen pharmaceuticals within the samples for LC-MS, we performed solid phase extraction (SPE). SPE is a common extraction method that separates compounds dissolved or suspended in the liquid mixture according to their physical and chemical properties. It works to isolate target analytes from a complex sample and remove sample components that may block instrument columns. It also significantly improves detection sensitivity by increasing analyte concentration, which is critical to our objective of achieving accurate levels and signals of our antibiotics in surface water and wastewater samples. Since wastewater often contains very low chemical concentrations, as low as micrograms per liter, they may be undetectable by LC-MS without increased sensitivity. Thus, by performing SPE we hope to yield more successful results. According to literature, SPE has specifically proven effective when separating pharmaceuticals, which is the focus of this research. This method is quicker, less expensive, and more efficient at separation than liquid phase extractions.

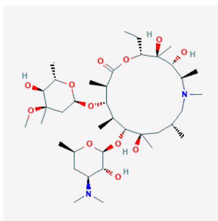
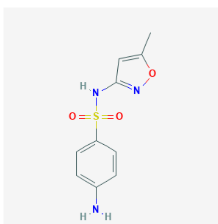
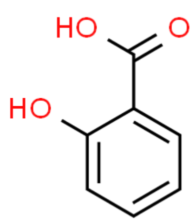
To prepare for the solid phase extraction, we used optimized procedures specific to each antibiotic as shown in Appendix A. The materials used for extraction were acetone, methanol, sulfuric acid (H_2SO_4), ethylenediaminetetraacetic acid (EDTA), acetonitrile (ACN), hydrochloric acid (HCl), triethanolamine and calcium chloride ($CaCl_2$).Three mL SPE cartridges were used for all three antibiotics. For azithromycin, cartridges were preconditioned with acetone, methanol, and water. After the samples were acidified by adding H_2SO_4, they were passed through the cartridges and eluted with methanol in accordance with the procedures in Appendix A. For SMZ, the cartridges were preconditioned using the same methods as for azithromycin, but with adding EDTA to improve recovery efficiency. Note that Na_2EDTA was our first option as it is more soluble in water than regular EDTA, however this disodium salt did not ship in time for this procedure. For salicylic acid, after the SPE cartridge was prepared with ACN and HCl, the sample was prepared with triethanolamine, EDTA and $CaCl_2$ and then loaded on the cartridge. All samples were eluted with methanol, more detailed procedures can be found in Appendix A.

2.3 Analysis Methods

For our second objective, we chose the following analytical methods: Liquid Chromatography-Mass Spectrometry (LC-MS) and UV-Vis Spectroscopy. LC-MS has become increasingly popular for analyzing pharmaceuticals in recent years, as it is capable of performing very sensitive analyses. Chromatography can separate substances fairly easily due to its dependence on a compound’s mobility in a certain solvent, making it ideal for analyzing complex samples. MS is a major analysis technique that relies on the molecular masses and abundance of different compounds. By analyzing its results, hypothetical chemical structures including these compounds can be formed. The result from liquid chromatography creates a clean sample that can be easily analyzed by a mass spectrometer, and clearly demonstrates if one of our pharmaceuticals is present. Then, by creating a calibration curve from the serial dilution in Appendix A, we were able to quantify the peaks produced by LC-MS. However, if the concentrations of our pharmaceuticals are too low, or there are too many contaminants, it may be difficult to determine which values belong to our pharmaceuticals. Because of this, we have also included UV-Vis analysis.

UV-Vis is a quick, simple analysis method readily available in most laboratories. It measures a chemical’s ability to absorb different wavelengths of light. Because different chemical bonds and functional groups absorb at characteristic wavelength values, they can be used to determine present functional groups and their relationships to one another. This provides an easy way to determine whether our pharmaceuticals are present or not. Because this method analyzes all chemicals in a sample, it will also tell us how well the water is being treated overall. With UV-Vis in mind, we found the structure, functional groups, volatility, and wavelengths for all three antibiotics to separate the analytes based on these characteristics. The table below was used to determine the above characteristics and were used when interpreting our graphs.

Table 1. This table shows the physical and chemical characteristics that belong to each of the chosen pharmaceuticals, azithromycin, sulfamethoxazole, and salicylic acid.

Antibiotic	**Structure**	**Functional Groups**	**Volatility**	**Wavelength**
Azithromycin		Ether (C-O-C), Alcohol (C-O-H), amine (N-C,N-H), ester (-COOC-), acetal (-O-C-O-)	No data	412 nm, if colored
SMZ		Amide (RC(=O)NR′R″)	Nonvolatile	200-300 nm
Salicylic Acid		Hydroxyl (-OH), carboxylic (-COOH), benzene ring	Steam volatile	230-300 nm

2.3.1 Ultraviolet-Visible (UV-Vis) Spectrophotometer

Ultra-violet (UV-Vis) spectroscopy is an effective tool for qualitative analysis and quantitative detection of contaminants in water samples including antibiotics. To use the UV-Vis, we blanked the instrument with water, then analyzed the three standard pharmaceuticals dissolved in methanol. The resulting graphs showed where to expect a signal. Then, we analyzed all other samples from WWTP and the environment. The range we chose was 200-400nm, due to expected pharmaceutical values and equipment limitations. We used quartz cuvettes instead of test tubes because they can absorb light more easily.

2.3.2 Liquid Chromatography - Mass Spectrometry (LC-MS)

Liquid chromatography is a widely used separation technique often used in tandem with mass spectrometry. The solubilized compounds, called the mobile phase, pass through a column packed with a stationary, or solid, phase. This method separates compounds based on their affinity to the mobile or stationary phase. The sample then passes through a mass spectrometer for analysis. This is a good option for larger compounds that are not volatile, such as SMZ. Optimization of the preparatory methods is required for successful LC-MS, with further details in Appendix A.

2.3.3 Additional Water Quality Tests

The physio-chemical characteristics of our water samples are important to analyze not only for the presence of pharmaceuticals, but also for water quality. About 1.8 billion people worldwide use unsafe water, with an additional 1.2 billion using water from sources with significant sanitary risks (Sila, 2018). We tested for water quality characteristics such as: general hardness (mg/l), nitrate (mg/l), nitrite (mg/l), free chlorine (mg/l), carbonate (mg/l) and pH, salinity, and coliform. The first five tests were completed using "SJ Wave" water test strips, pH tests with a pH meter, salinity tests through an electric conductor, and coliform using an "Aquavial" *E. Coli* kit. All tests were conducted with the original samples. For water quality characteristics, we immersed the strip fortwo seconds in the sample, removed it and then held it horizontally for 30 seconds. We compared the results against the given color chart shown in Figure 4.

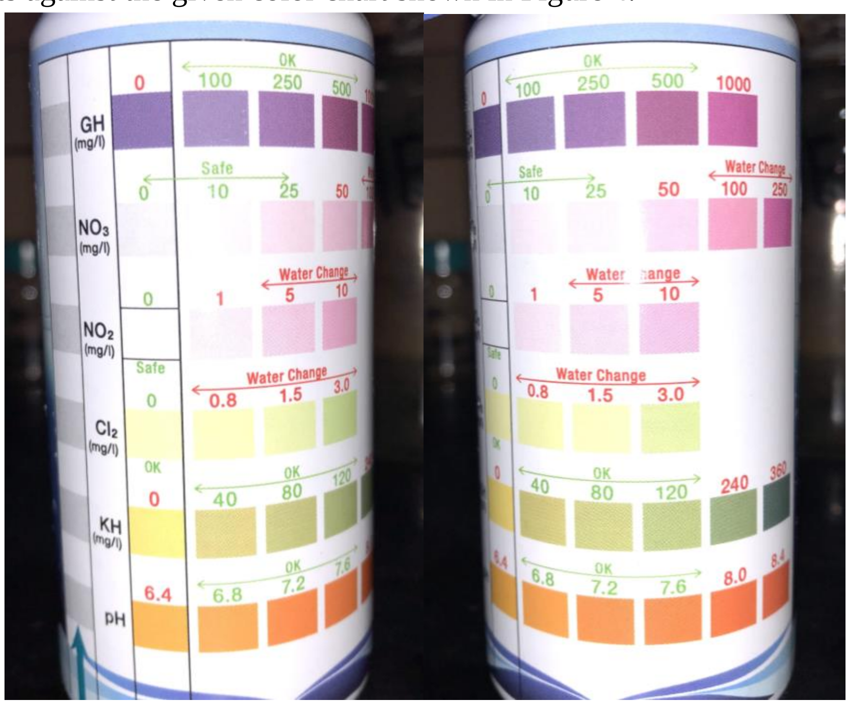


Figure 4. The water quality parameters starting from the top General Hardness, Nitrate, Nitrite, free Chlorine, Carbonate, and pH. This shows the acceptable values for each characteristic.

General Hardness

Hardness is a measurement of the dissolved minerals water contains. Soft water contains a low mineral content, while hard water has a high mineral content. This characteristic is important, as it is a critical factor in biological processes such as fish egg development. The strip for this property ranged from 0-1000 mg/l, where 100-500 mg/l was the range considered safe.

Nitrate/Nitrite

Microorganisms in soil, water and sewage convert nitrate to nitrite, which can be a significant health concern. For example, this changes hemoglobin in the blood to methemoglobin and reduces the amount of oxygen in the blood (California Health Services, 2000). It is ideal to have a nitrate level below 50 ppm, while nitrite level should be maintained at 0 ppm. To test for nitrate/nitrite, we used test strips that changed color depending on the amount of nitrate present. The nitrate value ranged from 0-250 mg/l, where 0-25 mg/l is considered safe. The nitrite value ranged from 0-10 mg/l, with 0-4 mg/l being the safe zone.

Free Chlorine

Free chlorine is a halogen chemical element that damages aquatic life-forms when concentrated. The presence of free chlorine in water indicates that enough chlorine to inactivate bacteria and some viruses was initially added to the water, and that the water is protected from recontamination during storage. A free chlorine level of 0.5 mg/L of free chlorine is enough residual to maintain the quality of water through the distribution network, but most likely will not be able to maintain the quality of the water when stored at home in a bucket or jerry can for 24 hours (CDC, 2020). The test strip we used ranged from 0-3 mg/l with 0-0.7 mg/l being the safe zone.

Carbonate

The carbonate hardness scale is based on the concentrations of carbonate and bicarbonate and reflects the water's buffering capacity. It is an important property, as water with high buffering capacity resists changes in pH, creating very stable water conditions. We used the test strip which ranged from 0-360 mg/l, with 40-240 being the safe zone.

pH

One of the most common water quality tests performed is a pH test, which indicates the sample's acidity. Since pH can be affected by chemicals in water, it serves as an indicator if water is changing chemically, and a very low or high pH may be from chemical or heavy metal pollution (Butler, 2019). To measure the pH, we used the same water quality test strips that once submerged in the sample it read its pH value.

Coliform

The coliform bacteria test is used to indicate the suitability of consumption for drinking water. Coliform bacteria are organisms that are present in the environment and that may cause gastrointestinal illnesses if present (Minnesota Department of Health, 2021). To test for it, water is added to a tube of broth and then incubated for 48 hours at 35-37 ^{o}C. The coliforms will be present if the broth changes from a yellow to red color.

2.4 Additional Analytical Methods for Future Studies

The following analytical methods have been used to identify and quantify other pharmaceuticals in literature. Gas chromatography (GC) and Fourier-transform infrared spectroscopy (FTIR) are two additional methods that may be helpful depending on the chemical properties of other pharmaceuticals. Given the nonvolatility of our selected pharmaceuticals, we opted for LC-MS and did not pursue GC to great lengths. Similarly, because wastewater samples may include a plethora of other chemicals, FTIR may be too sensitive for surface water or wastewater samples.

2.4.1 Gas Chromatography (GC)

Gas chromatography is an analytical separation technique used to analyze volatile substances in the gas phase (Thet, 2020). We introduced our sample into GC by injecting it through a syringe. After injection, the chemical components of our sample were first vaporized and since they were low concentration samples, the vapor cloud was transferred into the analytical column by carrier gas. The sample components were separated by their different interactions with the stationary phase, that is why it was important to be aware of the volatility and functional groups of the analytes as mentioned in Section 2.3 Table 1.

2.4.2 Fourier-transform infrared spectroscopy (FTIR)

Fourier-Transform Infrared Spectroscopy is the preferred, and most popular, form of infrared spectroscopy. Different functional groups absorb infrared light at varying wavelengths, with each type of chemical bond resulting in a unique wavelength value. An FTIR machine sends infrared light through a water sample, then forms a graph based on how the light is either absorbed by or passes through the sample. Because both different functional groups and different types of bonds (such as single, double, or triple) affect the graphs' peak width and length, an FTIR graph can be used to easily identify chemicals present in the sample.

Results and Discussion

3.1 UV-Vis Data Analysis

When UV-Vis samples have a strong signal, the absorbance of that signal could be measured, and the Lambert Beer Law used to analyze the results. This law relies on a beam of monochromatic parallel light that radiates the surface of the tested medium, and is the basis of quantitative analysis using UV-Vis. The mathematical expression is as follows:

$$A = log(1/T) = K * a * L$$

A= absorbance, T= ratio of the intensity of outgoing light to incident light, K= molar absorption coefficient, a= concentration of the absorbing substance, L=thickness of the absorbing layer (cm).

Unfortunately, the signals in our samples were too weak to definitively interpret as one of our chosen antibiotics. This is most likely because the concentrations of said antibiotics are very low, or the method did not separate the signals clearly. Overall, our graphs showed differences and shifts in graphs from sample to sample. The UV-Vis spectra of the standards clearly signal the presence of antibiotics as shown in Figure 5 and 6. For SMZ spectra, we see that it absorbs light between 210-310 nm, while salicylic acid absorbs between 210-330 nm. These spectra have many little peaks because the samples were dissolved in methanol, while the instrument was auto blanked using water. The antibiotics were dissolved in methanol because they were poorly soluble in water. For future studies, the graphs can be obtained more clearly using only one drop of methanol to dissolve and then diluted with water. In both the SMZ and salicylic acid spectra, we can see their highest peaks at around 240-250 nm, which were expected as compared to literature.

The azithromycin spectra were not similar to the previous two as shown on Figure 7. From literature values, azithromycin signal was expected at 200 nm. Since, the limit of the instrument was limited from 200-700 nm, no data could be collected before 200nm. However, we can see that around 200 nm, the spectrum starts to rise to a peak, which can be a signal of azithromycin.

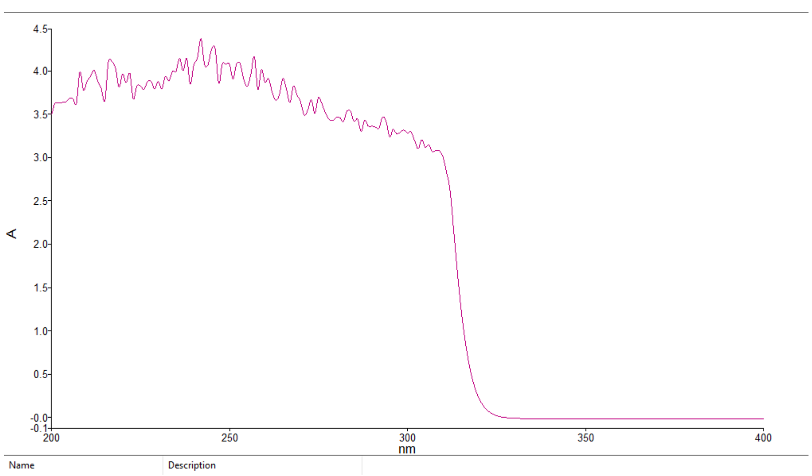


Figure 5. The UV-Vis Spectra of SMZ

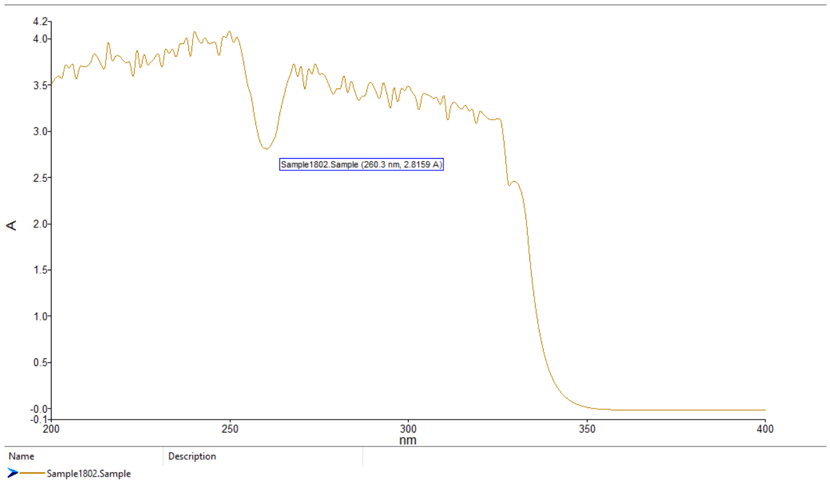


Figure 6. The UV-Vis Spectra of Salicylic Acid

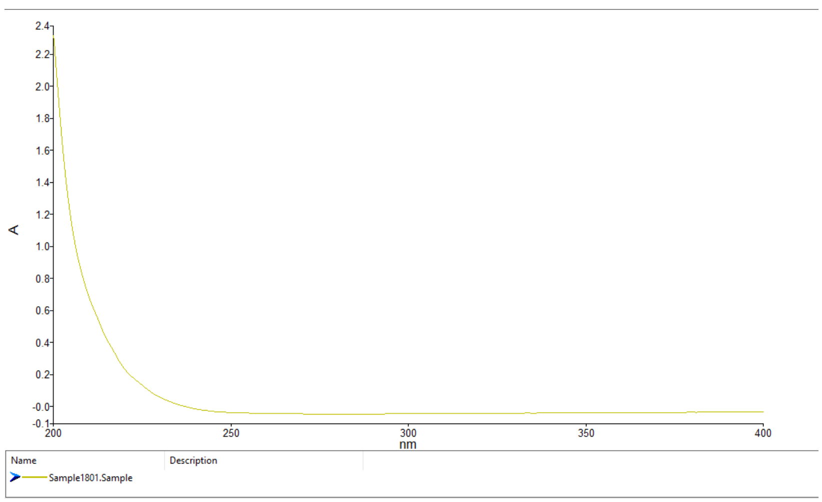


Figure 7. UV-Vis Spectra of Azithromycin

The next comparison we make, is between spectra of Influent and Final Effluent, as shown in Figure 8 and 9. As we can see, there is a difference in the shape of both spectrums. The Final Effluent spectra is smoother than the one of Influent, and this is expected as water has been treated between stages. The two graphs do not give us enough data to calculate or signal our antibiotics, but it gives us enough information to see which of the stages contains more pharmaceuticals or other elements. The Influent spectrum is steeper and has more curves than the Final Effluent. This makes sense because influent is the raw, untreated wastewater, while effluent is the last water treatment stage where the cleanliness of water is expected. The curves on the Influent graph and the flatness of Effluent show that the water treatment is effective on removing water pharmaceuticals and other waste elements. The other graphs of stages between Influent and Final Effluent are shown in Appendix B, and they also represent a waste elimination trend and flatness from one stage to another further down the wastewater treatment.

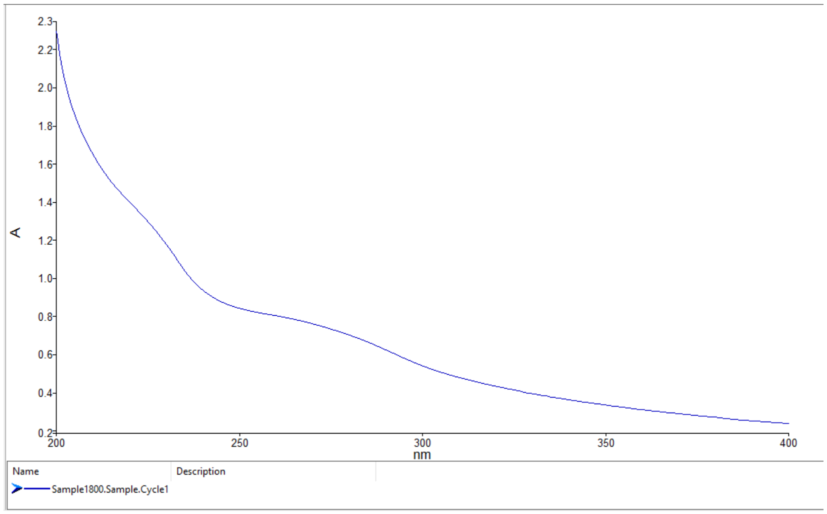


Figure 8. The UV-Vis Spectra of Influent

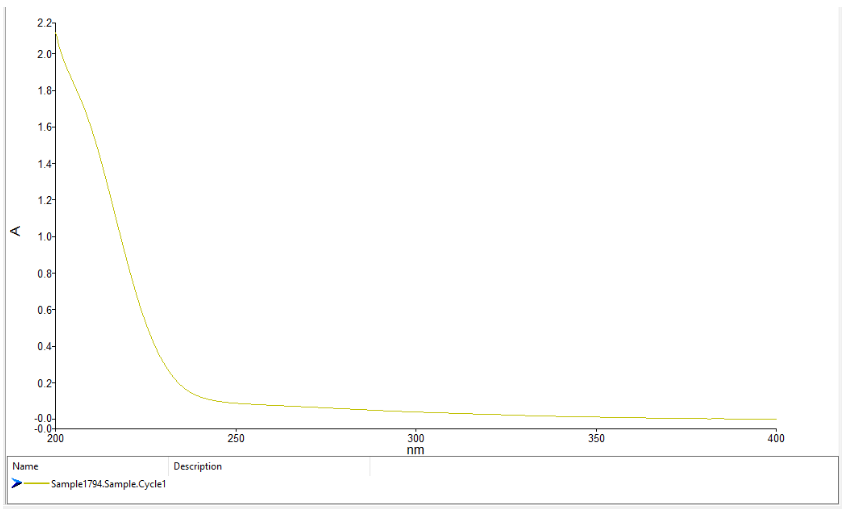


Figure 9. The UV-Vis Spectra of Final Effluent

Lastly, the UV-Vis Spectra between the three lakes were compared as shown in Figure 10, 11, and 12. Lake Quinsigamond (LQ) and Salisbury Pond (SP) have similar graph shape, while Green Hill Pond (GH) has a steeper shape. This can be interpreted as pharmaceuticals present in LQ and SP are in similar concentrations. However, it is expected that SP will be more polluted than the other two because it's suffocation from years of sedimentation build-up below its surface. More specific data could not be obtained from UV-Vis.

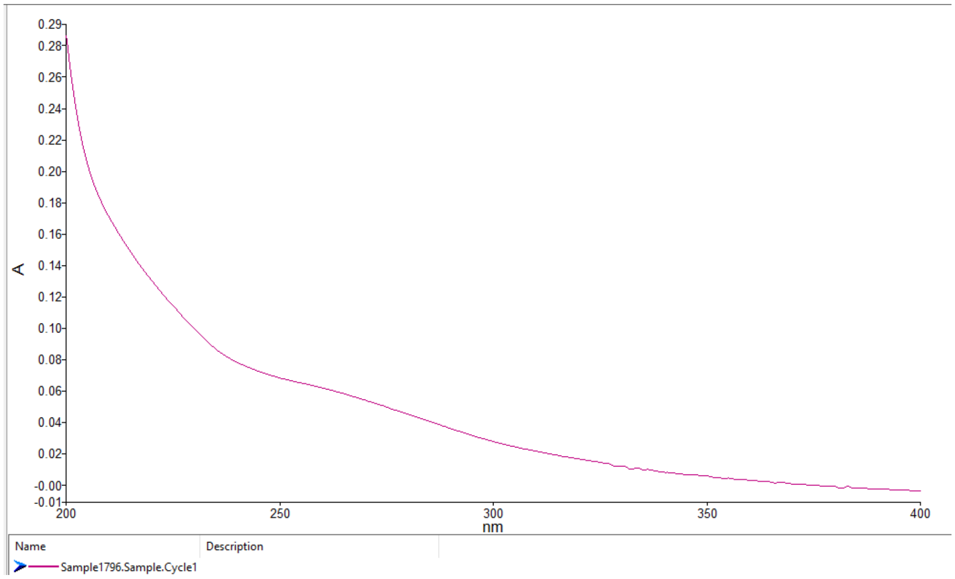


Figure 10. UV-Vis Spectra of Green Hill Pond

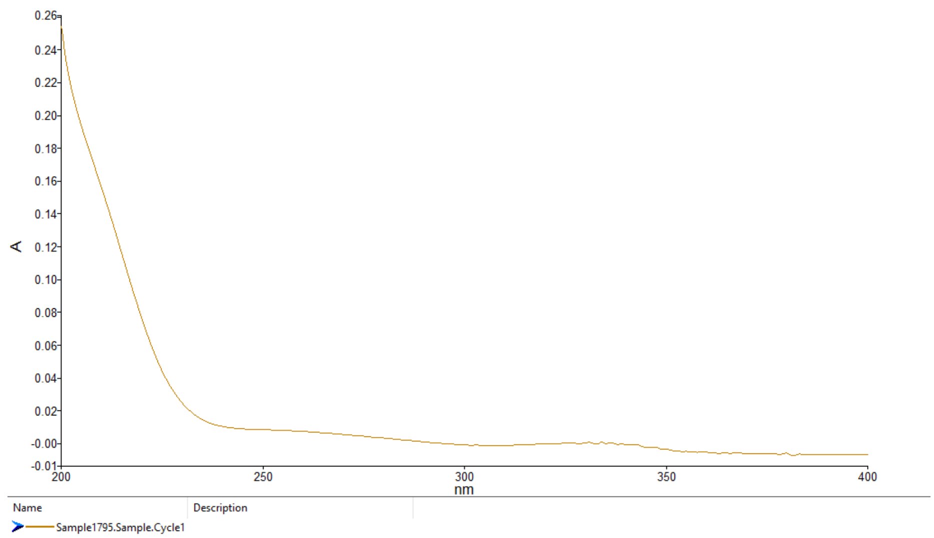


Figure 11. UV-Vis Spectra of Lake Quinsigamond

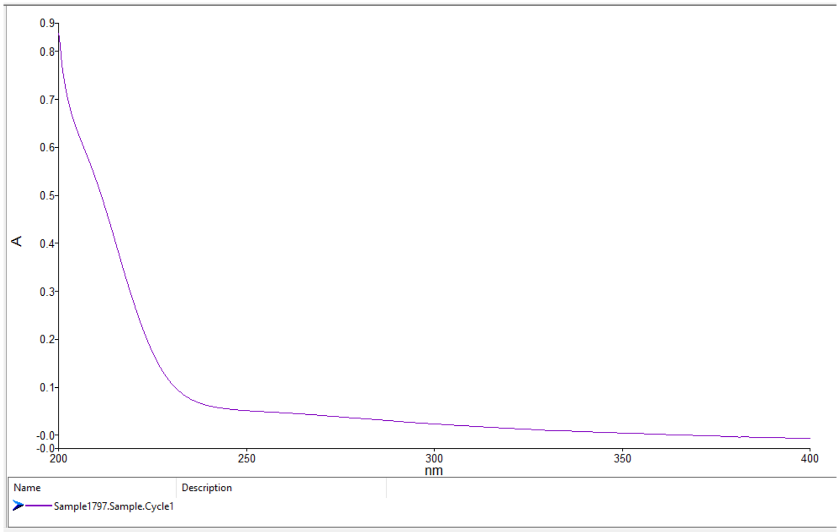


Figure 12. UV-Vis Spectra of Salisbury Pond

3.2 Coliform and Bacteria Test

To investigate the presence of *E. Coli* and coliform in wastewater, the tests were performed in three composite samples (influent, primary effluent, final effluent) and in the three bodies of water (Lake Quinsigamond, Green Hill Pond, and Salisbury Pond) as shown in Appendix E. Once the water sample was transferred to the test tube, it turned yellow, and after 48 hours of incubation at room temperature for certain samples the color had shifted from yellow to purple. Figure 13 shows the bacteria tests for the three water composites from WWTP. The Influent color had shifted completely from yellow to dark purple, the primary effluent color was mainly yellow but with some hints of purple, while the effluent color had remained purely yellow. This color change is consistent with our expectations as Influent is the raw, untreated wastewater which contains different pharmaceuticals, chemicals and effluent is the last stage of the treatment plant which is safer and well-treated for discharge. Primary effluent is the stage between which justifies the color it has as it is not completely treated. This result also implies that the wastewater treatment methods currently in place are effective.

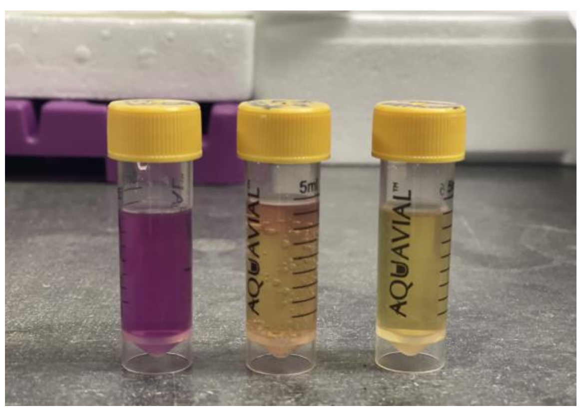


Figure 13. From left to right: influent, primary effluent, and final effluent coliform testing

The next comparison was between the three lakes as shown in Figure 14. As we can see after testing for the presence of bacteria, Lake Quinsigamond and Green Hill Pond had remained yellow, while Salisbury Pond had turned slightly purple, indicating a greater level of coliform contamination. This test was important because it quickly detects water quality issues before they become serious health risks. Even though this test is most commonly used on drinking water, seeing the level of bacteria within the environment can raise awareness about necessary steps to improve its quality. The test kit was able to detect *E. Coli* and Coliform bacteria concentrations as little as 1 CFU/ml.

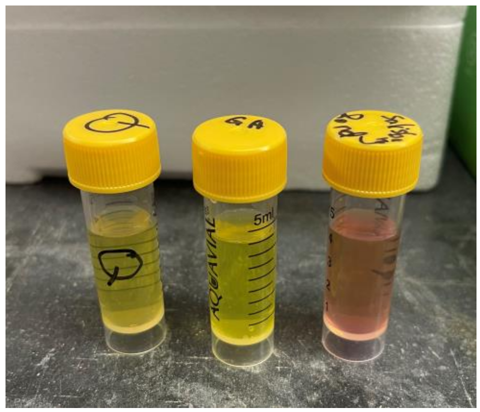


Figure 14. From left to right: Lake Quinsigamond, Green Hill Pond, and Salisbury Pond Coliform Testing

3.3 General Hardness, Nitrate, Nitrite, free Chlorine, Carbonate, and pH

The other water quality tests included parameters such as general hardness, nitrate, nitrite, free chlorine, carbonate, and pH. All images of the test strips can be found in Appendix E. The color changes were compared to the instructions given. To check if the tests worked accurately, we first submerged them in our three antibiotic standards which were dissolved in methanol and water as shown in Figure 15. Azithromycin is an acid-stable antibiotic, salicylic acid has two acidic groups and SMZ interferes with folic acid synthesis. This means that our antibiotics have an acidic profile, resulting in a pH lower than seven. This was confirmed with our test strips, where the pH square turned completely yellow indicating that the standard solution had a pH even lower than 6.4. This test confirmed that the quality test strips worked accurately.

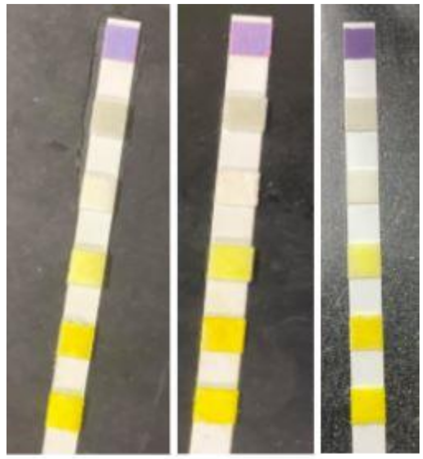


Figure 15. Standards test strips (from left to right: Azithromycin, Salicylic Acid, SMZ)

Next, test strips were used in all of our water samples as shown in Figure 16 and 17. There was consistency in the color changes and all of them within limits of each quality, however with slight changes. The general hardness turned purple in all of them indicating a general hardness value between 0-250 mg/l which is normal for a water sample. However, the aerobic, anoxic, and anaerobic samples have a slightly lighter purple color that means higher general hardness values. Different species require different water hardness, with 0-17.1 mg/l (soft), 17.1-60 mg/l (slightly hard), 60-120 mg/l (moderately hard), 120-180 mg/l (hard) and 180&over (very hard) (2). In our test strips which were commonly used for aquarium water testing, 100-500 mg/l was considered safe for fish species. The second quality was nitrate, which was considered safe from 0-25 mg/l with test strip color from white to light pink. We can see that from influent (white) to final effluent (slight pink) the level of nitrates has increased. High nitrate in the effluent is very normal for biological processes using aerobic processes, due to oxidation of nitrogen by nitrification process, which is present in our WWTP. This is similar to what happens with nitrite levels, the third test strip square that changes between processes from white to light pink. Compared to the test strips instructions, if the water was used for aquariums or for fish species, it would not be completely safe, and it would require water change.

The other water qualities tested were free chlorine and carbonate values. Free chlorine values varied between 0.8-3.0 mg/l and carbonate values between 40-240 mg/l. These ranges for free chlorine require water change for fishes, while the carbonate value above 120 mg/l isn't considered completely safe. However, during wastewater treatment chlorine is most widely used as a disinfectant because it destroys target organisms by oxidizing cellular material. That's why the results of the test strips for chlorine values are consistent with what was expected. The same analysis can be made for carbonate values which are related with alkalinity that is often used as an indicator of biological activity. These results make sense because lack of carbonate alkalinity stops nitrification which is an important step of WWTP. Lastly, pH was measured using the test strips. According to instructions, pH for all of the stages ranged between 6.8-7.6 which is considered safe.

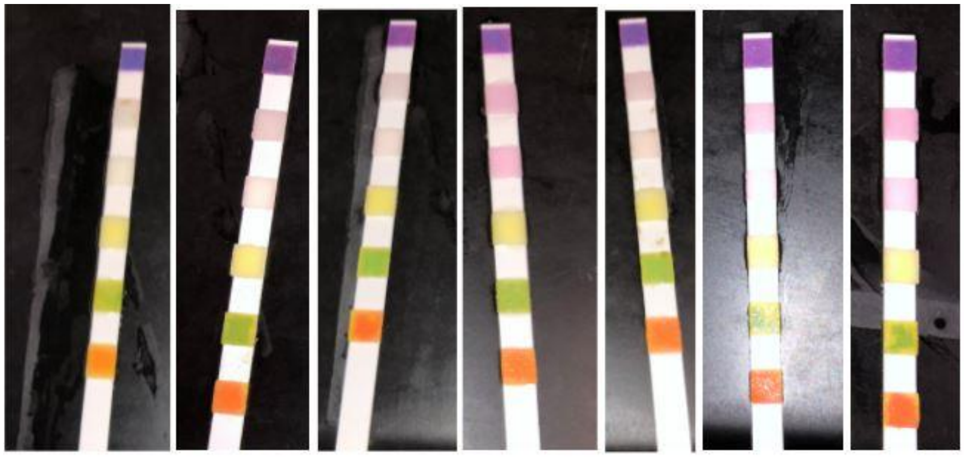


Figure 16. Water quality test strips (from left to right: Influent, Aerobic, Anoxic, Anaerobic Primary Effluent, Final Settling, Final Effluent)

The same analysis was performed for the three bodies of water: Salisbury Pond, Lake Quinsigamond and Green Hill Pond. The color changes on the test strips were similar to each other, but slightly different from the WWTP samples. The main difference is on nitrate/nitrite values, which for the lakes it is close to 0 mg/l. This is expected as these samples have not been treated yet and have not gone through the nitrification steps. Other qualities remain consistent between the lakes with close to safe regions.

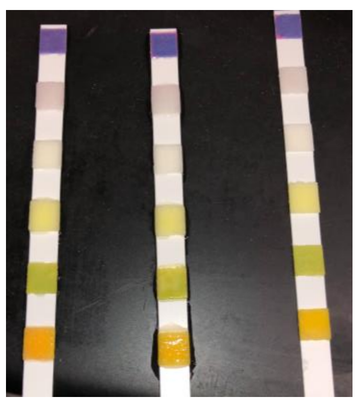


Figure 17. Water quality test strips (from left to right: Salisbury Pond, Lake Quinsigamond, Green Hill Pond)

3.4 LC-MS Analysis

After performing SPE, we had about 30 samples to test using LC-MS: seven wastewater treatment stages plus three surface water for each of the three selected pharmaceuticals. A complete list of these samples can be found in Appendix C, Table 2. We tested several standards to optimize the methods for LC-MS, and details of this optimization can be seen in Appendix A. To detect the pharmaceuticals, we used the scanning mode to identify the MS peaks using their chemical properties. Once we were able to identify the peaks in our standards, we were able to switch to the selected ion monitoring (SIM) mode to focus on each pharmaceutical. Since we performed three different SPE procedures to elute the pharmaceuticals separately, this reduced the workload on the LC-MS and we could run all 51 standards and samples at once. We had 51 samples total, including 21 standards and 30 samples of unknown concentration.

In order to find the concentrations of our samples, we needed to make a calibration curve. By creating standards of known concentrations, we were able to compare these concentrations to the peak area in the MS reports. Once we have these data, we can use the trendline equation to work backwards to find the unknown concentration of our samples. For example, Figure 18 shows the calibration curve for SMZ. The linear relationship is represented by the equation below:

$$y = 246.91x \qquad \text{(Trendline equation for SMZ)}$$

We assumed the y-intercept to be zero to avoid receiving negative concentrations in our samples. This problem would be avoided altogether if we had run a blank sample on the LC-MS that went through our previous methods. Without this information, we are assuming all of the peaks present in the MS reports indicate our pharmaceuticals and trace contaminants from SPE.

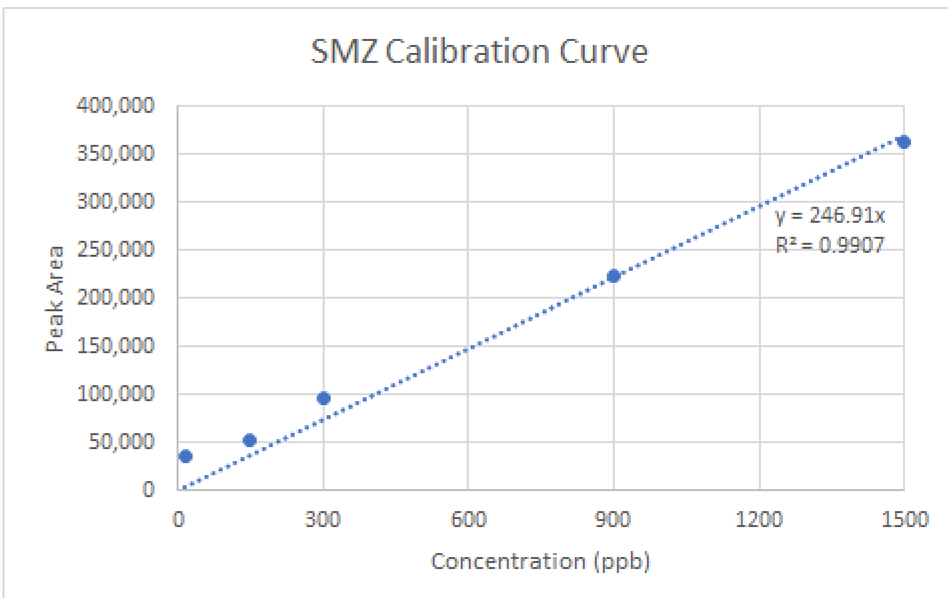


Figure 18. The linear calibration curve for SMZ shows concentration in parts per billion against peak area. We created standards of SMZ at various concentrations (see Appendix A) and analyzed them using LC-MS to find peak areas. By adding a trendline with y-intercept set to zero, we were able to retrieve the trendline equation that we then used to find the unknown concentration in our samples.

The R-squared value of 0.9907 in Figure 18 shows the high correlation between peak area and concentration in ppb. Using the equation above, the concentration of SMZ was found for each stage of Upper Blackstone's treatment process shown in Figure 19.

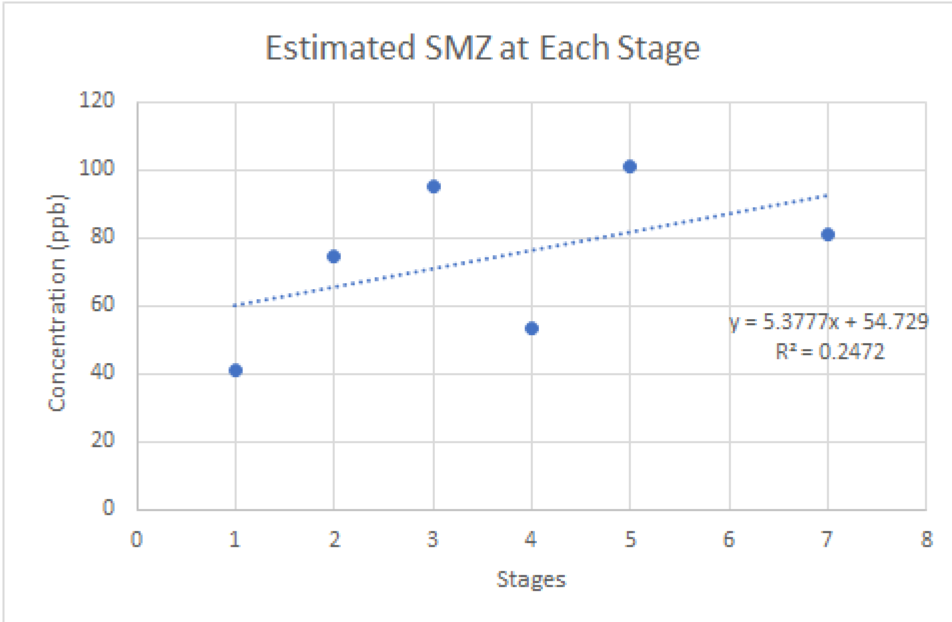


Figure 19. We estimated the concentration of SMZ by using the trendline equation in Figure 18 to calculate the concentration of our wastewater treatment samples. Stage one through seven on the x-axis represent the stages Influent (1), Primary Effluent (2), Anaerobic (3), Anoxic (4), Aerobic (5), Final Settling (6), and Final Effluent (7) of Upper Blackstone's treatment process.

Although we hoped to see a reduction in SMZ as treatment stages progressed, we see no significant trend in these results, as seen with the low R-squared value. Rather, the scatter represents the variance in samples and procedures, and is expected at such low concentrations. The concentration of SMZ stays between 40 and 100 ppb throughout the treatment processes. The data point at stage 6, the final settling sample, was not tested by LC-MS to save supplies for other samples.

The same procedure was followed for creating a calibration curve for both salicylic acid and azithromycin, which can be seen in Figure 20 and Figure 21, respectively. The linear trendline for salicylic acid had an R-squared value of 0.9697, which is high enough to estimate reliable concentrations for our unknown samples using the equation below:

$$y = 207.12x \qquad \text{(Trendline equation for salicylic acid)}$$

The equation for azithromycin had a lower R-squared value of 0.9075, which makes for a less reliable concentration estimation for our samples. This could have occurred because as seen in Figure 21, the concentrations for the 15 ppb, 75 ppb, 150 ppb, and 300 ppb standards all resulted in very similar peak areas and threw off the trendline for azithromycin. Keeping this in mind, the following trendline equation was given:

$$y = 207.12x \qquad \text{(Trendline equation for salicylic acid)}$$

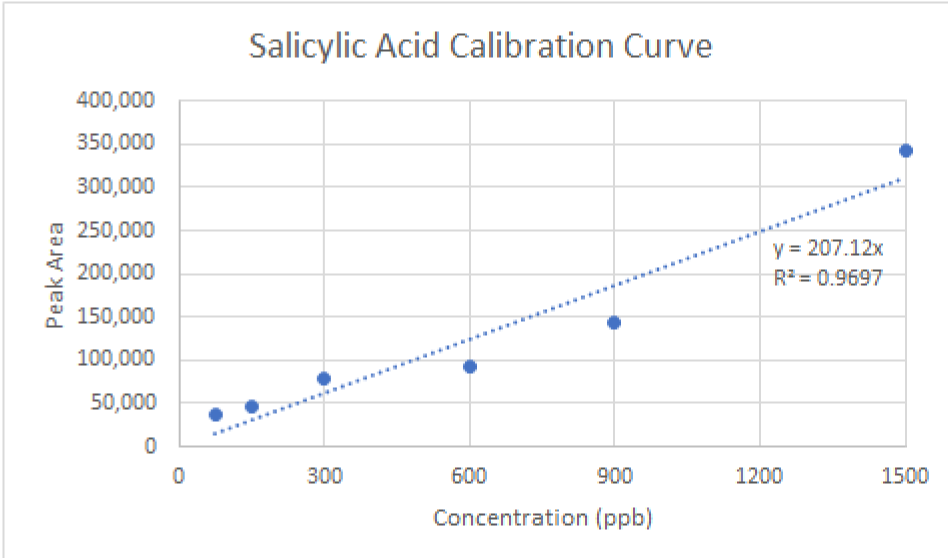


Figure 20. The calibration curve for salicylic acid shows concentration in parts per billion against peak area. By creating standards using procedures in Appendix A and analyzing them using LC-MS, we were able to create this linear curve to find the unknown concentrations of our samples for salicylic acid from the peak areas measured by LC-MS.

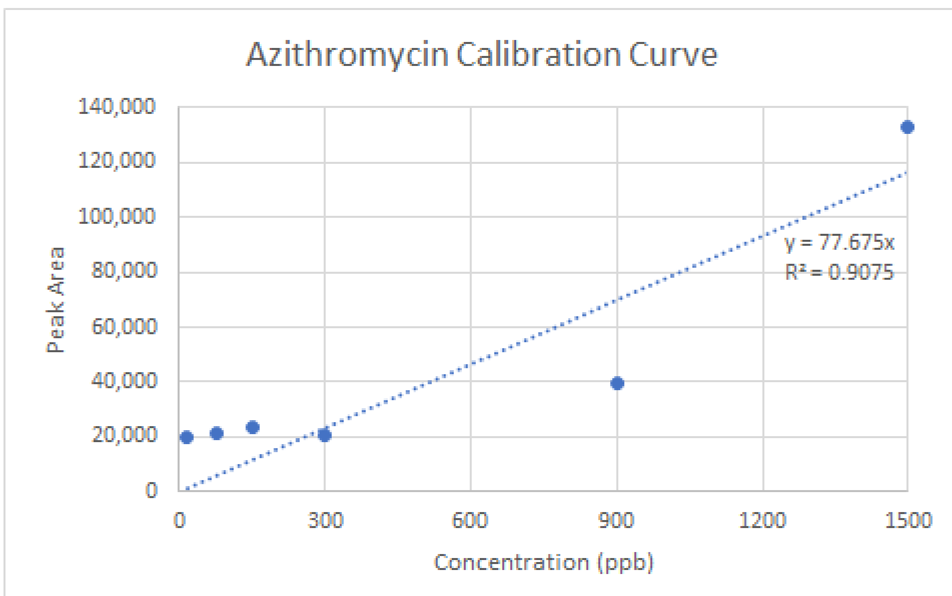


Figure 21. The calibration curve for azithromycin shows concentration in parts per billion against peak area. By analyzing standard concentrations of azithromycin using LC-MS, we were able to create this linear calibration curve to find the unknown concentrations of our samples from the peak areas.

There were five MS reports that were unable to be produced due to an error with the instrument. Details of these errors were noted in Table 2 in Appendix C. The other problem we encountered, in addition to no MS reporting, was not seeing peaks for salicylic acid. We think this occurred because the monoisotopic mass of salicylic acid was much lower than the other two pharmaceuticals. Smaller chemicals are more common in the environment, and therefore salicylic acid has a higher chance of blending in with other contaminants or chemicals. As seen in Figure 22, only one sample had a peak area we could observe, and that was for stage 3, the anaerobic section of the bioreactor. With these limited data, we cannot say whether there was a decrease in the concentration as treatment processes continued, but we can report that the approximate concentration of salicylic acid in Upper Blackstone's wastewater is about 50 ppb.

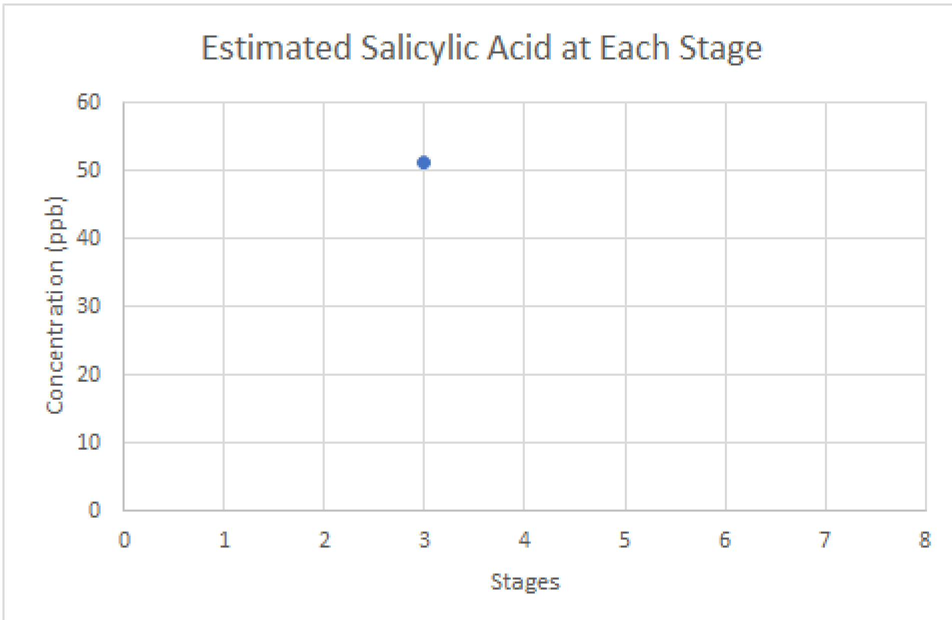


Figure 22. Due to a combination of instrument error and possible contamination, two MS reports were not produced, and the remaining reports showed no sign of salicylic acid peak, therefore the area was not found. The one successful MS report showed an approximate concentration of 50 ppb salicylic acid at the anaerobic stage.

Figure 23 yielded a more complete set of results for the estimated concentration of azithromycin. Although the trendline shows a negative slope, the scatter and R-squared value show there is no reliable trend at each stage. However, the data show the concentration of azithromycin stays pretty consistently between 200 and 300 ppb throughout the wastewater treatment process. This is much higher than SMZ and salicylic acid concentrations in these wastewater samples, even though we expected higher concentrations of SMZ.

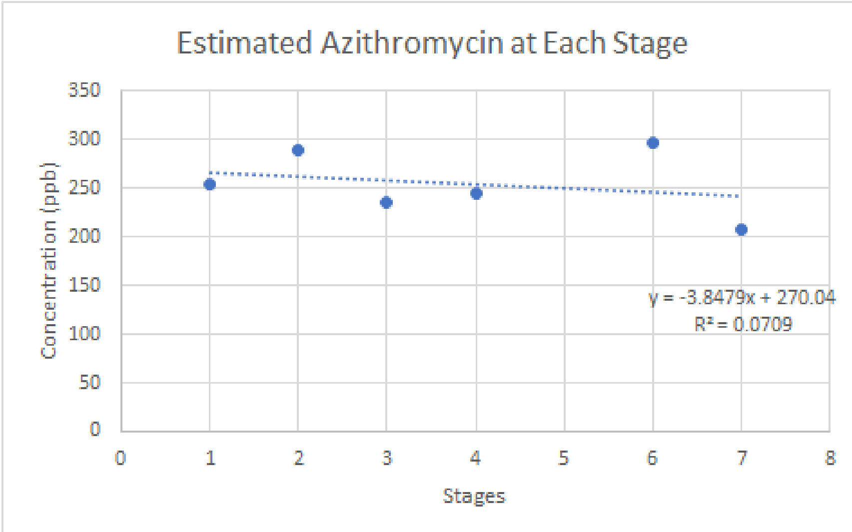


Figure 23. By comparing the estimated concentration of azithromycin at each stage, this scatter shows no reliable reduction of the pharmaceutical by Upper Blackstone's treatment processes.

The LC-MS results for surface water samples taken from Lake Quinsigamond, Green Hill Pond, and Salisbury Pond show similar levels. Only one surface water sample was tested for SMZ, Lake Quinsigamond, and about 63 ppb was detected. In Figure 24, we can see the concentration is slightly higher for salicylic acid, at 74 ppb. The salicylic acid concentration jumps for Salisbury Pond to around 134 ppb. Azithromycin has the highest concentrations by far for all three bodies of water at 276 ppb, 219 ppb, and 282 ppb for Lake Quinsigamond, Green Hill Pond, and Salisbury Pond, respectively. This shows azithromycin levels should be monitored in all Worcester bodies of water, and Salisbury Pond, specifically, should be monitored for pharmaceutical contamination in general.

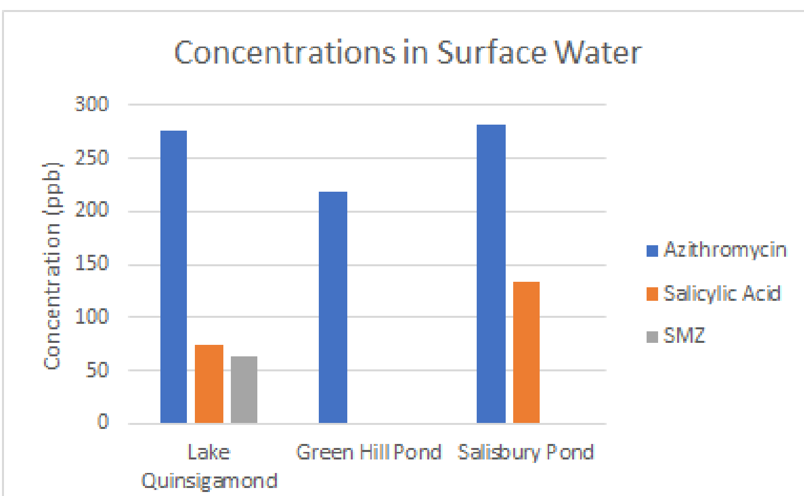


Figure 24. MS data show the concentration of SMZ, salicylic acid, and azithromycin in Lake Quinsigamond, Green Hill Pond, and Salisbury Pond. Due to complications, SMZ samples for Green Hill Pond could not be tested, in addition to both SMZ and salicylic acid samples for Salisbury Pond.

For our final LC-MS sample, we ran two tests on the same 1500 ppb standards for each of the pharmaceuticals. This was to show reproducibility and consistency in data. As seen in Figure 25, only a small amount of each sample may have evaporated by the end of the 19-hour sequence. Preparing the samples in LC-MS compatible vials was performed the same day as the run because the samples were eluted in methanol, a highly volatile chemical. Figure 25 shows the most evaporation occurred for SMZ. This was expected since SMZ was the first pharmaceutical we tested, and once the cap of the vial was breached by the LC-MS it became much less airtight, leading to some evaporation.

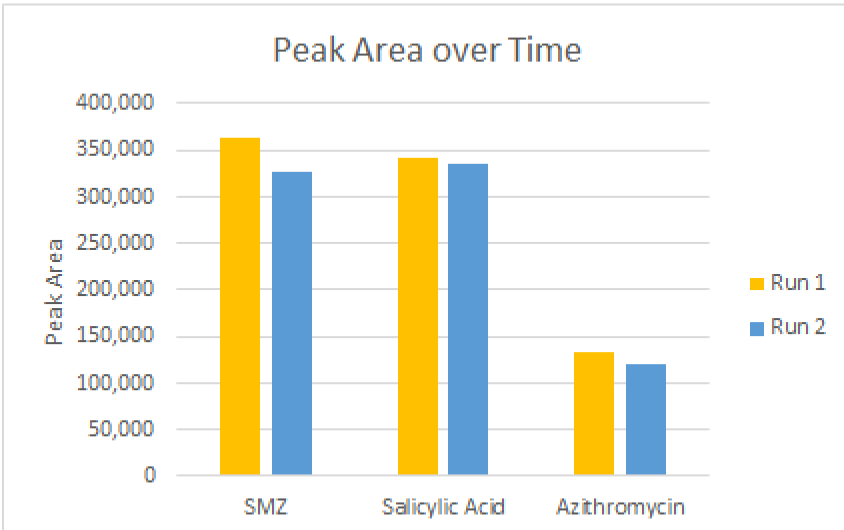


Figure 25. Run 1 and Run 2 of the same 1500 ppb standards for each pharmaceutical. Run 1 was tested first, and the second run happened at the end of all the LC-MS runs. This was to observe reproducibility with this method, and to see if evaporation occurred. This figure shows only a small amount of each sample evaporation by the end of the total run, 19 hours later.

Conclusions and Recommendations

Overall, our study confirmed the rising concern of pharmaceuticals in wastewater and the necessity of further research on possible treatments. We saw a large decrease in UV-Vis detection and bacteria between the influent and final effluent samples, indicating the overall effectiveness of Upper Blackstone's wastewater treatment process. However, our LC-MS data are unable to prove whether the WWTP's current system is capable of effectively treating SMZ, azithromycin, salicylic acid, or other pharmaceuticals. There was difficulty detecting salicylic acid in the wastewater samples due to possible contamination and instrument error, while SMZ and azithromycin concentrations remained relatively consistent throughout treatment. This proves current wastewater treatment methods alone are not enough to treat pharmaceuticals. If pharmaceuticals were to become more regulated, modifications or additional treatment methods may be required to directly treat pharmaceuticals. SMZ, azithromycin, and salicylic acid were found in such low concentrations it becomes uncertain whether a treatment plant is even capable of reducing these contaminants.

For future studies, we recommend LC-MS, FTIR, and GC analysis depending on the characteristics and chemical properties of the chosen pharmaceuticals. As for our methods, we recommend using as little methanol as possible to dissolve the pharmaceuticals for UV-Vis, this may improve identification in spectra. For LC-MS, a blank sample containing only water should undergo the same procedures as unknown samples. This blank will help identify pharmaceuticals in the MS reports by giving a baseline and showing possible contamination due to SPE or in general.

We recommend WWTPs repeat our experiments to a more in-depth level and consider our aerobic recycling stream design if a bioreactor is already in place. From the data gathered, we have designed one possible minimally intrusive modification to Upper Blackstone's current treatment system, which is detailed below.

Design of an Aerobic Recycling Stream for Pharmaceutical Treatment

To increase Upper Blackstone's efficiency in treating pharmaceuticals, particularly SMZ, azithromycin, and salicylic acid, a design was developed for an aerobic tank recycling stream. Results from our LC-MS analysis clearly indicated the presence of all three pharmaceuticals in both our wastewater and environmental samples, making it prudent to consider methods of treating said contaminants. Both a second biological reactor and recycling stream were considered. Biological reactors have proven effective in definitively treating salicylic acid, but have not been researched for SMZ or azithromycin, are very expensive, and would require temporarily closing Upper Blackstone while the tank was implemented into the treatment system. Adding bacteria known for treating salicylic acid to the pre-existing aerobic tank was considered, but similar problems arose, and it is unknown how these bacteria would react with the current bacteria or treatment of other contaminants. LC-MS results show that little treatment was successfully completed with the current system, but it is unknown if this is because of inadequate methods or because of extremely low concentrations. Thus, to aid us in narrowing our design, we looked at the results from our UV-Vis spectroscopy. This showed a clear, significant decrease in contaminants around 300 nm, the range our respective pharmaceuticals are visible in. Because of this, the aerobic tank was chosen to focus on.

Aerobic tanks require air to function, specifically oxygen. It provides the bacteria necessary fuel, while also mixing the bacteria, wastewater, and contaminants. The more mixed treatment is, the more bacteria will have access to contaminants that can be consumed and removed from the water. Thus, it was important to design a recycling stream around oxygen values within the water. The average dissolved oxygen in the aerobic tank was 0.6 mg/L, or 103 kg/day, while the biological oxygen demand was 22,077 kg/day for the entire aerobic tank. This means that an average of 6,043 kg oxygen is consumed each time the aerobic tank completes a single run time. The volume of the tank can only absorb 189.1 kg of oxygen at a time, so this is the amount that would be added into the recycling stream. The recycling stream itself is 359.8 ft long, requiring 10 pumps to fully transport the wastewater to the beginning of the aerobic tank. The air blowers used at Upper Blackstone are capable of 17,900 acfm, so only one is needed to reach the dissolved oxygen limit. To ensure even mixing throughout the pipe, 5 air blowers are placed every 72.0 ft along the recycling stream. The remaining 5,853.9 kg of necessary dissolved oxygen is added in the aerobic tank with pre-existing air blowers during the treatment process. After the wastewater has been treated a second time, it exits the aerobic tank and travels to final settling. A second set of calculations was completed with a dissolved oxygen level of 1.0 mg/L. This is the lower average dissolved oxygen level for wastewater treatment plants. While overall oxygen consumed is reduced to 6025 kg/run time, this value still allows adequate treatment, and the increased air flow provides a more thorough mixture. The wastewater in the recycling stream has already been treated by the aerobic tank before, so additional mixing may allow for contaminants that were missed due to low concentrations-such as pharmaceuticals- to be treated a second time through.

Both dissolved oxygen levels have benefits- 0.6 mg/L ensures that the system remains at levels known to function well within the aerobic tank, while 1.0 mg/L increases mixing and may provide a more thorough pharmaceutical treatment. It is recommended that Upper Blackstone conducts a more in-depth analysis of this design to ensure optimal treatment efficiency and system assimilation. This recycling stream is fairly simple in design, allowing for modifications as necessary, and reproducibility for other treatment plants that could benefit. It is a safe, inexpensive method of increasing treatment efficiency with minimal impact on the environment or surrounding community, for preemptive pharmaceutical treatment or simply increasing efficiency. Detailed calculations for this design with both dissolved oxygen values can be found in Appendix D.

References

Azithromycin: Medlineplus drug information. (2020, April 15). Retrieved March 22, 2021, from https://medlineplus.gov/druginfo/meds/a697037.html

Barlas, S. (2009, August). Pharmacy take-back programs: Opportunities for congress, liabilities for pharmacies. Retrieved March 22, 2021, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2799122/

Blake. (2017, October 07). How to become a licensed professional engineer in other states. Retrieved January, from http://peexamcoach.com/how-to-become-a-licensed-professional-engineer-in-other-states

Boxall, A. (2004,December). The environmental side effects of medication. Retrieved March 22, 2021, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1299201/#:~:text=Residues%20released%20during%20the%20manufacturing,excreted%20to%20the%20sewer%20system.&text=Other%20minor%20routes%20of%20entry,of%20unused%20medicines%20and%20containers

Butler, N. (2019, March 29). What pH Should My Drinking Water Be? Retrieved March 22, 2021, from https://www.healthline.com/health/ph-of-drinking-water

Thet, K., & Woo, N. (2020, August 15). Gas chromatography. Retrieved March 22, 2021, from https://chem.libretexts.org/Bookshelves/Analytical_Chemistry/Supplemental_Modules_(Analytical_Chemistry)/Instrumental_Analysis/Chromatography/Gas_Chromatography

California Department of Health Services. (2000, February). Health Concerns Related to Nitrate and Nitrite in Private Well Water. Retrieved March 22, 2021, from https://www.atsdr.cdc.gov/hac/pha/reports/pacificgaselectric_04252003ca/pdf/appf.pdf

CDC. (2020, November 12). Chlorine residual testing. Retrieved March 22, 2021, from https://www.cdc.gov/safewater/chlorine-residual-testing.html#:~:text=A%20free%20chlorine%20level%20of,jerry%20can%20for%2024%20hours

Chinchilla, A. (2017, July 3). This is why you need a professional engineer. Retrieved from https://info.stonewallco.com/blog/why-you-need-a-professional-engineer

Coliform bacteria fact sheet - EH: Minnesota Department of health. (n.d.). Retrieved March 22, 2021, from https://www.health.state.mn.us/communities/environment/water/factsheet/coliform.html

Common Terms Used in Wastewater Treatment. (n.d.). Retrieved March 22, 2021, from https://treeo.ufl.edu/media/treeoufledu/waterwastewater/student-resources/Glossary-of-Common-WW-Terms.pdf

Cressler, A. (n.d.) Wastewater treatment water use. Retrieved March 22, 2021, from https://www.usgs.gov/special-topic/water-science-school/science/wastewater-treatment-water-use?qt-science_center_objects=0#qt-science_center_objects

Doud, S. (2021, January 22). Professional engineer vs engineer: What's the difference? Retrieved from https://encorus.com/2019/01/18/engineer-vs-professional-engineer/#:~:text=After%20accumulating%20an%20amount%20of,licensed%20Professional%20Engineer%20(PE)

EPA. (1999, September). Chlorine Disinfection. Retrieved March 22, 2021, from https://www3.epa.gov/npdes/pubs/chlo.pdf

EPA. (2018, April). Final 2016 Effluent Guidelines Program Plan. Retrieved March 22, 2021, from https://www.epa.gov/sites/production/files/2018-05/documents/final-2016-eg-plan_april-2018.pdf

Flanders, P. (2021,January 12). Effluent guidelines plan. Retrieved March 22, 2021, from https://www.epa.gov/eg/effluent-guidelines-plan

Hardness of water. (n.d.). Retrieved March 23, 2021, from https://www.usgs.gov/special-topic/water-science-school/science/hardness-water?qt-science_center_objects=0#qt-science_center_objects

Hayat, Q., Hayat, S., Irfan, M., & Ahmad, A. (2009, August 22). Effect of exogenous salicylic acid under changing environment: A review. Retrieved March 22, 2021, from https://www.sciencedirect.com/science/article/pii/S0098847209001579#:~:text=A%20survey%20of%20literature%20indicates%20that%20salicylic%20acid%20plays%20a,to%20exogenously%20applied%20salicylic%20acid

Kotsopoulos,N. (2013, August 30). City life takes toll on salisbury pond. Retrieved March 23, 2021, from https://www.telegram.com/article/20130829/NEWS/308299789

Kulkarni, P., Olson, N., Raspanti, G., Rosenberg Goldstein, R., Gibbs, S., Sapkota, A., & Sapkota, A. (2017, June 21). Antibiotic concentrations decrease during wastewater treatment but persist at low levels in reclaimed water. Retrieved March 22, 2021, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5486354/

Lehman,R. (2018, April 12). Antibiotics: Helping our bodies, hurting our environment. Retrieved March 22, 2021, from https://environment-review.yale.edu/antibiotics-helping-our-bodies-hurting-our-environment

López-Serna, R.,Posadas, E., García-Encina, P., & Muñoz, R. (2019, January 18). Removal of contaminants of emerging concern from urban wastewater in novel algal-bacterial photobioreactors. Retrieved March 22, 2021, from https://www.sciencedirect.com/science/article/pii/S0048969719302256

Milakovic, M., Vestergaard, G., Gonzalez-Plaza, J. J., Petric, I., Simatovic, A., Senta, I., . . . Smalla, K. (2019, January 5). Pollution from azithromycin-manufacturing promotes macrolide-resistance gene propagation and induces spatial and seasonal bacterial community shifts in receiving river sediments. Retrieved March 22, 2021, from https://pubmed.ncbi.nlm.nih.gov/30622075/

National Society of Professional Engineers. (2018, July). When Can I Take the PE Exam? States Allowing Examination Before Experience. Retrieved from https://www.nspe.org/sites/default/files/resources/pdfs/admin/publications/NSPE-When-Can-I-Take-the-PE-Exam.pdf

NCEES. (2021, February 12). NCEES professional licensure. Retrieved from https://ncees.org/licensure/

NSPE. (2021). What is a PE?. Retrieved from https://www.nspe.org/resources/licensure/what-pe

NSPE. (2021). Why Get Licensed?. Retrieved from https://www.nspe.org/resources/licensure/why-get-licensed#:~:text=Career%20Development%3A%20Employers%20are%20impressed,heightened%20leadership%20and%20management%20skills.&text=Money%3A%20Studies%20have%20shown%20that,pay%20throughout%20their%20business%20careers

Patel, M., Kumar, R., Kishor, K., Mlsna, T., Pittman, C. U., Jr., & Mohan, D. (2019, March 4). Pharmaceuticals of Emerging concern in Aquatic Systems: Chemistry, Occurrence, Effects, and Removal Methods. Retrieved from https://pubs.acs.org/doi/10.1021/acs.chemrev.8b00299

Peters, D. H.,Friedel, H. A., & McTavish, D. (2012, October 27). Azithromycin. Retrieved March 22, 2021, from https://link.springer.com/article/10.2165/00003495-199244050-00007

Salicylic acid TOPICAL: MEDLINEPLUS drug information. (2021). Retrieved March 22, 2021, from https://medlineplus.gov/druginfo/meds/a607072.html

School of PE. (2018, October 31). Maintaining Your PE License After Passing The PE Exam. Retrieved from https://www.schoolofpe.com/blog/2018/10/maintaining-your-pe-license-after-passing-pe-exam.html

Sila, O. (2018, December 13). Physico-chemical and Bacteriological quality of water sources in rural settings, a case study of KENYA, Africa. Retrieved March 22, 2021, from https://www.sciencedirect.com/science/article/pii/S2468227618300930

Thomas, F. (2017, March). Pharmaceutical Waste in the Environment: A Cultural Perspective. Retrieved March 22, 2021, from https://www.euro.who.int/__data/assets/pdf_file/0010/334396/10-Pharmaseutical-waste-environment.pdf

Tuser, C. (2020,January 9). What is Wastewater? Retrieved March 22, 2021, from https://www.wwdmag.com/wastewater-treatment/what-wastewater#:~:text=Wastewater%20is%20used%20water%20that,domestic%2C%20industrial%20and%20commercial%20use.&text=The%20composition%20of%20wastewater%20is,matter%2C%20microorganisms%20and%20inorganic%20compounds.

Upper Blackstone Clean Water. (2016). Retrieved March 22, 2021, from http://www.ubwpad.org/index.html

Veolia Water.
(n.d.). Anaerobic Digestion Treatment. Retrieved March 22, 2021, from https://www.veoliawatertechnologies.co.uk/technologies/anaerobic-treatment#:~:text=Anaerobic%20treatment%20is%20a%20proven,in%20an%20oxygen%2Dfree%20environment

Appendix A: Lab Procedures

Creating 300 ppm Stock Standards:

1. Measure out about 0.03g of the pharmaceutical
2. Dissolve in as little methanol as possible
3. Add 100 mL of DI water to create a concentration of approximately 300 ppm or 300 µg/mL and store in sealable 5-dram vial

Creating Serial Dilution:

15 ppb:

1. Add 1 drop of 300 ppm stock standard to a 200 mL beaker
2. Add 100 mL of DI water
3. Transfer 1 mL of that solution to a 5-dram vial
4. Add 9 mL of DI water to create a 15 ppb or 0.015 µg/mL lower limit standard

75 ppb:

5. Add 5 drop of 300 ppm stock standard to a 200 mL beaker
6. Add 100 mL of DI water
7. Transfer 1 mL of that solution to a 5-dram vial
8. Add 9 mL of DI water to create a 75 ppb or 0.075 µg/mL lower limit standard

150 ppb:

1. Add 1 mL of 300 ppm stock solution to a 200 mL beaker
2. Add 99 mL of DI water
3. Transfer 1 mL of that solution to a 5-dram vial
4. Add 19 mL DI water to create a 150 ppb or 0.15 µg/mL standard

300 ppb:

1. Add 1 mL of 300 ppm stock solution to a 200 mL beaker
2. Add 99 mL of DI water
3. Transfer 1 mL of that solution to a 5-dram vial
4. Add 9 mL DI water to create a 300 ppb or 0.3 µg/mL standard

600 ppb:

1. Add 1 mL of 300 ppm stock solution to a 200 mL beaker
2. Add 99 mL of DI water
3. Transfer 2 mL of that solution to a 5-dram vial
4. Add 8 mL DI water to create a 600 ppb or 0.6 µg/mL standard

900 ppb:

5. Add 1 mL of 300 ppm stock solution to a 200 mL beaker
6. Add 99 mL of DI water
7. Transfer 3 mL of that solution to a 5-dram vial
8. Add 7 mL DI water to create a 900 ppb or 0.9 µg/mL standard

1500 ppb:

1. Add 1 mL of 300 ppm stock solution to a 200 mL beaker

2. Add 99 mL of DI water
3. Transfer 5 mL of that solution to a 5-dram vial
4. Add 5 mL DI water to create a 1500 ppb or 1.5 µg/mL upper limit standard

Macrolide Antimicrobials (Azithromycin) Extraction:

1. SPE cartridges were preconditioned with the following:
    a. 2 mL of acetone
    b. 2 mL of methanol
    c. 2 mL of water (pH 6.0)
2. The effluent samples (2 mL) were passed through the cartridges at a rate of approximately 1 drop/second.
3. After passage of the samples, each cartridge was eluted with 2 mL of methanol.

Sulfonamide Antimicrobials Extraction:

1. The previous SPE extraction procedure was adapted where this time the chelating agent, ethylenediamine tetraacetate (EDTA), was added to samples to improve recovery efficiency.
2. The SPE cartridges were preconditioned with the following:
    a. 2 mL of acetone
    b. 2 mL of methanol
    c. 2 mL of 50 mM EDTA
3. The effluent samples (2 mL) were acidified to pH 3.0 with 3.0 M H2SO4
4. Then followed by the addition of EDTA (0.1 g)
5. Samples were then passed through the SPE cartridges at a rate of approximately 1 drop/second
6. Just as before, after passage of the samples, each cartridge was eluted with 2 mL of methanol
7. The eluates were collected in a sealable 5-dram vials

Salicylic Acid Extraction:

1. SPE cartridges were preconditioned with the following:
    a. 1 mL ACN
    b. 2 mL 50 mmol/L HCl
2. The effluent samples were prepared by adding the following:
    a. 1 mL of a 50 mmol/L triethanolamine,
    b. 0.2 mmol/L EDTA,
    c. 0.4 mmol/L CaCl2 to the sample, then adjusting the pH to 7.5 with HCl.
3. Each cartridge was eluted with 2 mL of methanol

LC-MS: Agilent Technologies 5130 Quadrupole Methods:

- Pharmaceuticals were separated with an Epic C18 MSO 2.3 µ 150 Å 5 cm × 2.1 mm column
- Water with 0.1 % formic acid (A) 95 % acetonitrile with 5 % water and 0.1 % formic acid (B)
- The column was maintained at 30 °C at a flow rate of 0.3 ml/min
- Injection volume 2 µL with 10 sec needle wash and m/z 80-900

LC-MS Optimized Methods:
We used the scanning mode of LC-MS to observe the MS peaks for our samples. The first method used m/z 180-1200, which was too high and excluded salicylic acid. Since salicylic acid is a relatively small compound it may be harder to identify the MS peak. Once we were able to separate and identify the peaks in our samples, we were able to switch to the selected ion monitoring (SIM) mode to focus on each pharmaceutical. Since we extracted each pharmaceutical individually, we were able to use SIM to target the specific pharmaceutical in each sample. This reduced the workload on the instruction and improved MS results. We had 51 samples in total, shown in Table 2 of Appendix C, 21 standards and 30 samples. We chose to create standards ranging from 15 ppb to 1500 ppb to create the calibration curve.

Monoisotopic Masses:

- SMZ - 254 g/mol
- Azithromycin - 749 g/mol
- Salicylic Acid - 138 g/mol

Appendix B: UV-Vis Spectra

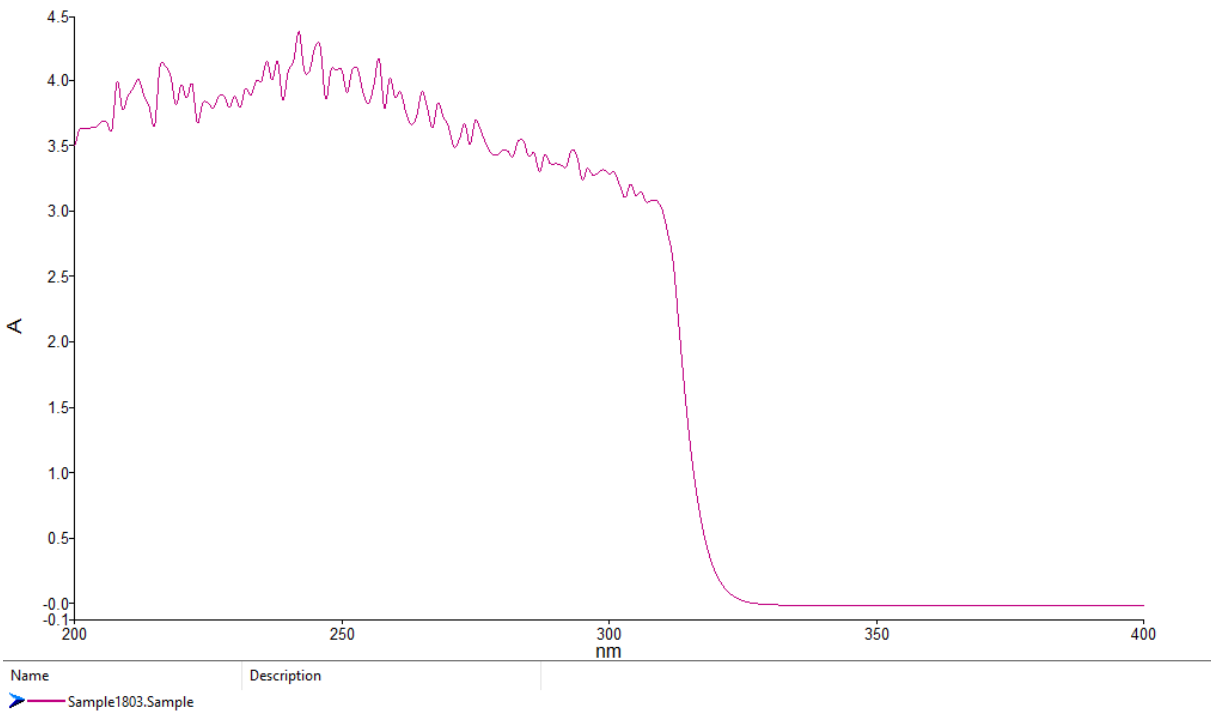


Figure 5. UV-Vis Spectra of SMZ Standard

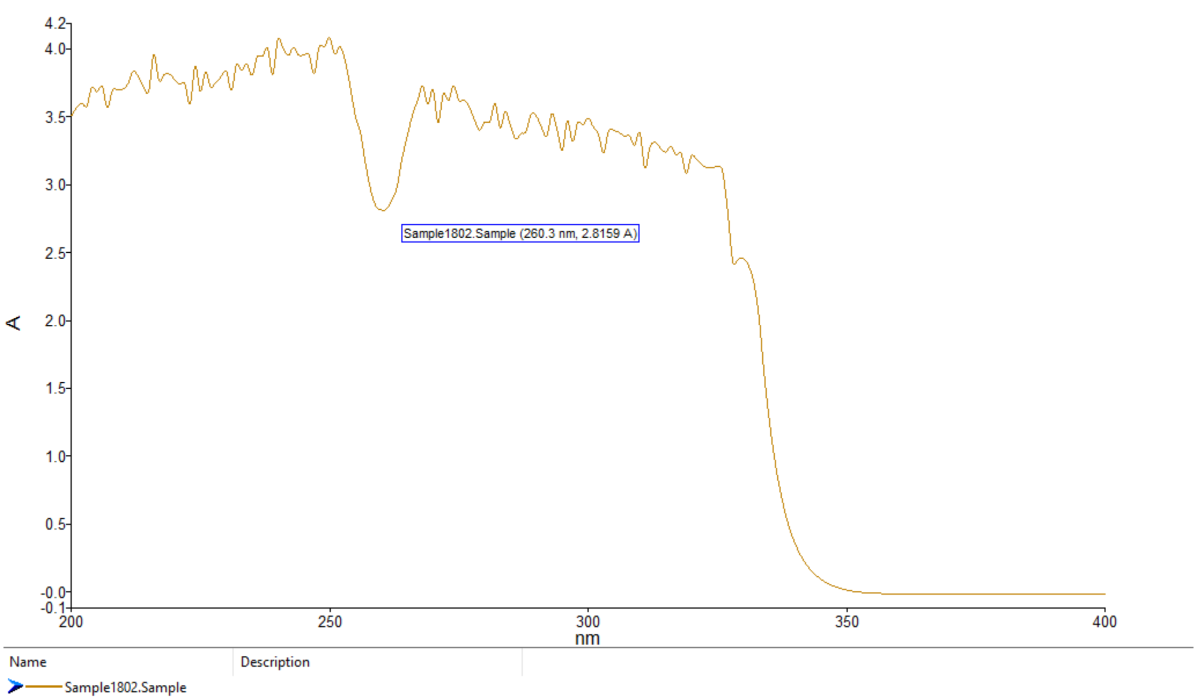


Figure 6. UV-Vis Spectra of Salicylic Acid Standard

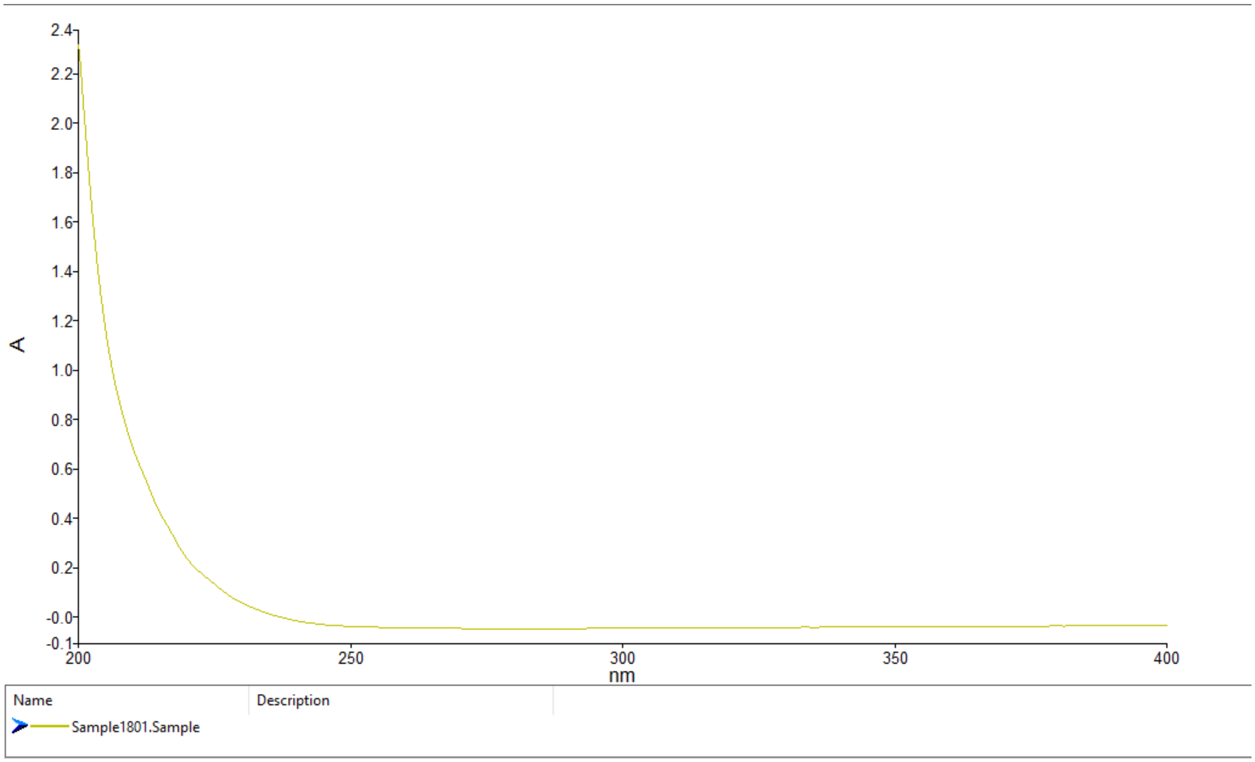


Figure 7. UV-Vis Spectra of Azithromycin Standard

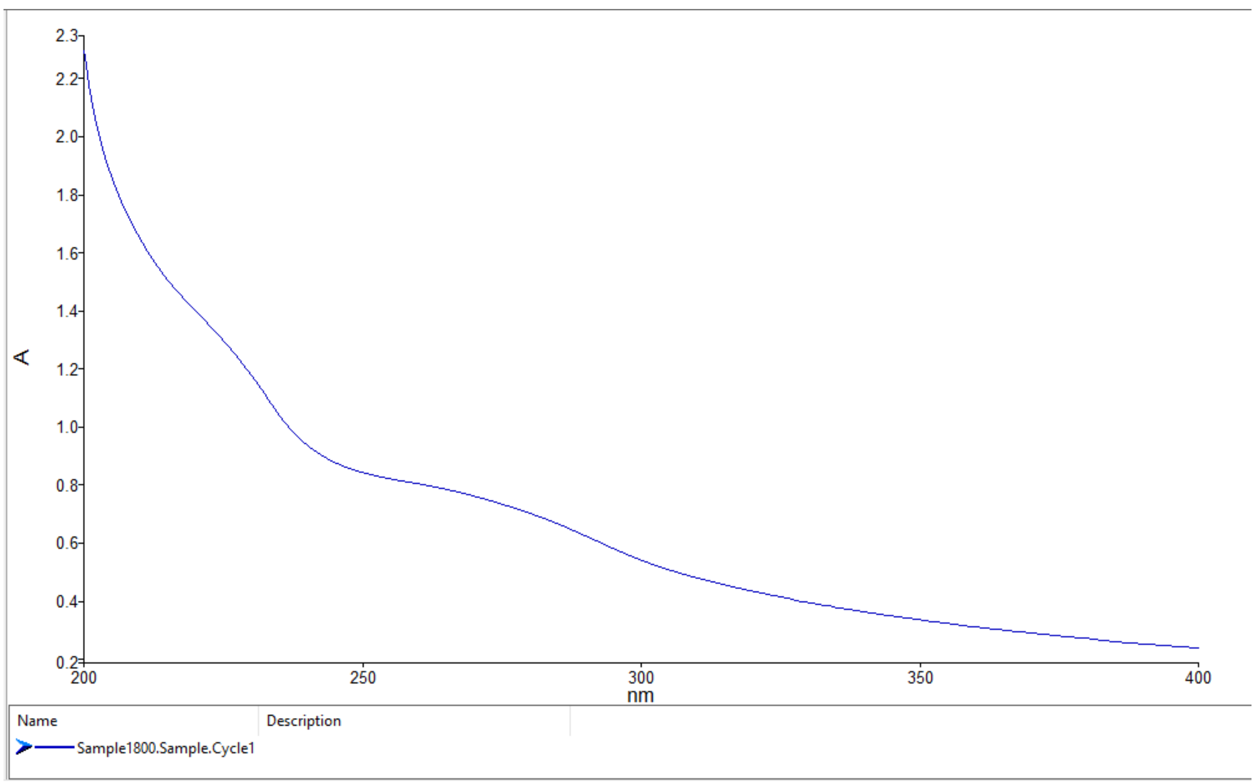


Figure 8. UV-Vis Spectra of Influent Sample

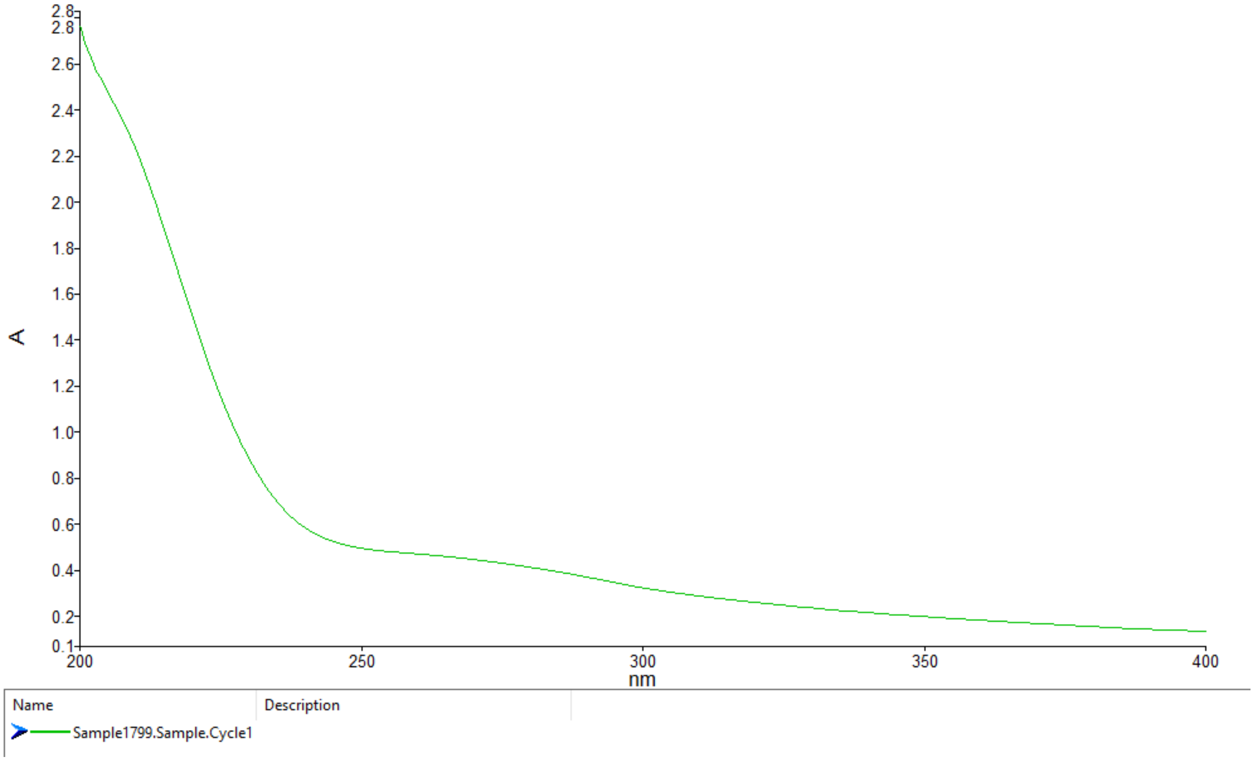


Figure 26. UV-Vis Spectra of Primary Effluent Sample

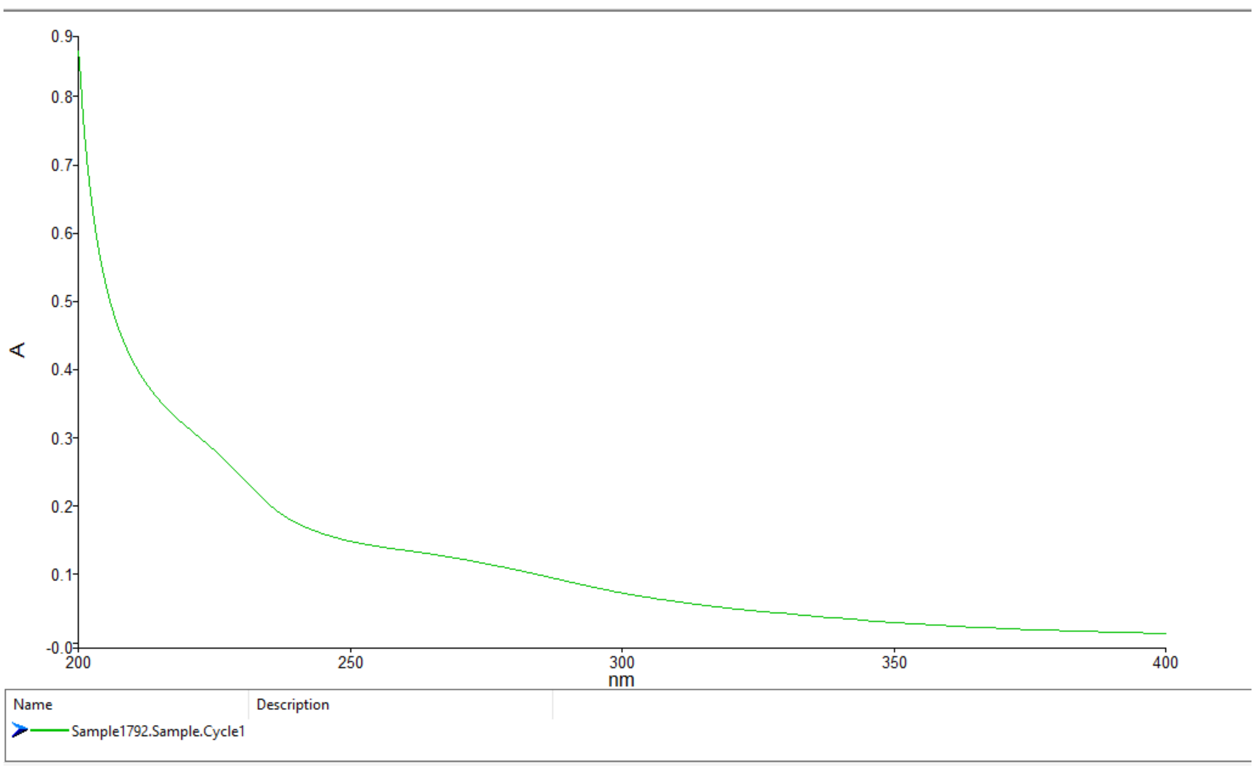


Figure 27. UV-Vis Spectra of Anaerobic Sample

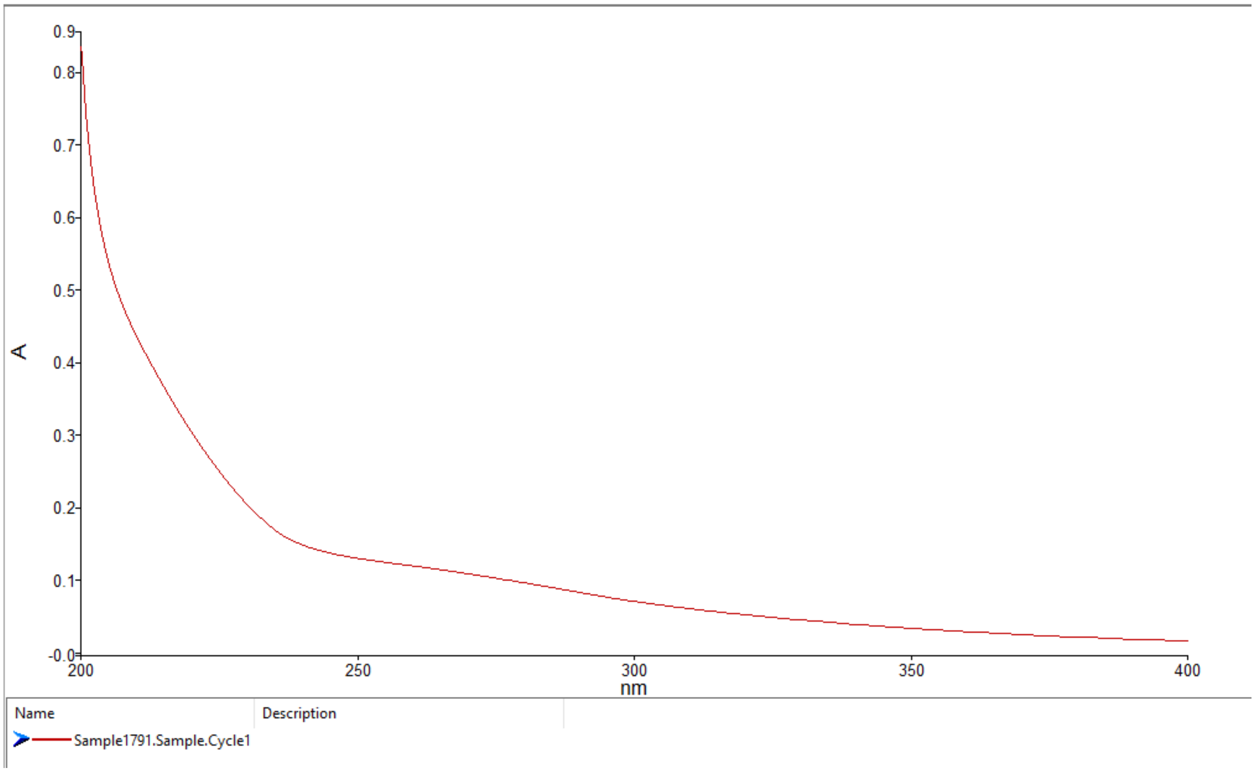


Figure 28. UV-Vis Spectra of Anoxic Sample

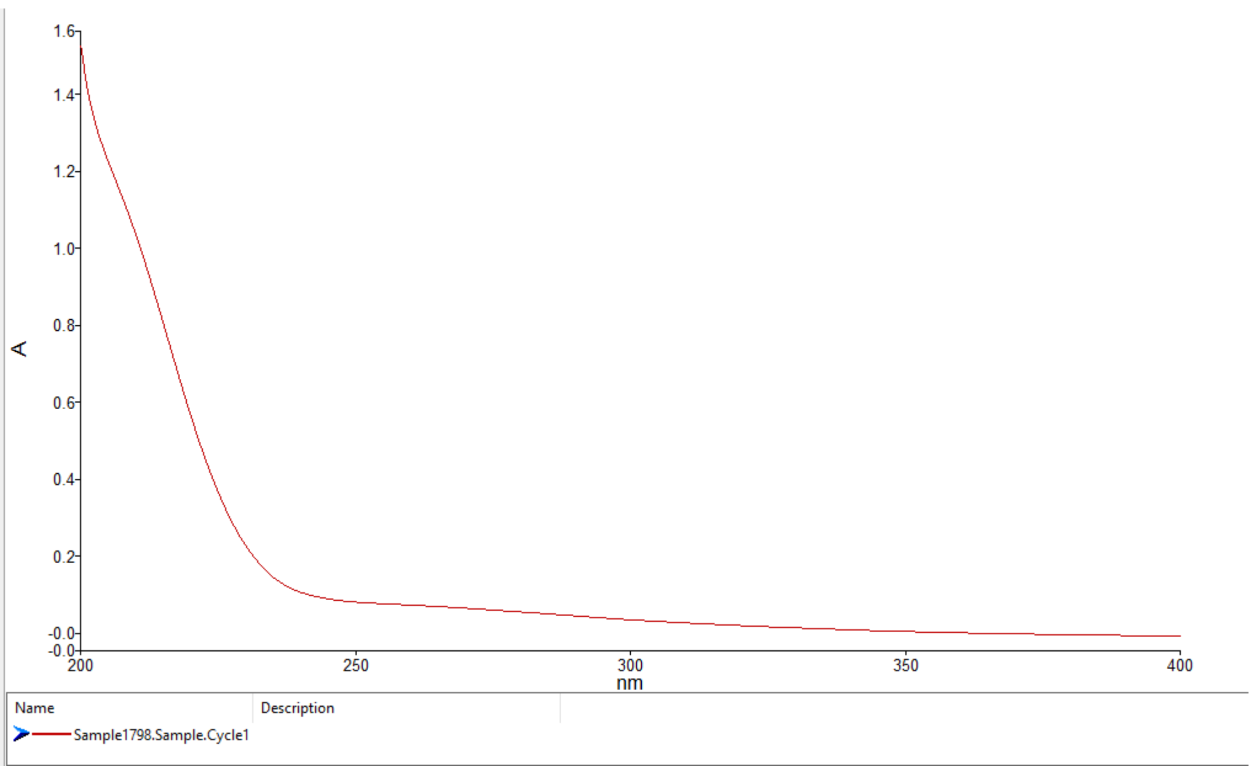


Figure 29. UV-Vis Spectra of Aerobic Sample

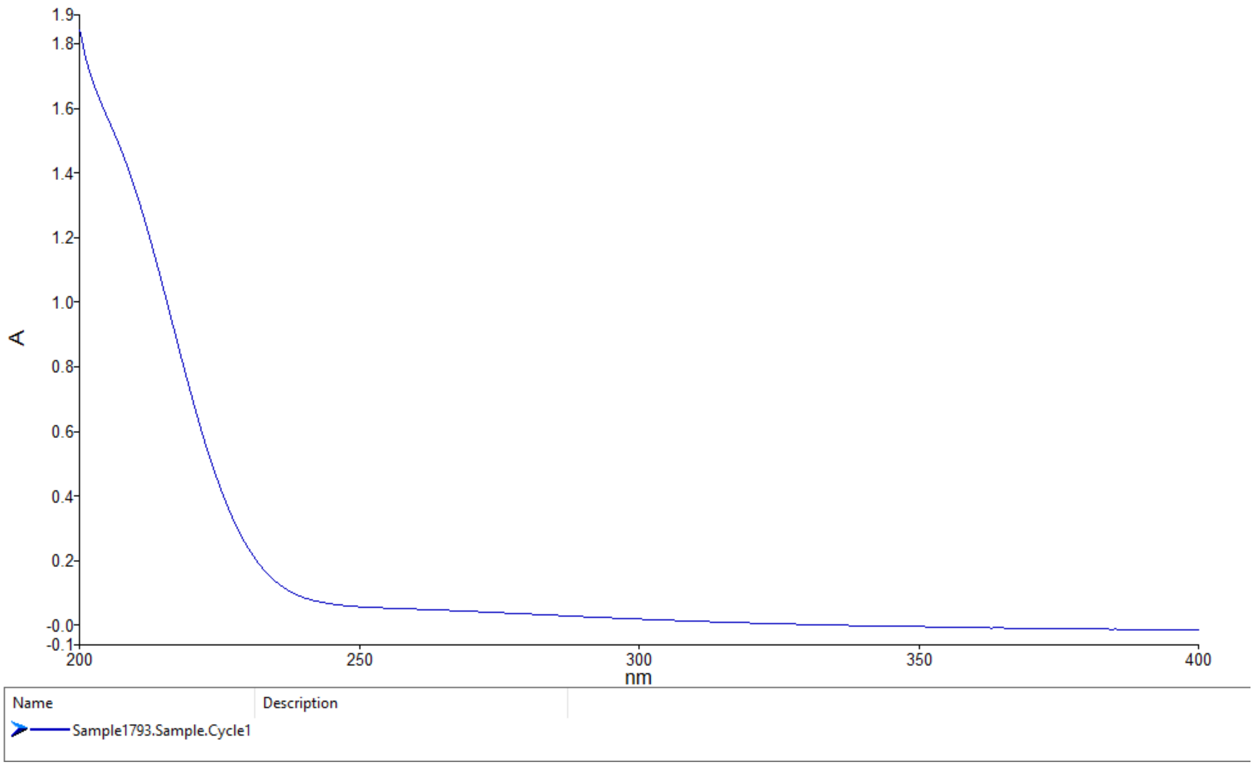


Figure 30. UV-Vis Spectra of Final Settling Sample

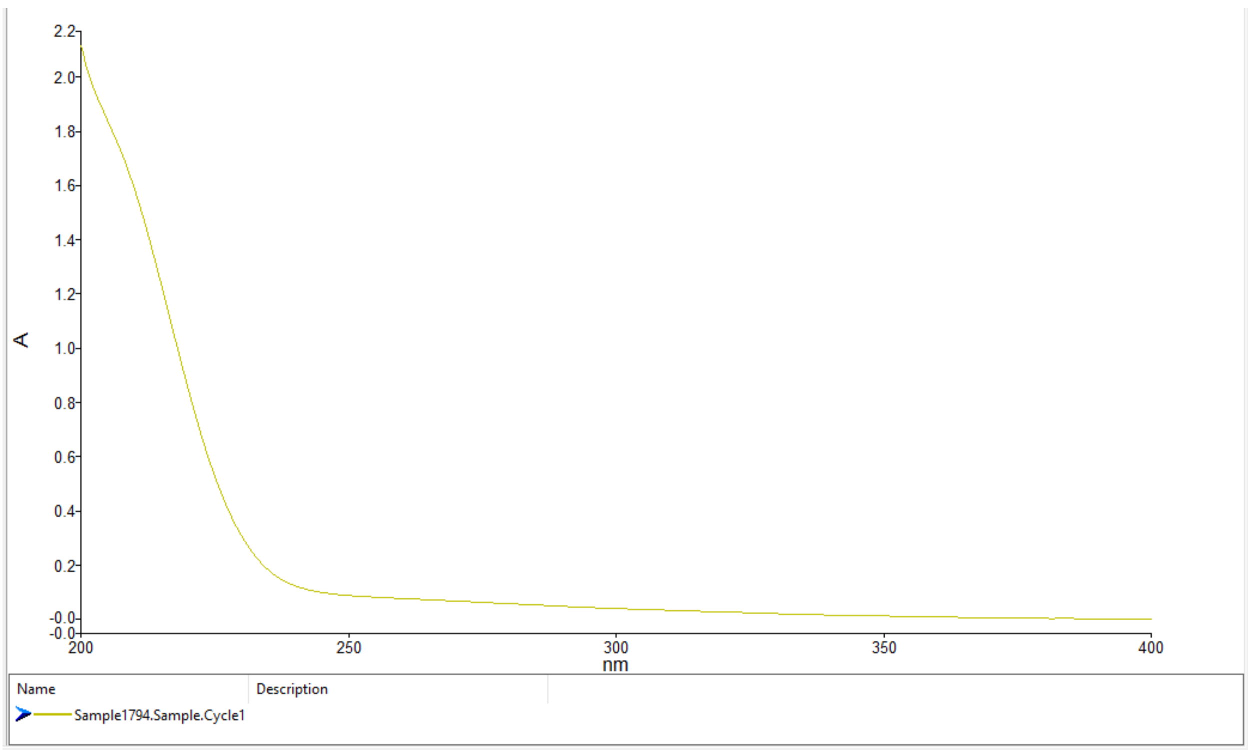


Figure 9. UV-Vis Spectra of Final Effluent Sample

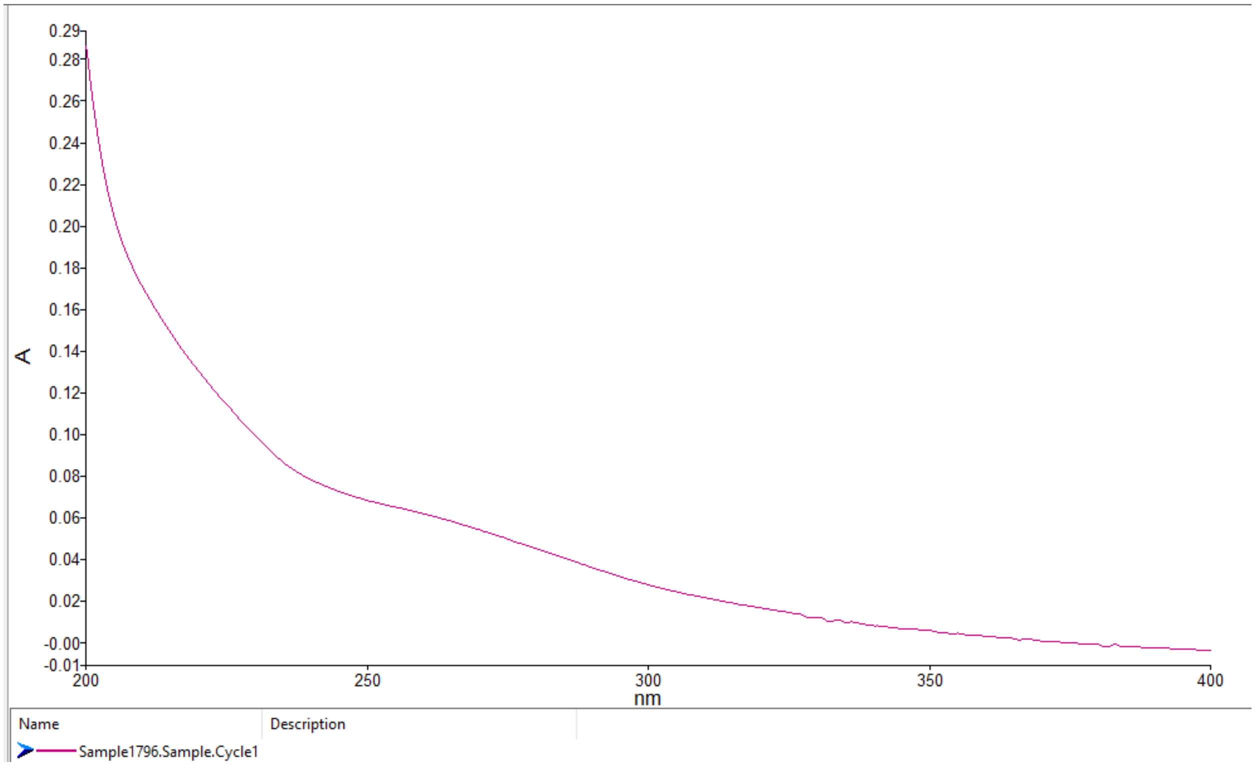


Figure 10. UV-Vis Spectra of Green Hill Pond Sample

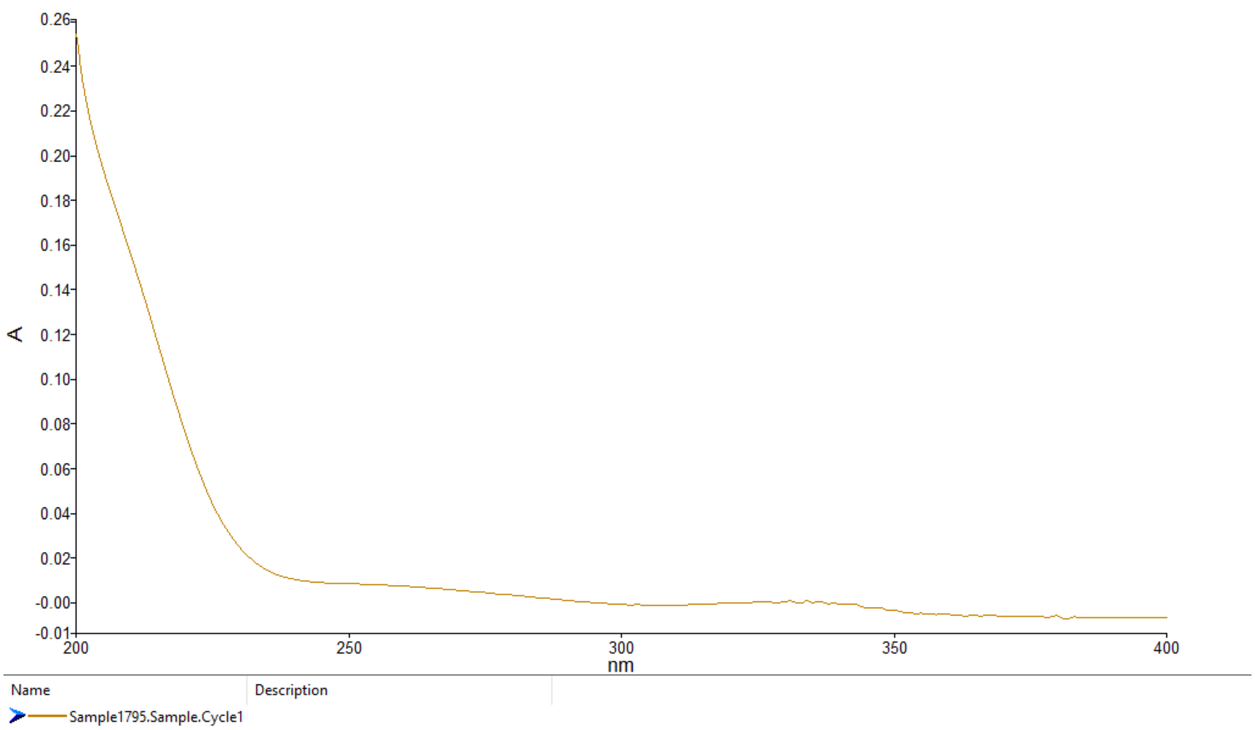


Figure 11. UV-Vis Spectra of Lake Quinsigamond Sample

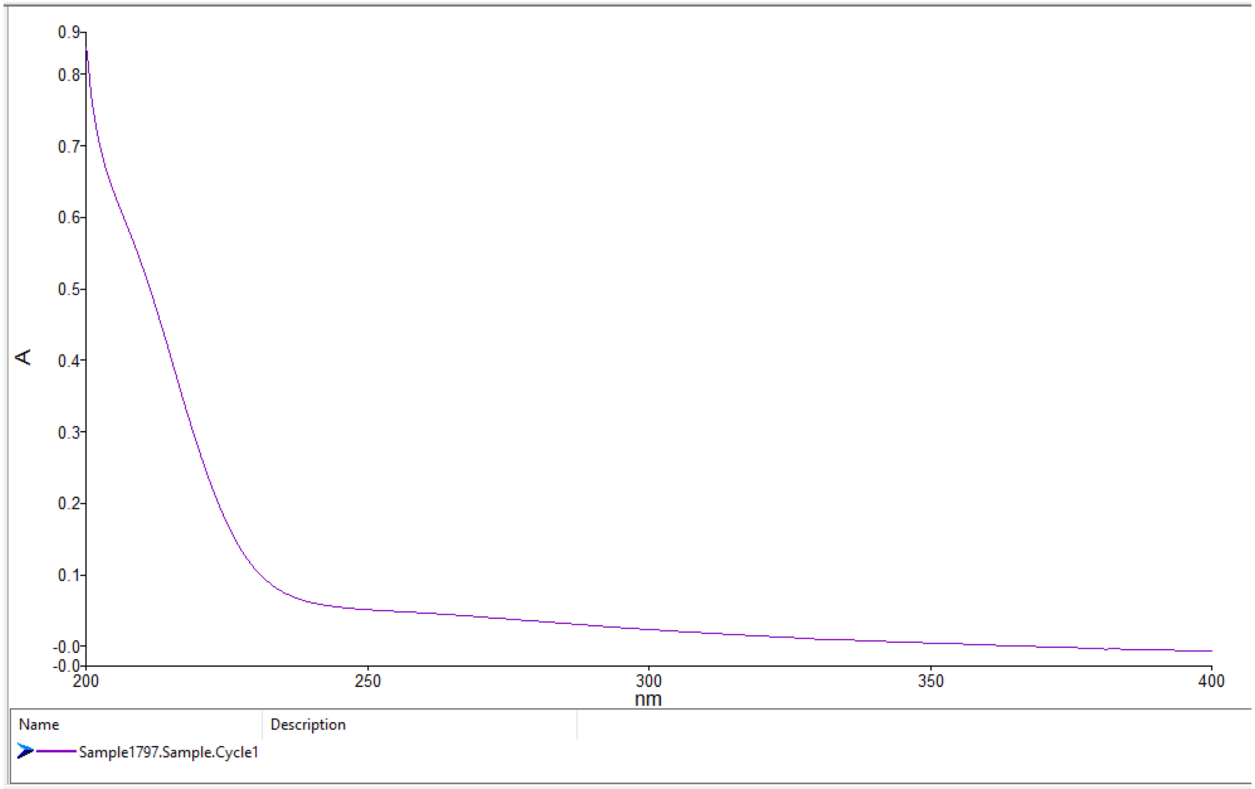


Figure 12. UV-Vis Spectra of Salisbury Pond Sample

Appendix C: LC-MS Data

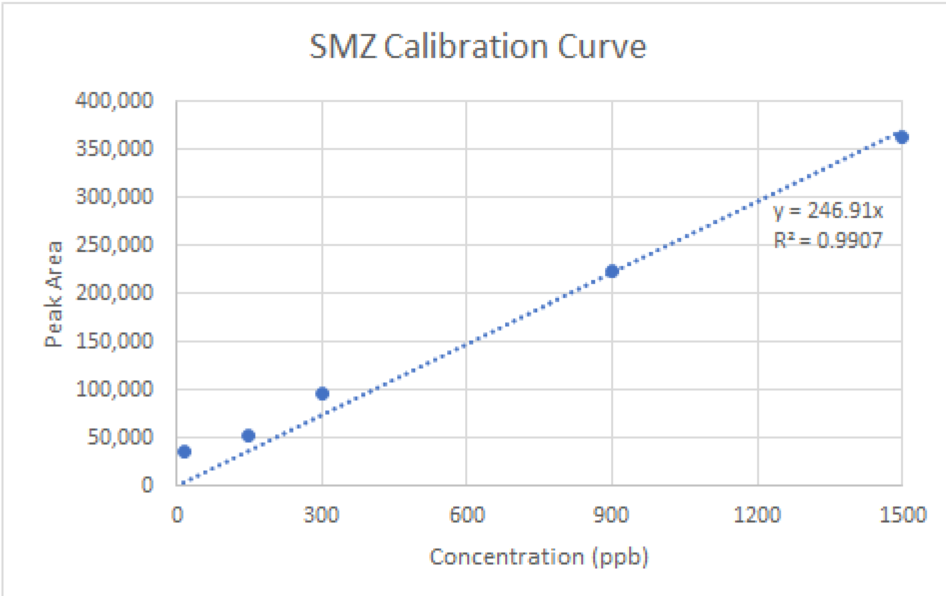


Figure 18. The linear calibration curve for SMZ shows concentration in parts per billion against peak area. We created standards of SMZ at various concentrations (see Appendix A) and analyzed them using LC-MS to find peak areas. By adding a trendline with y-intercept set to zero, we were able to retrieve the trendline equation that we then used to find the unknown concentration in our samples.

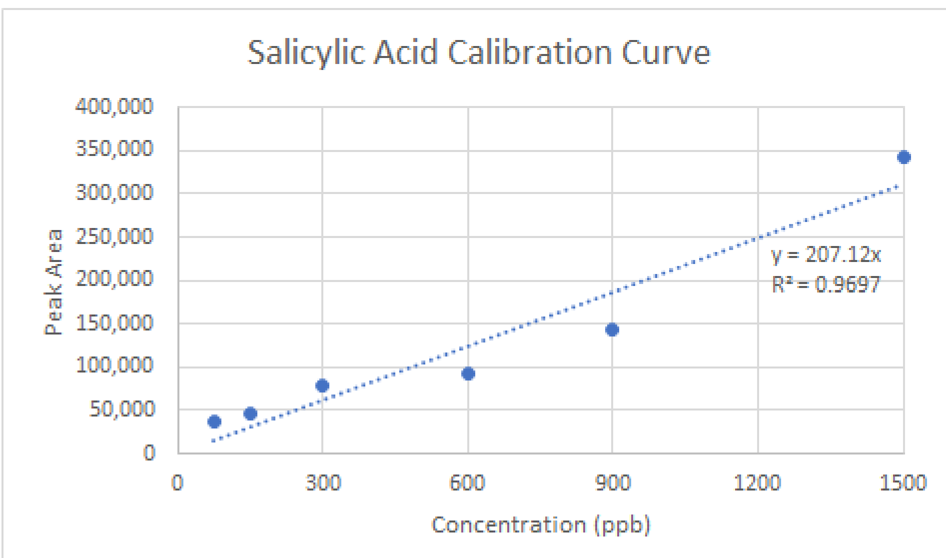


Figure 20. The calibration curve for salicylic acid shows concentration in parts per billion against peak area. By creating standards using procedures in Appendix A and analyzing them using LC-MS, we were able to create this linear curve to find the unknown concentrations of our samples for salicylic acid from the peak areas measured by LC-MS.

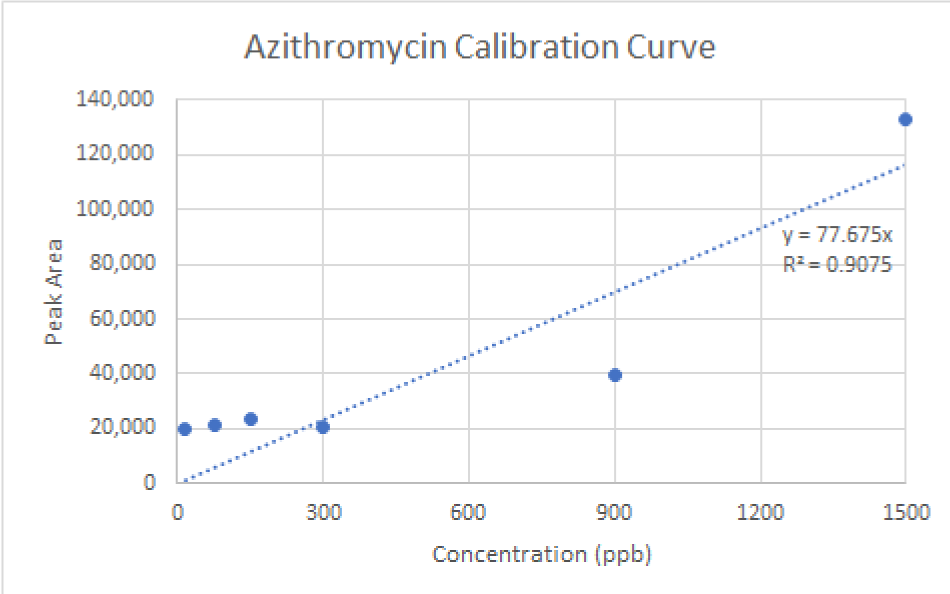


Figure 21. The calibration curve for azithromycin shows concentration in parts per billion against peak area. By analyzing standard concentrations of azithromycin using LC-MS, we were able to create this linear calibration curve to find the unknown concentrations of our samples from the peak areas.

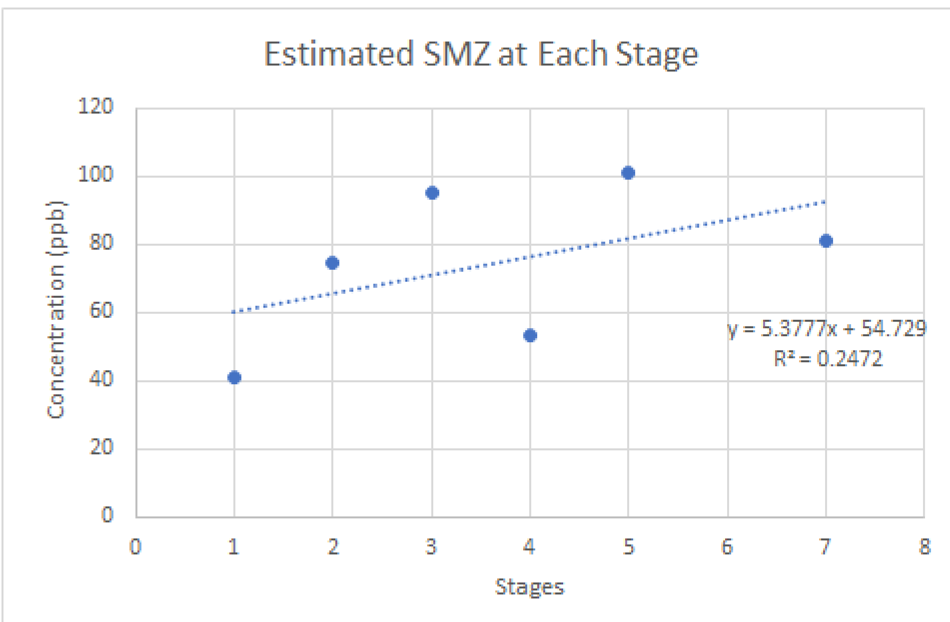


Figure 19. We estimated the concentration of SMZ by using the trendline equation in Figure 18 to calculate the concentration of our wastewater treatment samples. Stage one through seven on the x-axis represent the stages Influent (1), Primary Effluent (2), Anaerobic (3), Anoxic (4), Aerobic (5), Final Settling (6), and Final Effluent (7) of Upper Blackstone's treatment process. As the time goes on, we see no significant trend in the reduction of SMZ, as seen with the low R-squared value. The data point at stage 6, the final settling sample, was not tested by LC-MS.

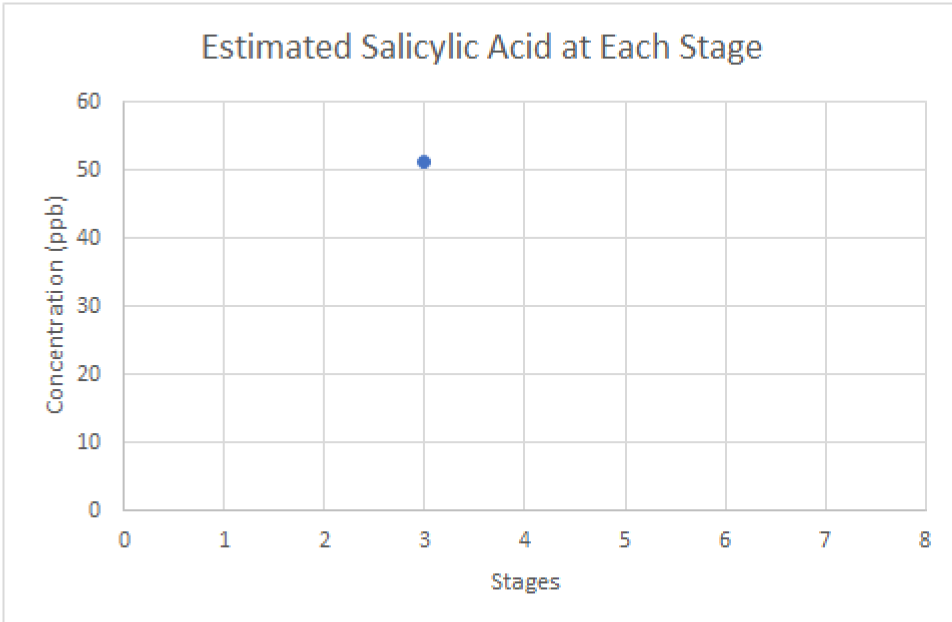


Figure 22. Due to a combination of instrument error and possible contamination, two MS reports were not produced, and the remaining reports showed no sign of salicylic acid peak, therefore the area was not found. The one successful MS report showed an approximate concentration of 50 ppb salicylic acid at the anaerobic stage. With these limited data, we cannot say whether there was a decrease in the concentration as treatment processes continued.

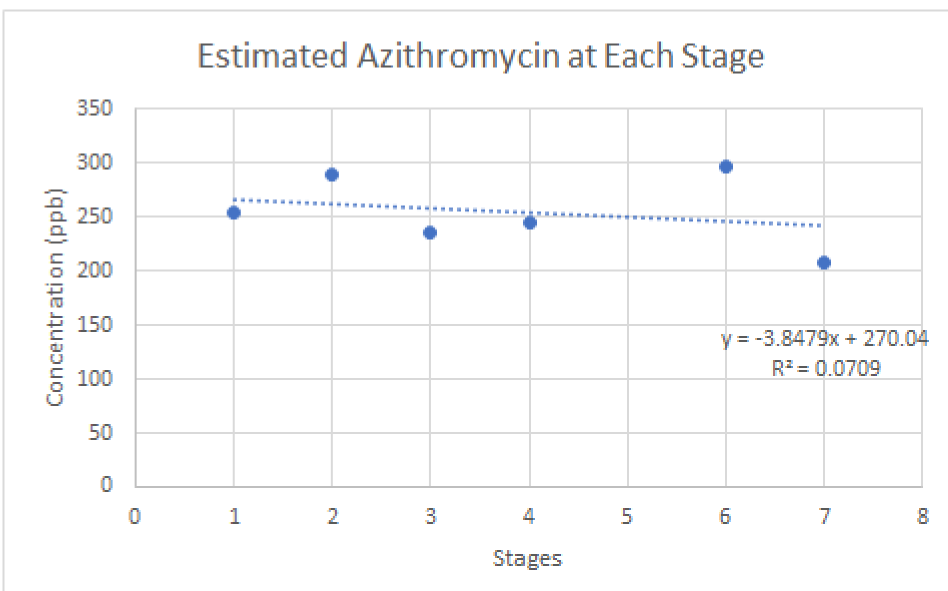


Figure 23. By comparing the estimated concentration of azithromycin at each stage, this scatter shows no reliable reduction of the pharmaceutical by Upper Blackstone's treatment processes.

Table 2. This shows our tabulated data from LC-MS reports for each of our samples. We ran 51 samples total, 21 standards to create calibration curves and 30 unknown samples either from wastewater treatment methods or surface water in Worcester, MA.

Pharmaceutical	Sample Name	Time (Minutes)	Peak Area	Standard Concentration (ppb)	Estimated Concentration (ppb)
SMZ	15 ppb Standard 1	6.393	36,740.3	15	149
	15 ppb Standard 2	No MS		15	
	150 ppb Standard	6.337	51,686.5	150	209
	300 ppb Standard	6.323	95,444.9	300	387
	600 ppb Standard	Removed			
	900 ppb Standard	6.329	223,248.4	900	904
	1500 ppb Standard 1	6.329	363,687.1	1500	1473
	1500 ppb Standard 2	No MS		1500	
	Lake Quinsigamond	6.339	15,481.1		63
	Green Hill Pond	No Sample			
	Salisbury Pond	No Sample			
	Influent	6.33	10,142.1		41
	Primary Effluent	6.334	18,410.9		75
	Anaerobic	6.335	23,526.0		95
	Anoxic	6.337	13,250.8		54
	Aerobic	6.325	24,945.0		101
	Final Settling	No Sample			
	Final Effluent	6.333	20,015.9		81
Salicylic Acid	75 ppb Standard	6.599	36,566.7	75	177
	150 ppb Standard	6.582	47,624.6	150	230
	300 ppb Standard	6.584	78,884.6	300	381
	600 ppb Standard	6.58	92,936.8	600	449
	900 ppb Standard	6.586	144,504.7	900	698
	1500 ppb Standard	6.585	342,301.9	1500	1653
	Lake Quinsigamond	6.583	15,314.7		74
	Green Hill Pond	No MS			
	Salisbury Pond	6.584	27,658.7		134
	Influent	No Peak			
	Primary Effluent	No Peak			
	Anaerobic	6.581	10,631.2		51
	Anoxic	No Peak			
	Aerobic	No Peak			
	Final Settling	No Peak			
	Final Effluent	No MS			
Azithromycin	15 ppb Standard	6.43	20,107.8	15	259
	75 ppb Standard	6.422	21,550.8	75	277
	150 ppb Standard	6.424	23,635.8	150	304
	300 ppb Standard	6.425	20,901.6	300	269
	600 ppb Standard	No MS		600	
	900 ppb Standard	6.424	39,483.4	900	508
	1500 ppb Standard	6.409	133,073.4	1500	1713
	Lake Quinsigamond	6.425	21,425.5		276
	Green Hill Pond	6.43	17,004.8		219
	Salisbury Pond	6.421	21,906.8		282
	Influent	6.427	19,817.8		255
	Primary Effluent	6.425	22,469.2		289
	Anaerobic	6.425	18,313.2		236
	Anoxic	6.426	19,053.8		245
	Aerobic	No Sample			
	Final Settling	6.421	23,118.7		298
	Final Effluent	6.445	16,205.9		209

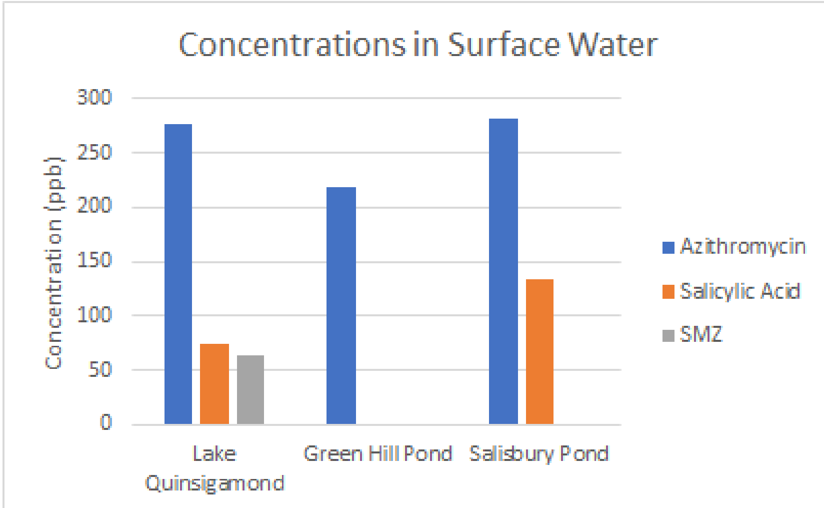


Figure 24. MS data show the concentration of SMZ, salicylic acid, and azithromycin in Lake Quinsigamond, Green Hill Pond, and Salisbury Pond. Due to complications, SMZ samples for Green Hill Pond could not be tested, in addition to both SMZ and salicylic acid samples for Salisbury Pond. Our MS data show the concentration of SMZ in the Lake Quinsigamond sample is about 60 ppb. We did not have supplies to test for Green Hill Pond and Salisbury Pond, so no samples were tested using LC-MS. Due to an instrumental error with the Green Hill Pond sample, no MS report was produced. However, this shows the concentration of salicylic acid in Worcester surface water is around 74 for Lake Quinsigamond and 134 for Salisbury Pond. The surface water concentration of azithromycin was higher than both SMZ and salicylic acid, at about 219 to 282 for these bodies of water.

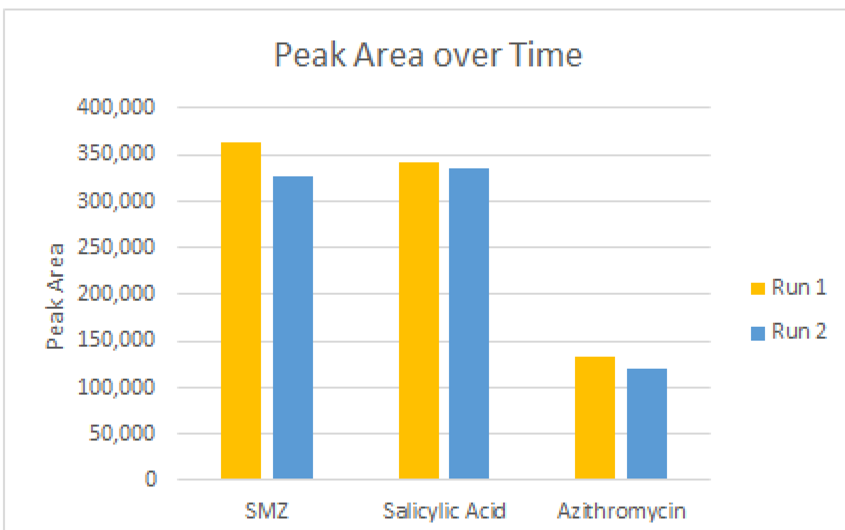
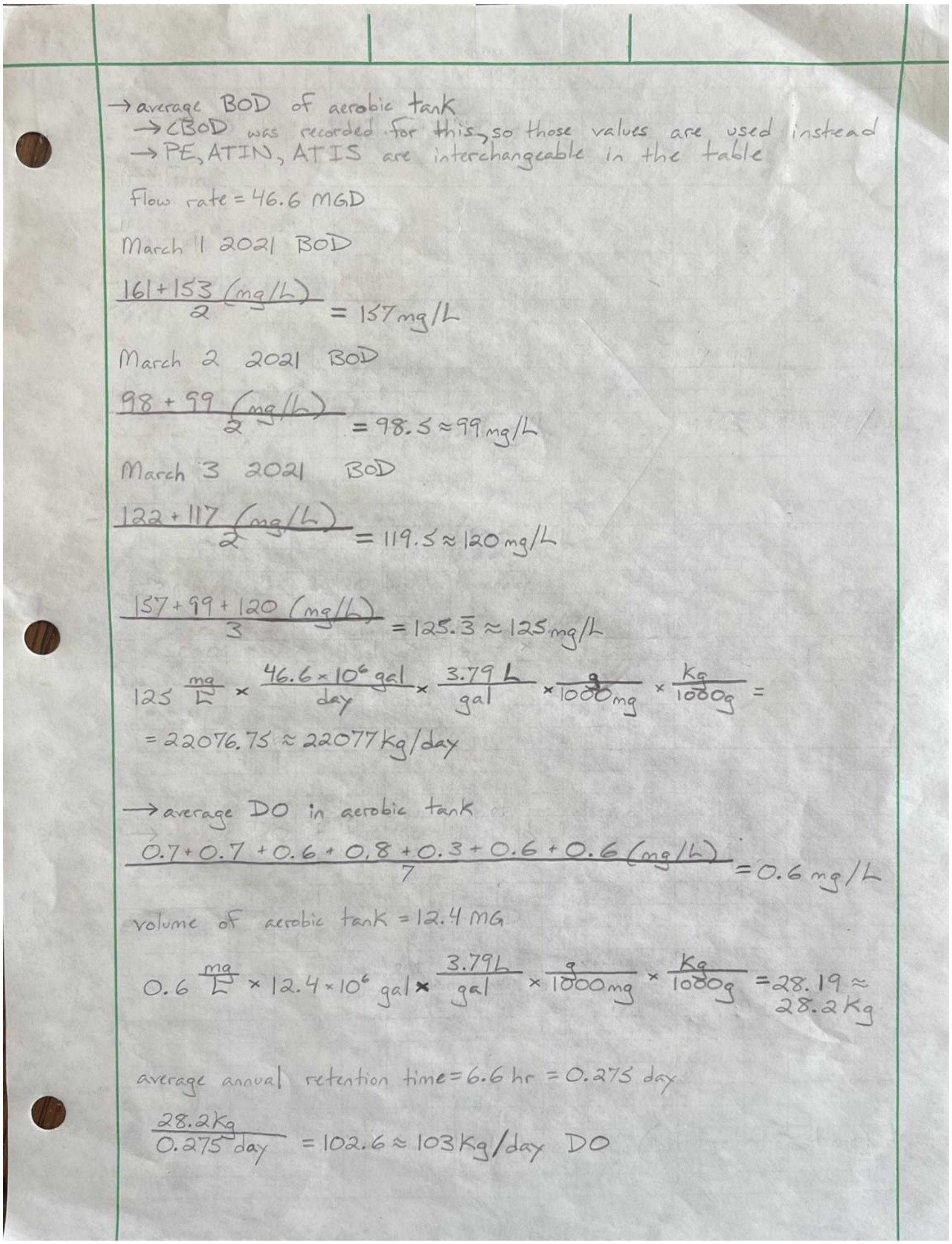


Figure 25. We ran two tests on the 1500 ppb standards for each of the pharmaceuticals, one at the beginning of the run and once at the end. This was to see what kind of reproducibility there is with this method, and to see if evaporation occurred. This figure shows only a small amount of each sample may have evaporated by the end of the run, 19 hours later.

Appendix D: Aerobic Recycling Stream Design Calculations



→ average BOD of aerobic tank
→ CBOD was recorded for this, so those values are used instead
→ PE, ATIN, ATIS are interchangeable in the table

Flow rate = 46.6 MGD

March 1 2021 BOD

$$\frac{161+153\ (mg/L)}{2} = 157\ mg/L$$

March 2 2021 BOD

$$\frac{98+99\ (mg/L)}{2} = 98.5 \approx 99\ mg/L$$

March 3 2021 BOD

$$\frac{122+117\ (mg/L)}{2} = 119.5 \approx 120\ mg/L$$

$$\frac{157+99+120\ (mg/L)}{3} = 125.\overline{3} \approx 125\ mg/L$$

$$125\ \frac{mg}{L} \times \frac{46.6\times10^6\ gal}{day} \times \frac{3.79\ L}{gal} \times \frac{g}{1000\ mg} \times \frac{Kg}{1000\ g} =$$

$$= 22076.75 \approx 22077\ Kg/day$$

→ average DO in aerobic tank

$$\frac{0.7+0.7+0.6+0.8+0.3+0.6+0.6\ (mg/L)}{7} = 0.6\ mg/L$$

volume of aerobic tank = 12.4 MG

$$0.6\ \frac{mg}{L} \times 12.4\times10^6\ gal \times \frac{3.79L}{gal} \times \frac{g}{1000\ mg} \times \frac{Kg}{1000\ g} = 28.19 \approx 28.2\ Kg$$

average annual retention time = 6.6 hr = 0.275 day

$$\frac{28.2\ Kg}{0.275\ day} = 102.6 \approx 103\ Kg/day\ DO$$

Figure 31. This is the first page of design calculations, showing average BOD and dissolved oxygen.

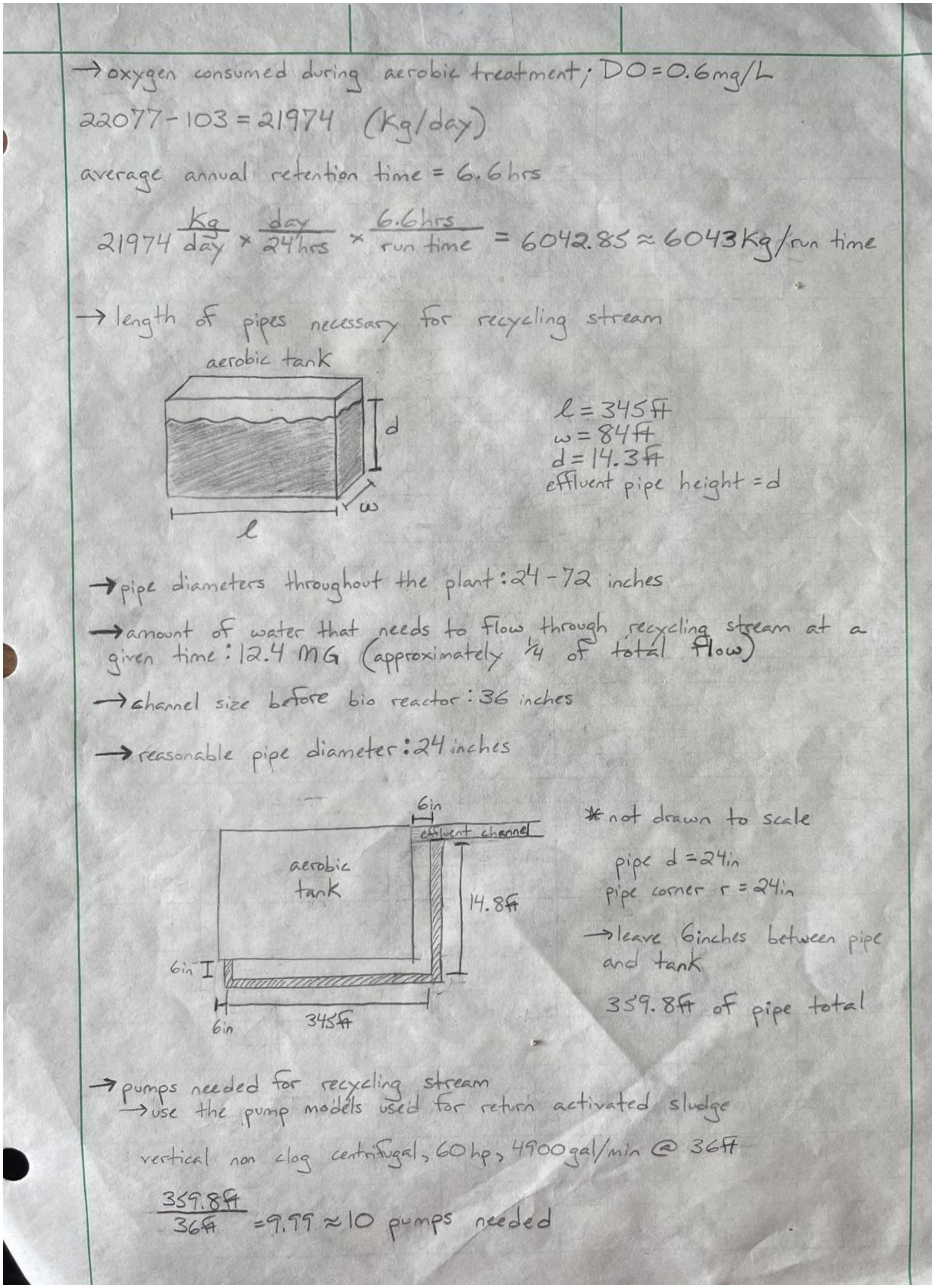
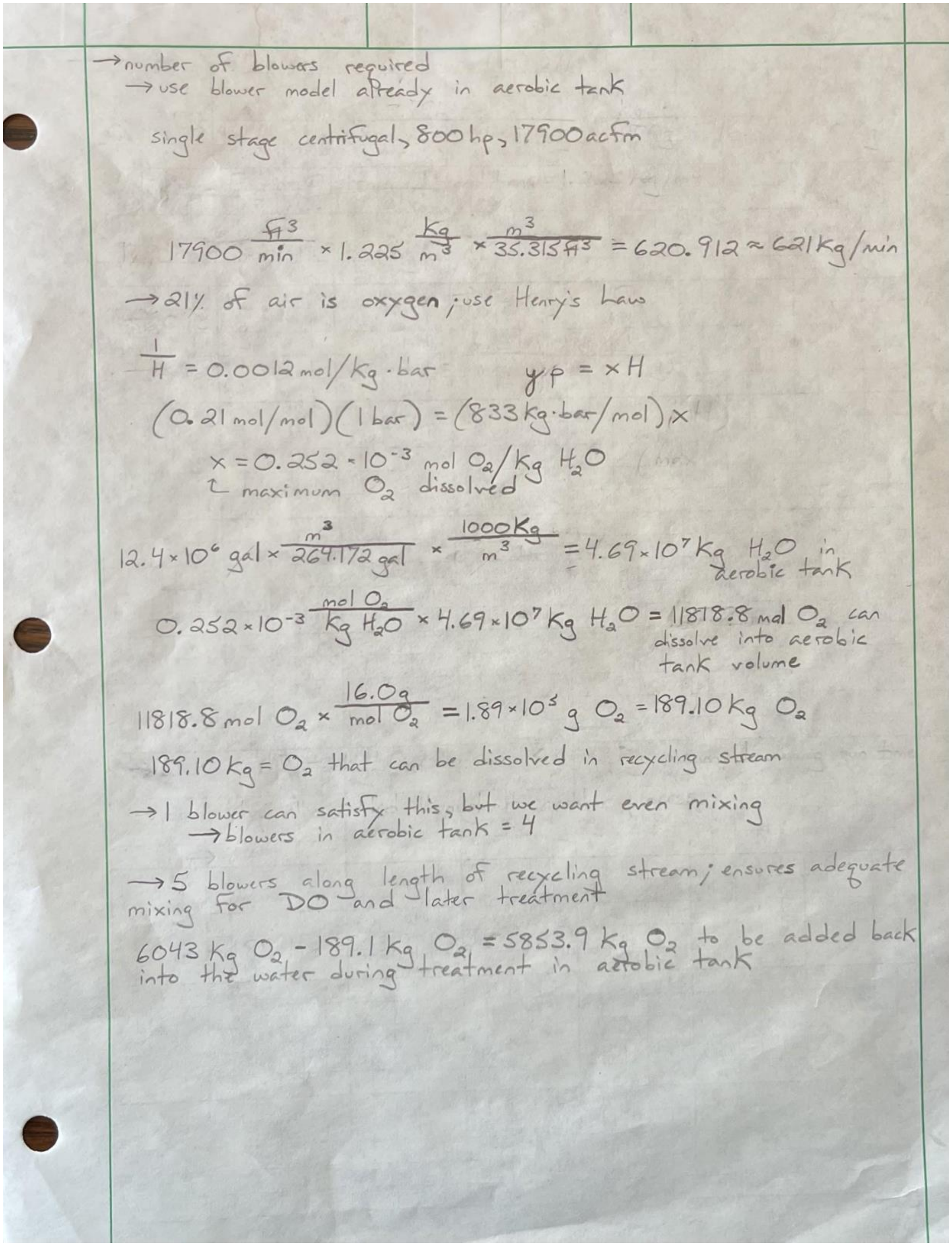


Figure 32. This is the second page of design calculations. Oxygen consumed, pipe length necessary, and number of pumps required are shown.



→ number of blowers required
→ use blower model already in aerobic tank

single stage centrifugal, 800 hp, 17900 acfm

$$17900\ \frac{ft^3}{min} \times 1.225\ \frac{Kg}{m^3} \times \frac{m^3}{35.315\ ft^3} = 620.912 \approx 621\ Kg/min$$

→ 21% of air is oxygen; use Henry's Law

$$\frac{1}{H} = 0.0012\ mol/Kg \cdot bar \qquad yP = xH$$

$$(0.21\ mol/mol)(1\ bar) = (833\ Kg \cdot bar/mol)\, x$$

$$x = 0.252 \cdot 10^{-3}\ mol\ O_2/Kg\ H_2O$$

↳ maximum O_2 dissolved

$$12.4 \times 10^6\ gal \times \frac{m^3}{264.172\ gal} \times \frac{1000\ Kg}{m^3} = 4.69 \times 10^7\ Kg\ H_2O$$ in aerobic tank

$$0.252 \times 10^{-3}\ \frac{mol\ O_2}{Kg\ H_2O} \times 4.69 \times 10^7\ Kg\ H_2O = 11818.8\ mol\ O_2$$ can dissolve into aerobic tank volume

$$11818.8\ mol\ O_2 \times \frac{16.0\ g}{mol\ O_2} = 1.89 \times 10^5\ g\ O_2 = 189.10\ Kg\ O_2$$

189.10 Kg = O_2 that can be dissolved in recycling stream

→ 1 blower can satisfy this, but we want even mixing
→ blowers in aerobic tank = 4

→ 5 blowers along length of recycling stream; ensures adequate mixing for DO and later treatment

6043 Kg O_2 − 189.1 Kg O_2 = 5853.9 Kg O_2 to be added back into the water during treatment in aerobic tank

Figure 33. This is the third page of design calculations, highlighting the amount of oxygen added during the recycling stream versus the aerobic tank, as well as the number of air blowers.

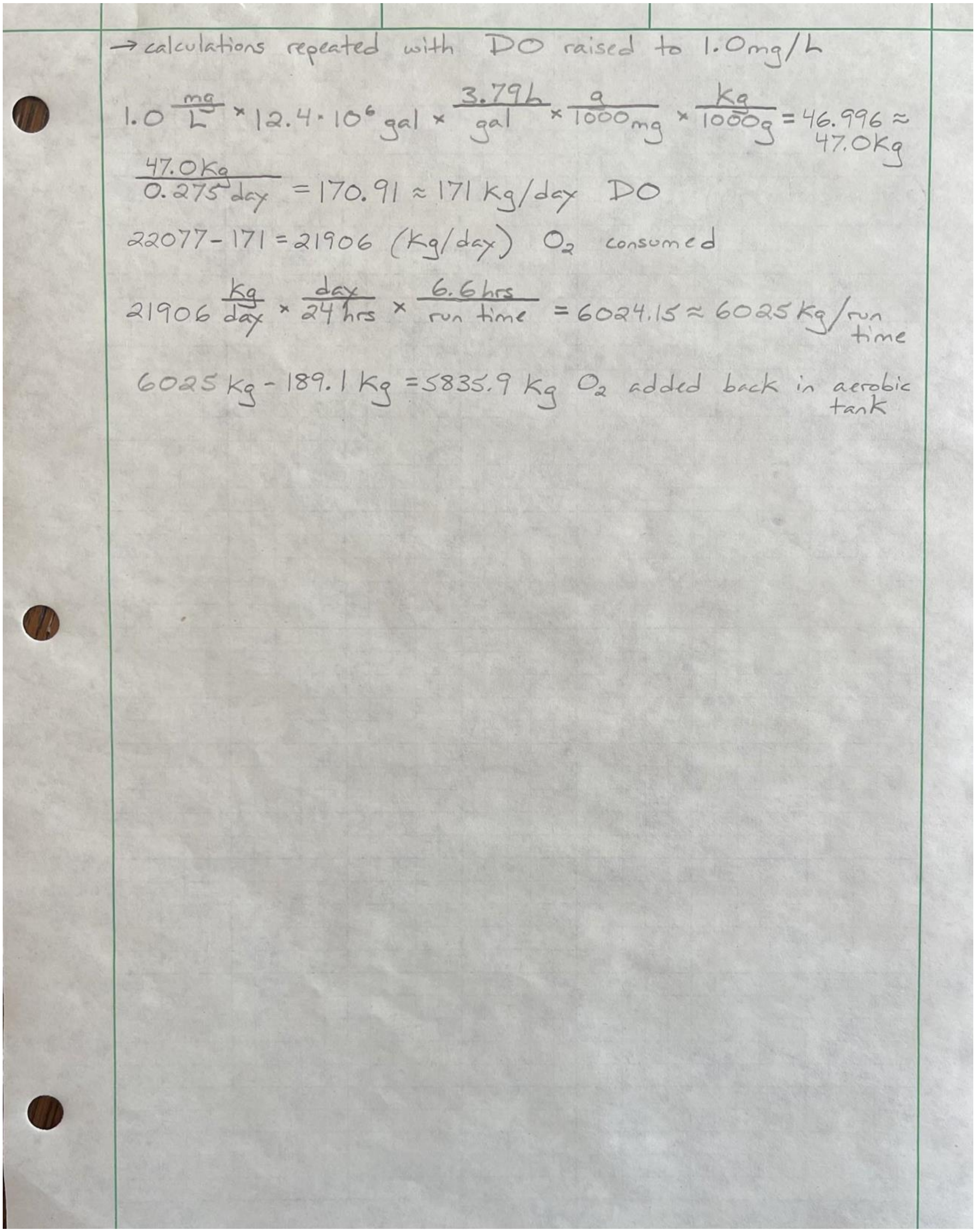


Figure 34. This is the fourth and final page of design calculations, focusing on repeating the above calculations with a dissolved oxygen value of 1.0 mg/L.

Appendix E: Water Quality Test Strips

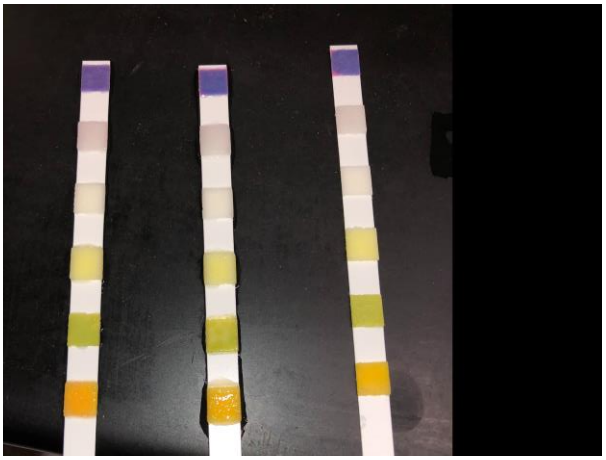


Figure 35. Salisbury Pond, Lake Quinsigamond, Green Hill Pond water test strips

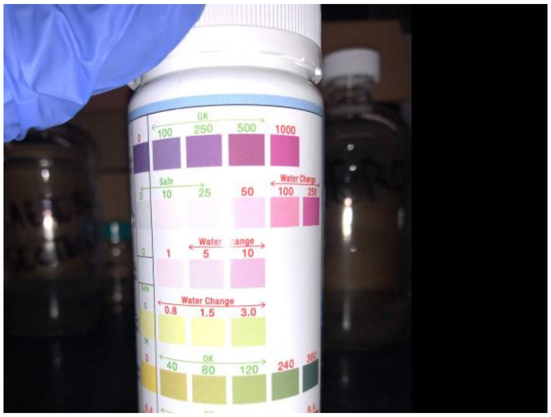


Figure 4. Water quality strips concentration range values

Figure 36. Influent and Primary Effluent test strips

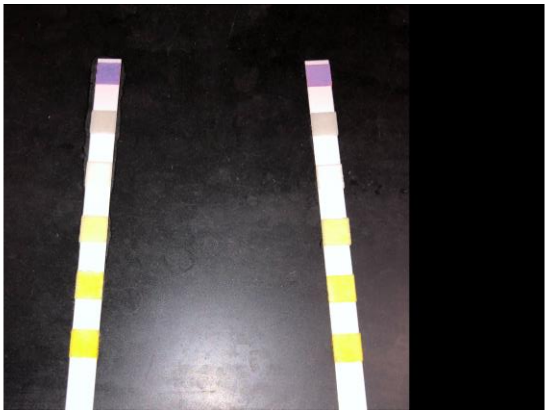


Figure 37. Azithromycin and Salicylic Acid water test strips

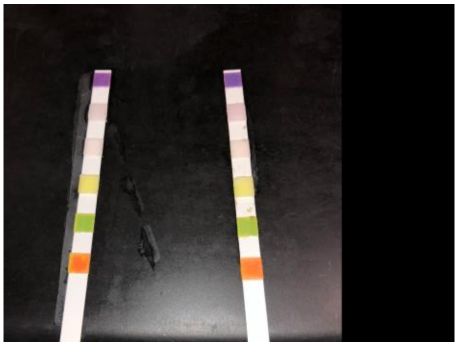


Figure 38. Anaerobic and Anoxic water test strips

Figure 39. Aerobic, Final Settling, Final Effluent water test strips

Chapter 2

Words of Water Quality: Community Communication

Submitted by:
Jacqueline Cardin

Advisor:
Professor Ryan Madan, PhD, Worcester Polytechnic Institute

Abstract

The Safe Drinking Water Act mandates all water quality testing results be publicly available in the form of Consumer Confidence Reports. However, there is no template or standard to which these reports are held. In the past, groups have employed the CDC Clear Communication Index to assess the clarity of water quality information, but they fail to address community-based factors that affect the effectiveness of these guidelines. The purpose of this study is to examine the communication channels surrounding water quality on a more local level, and evaluate common communication methods that have the most success. By surveying an environmental conservation group and interviewing local experts, I was able to determine how community interactions and involvement impact water quality communication and its effectiveness at the community level.

Introduction

To supplement our analysis on wastewater and surface water quality, this section of the report focuses on the communication between stakeholders in water quality and the effort to improve that dialogue. There are many stakeholders in water quality: landowners, homeowners, conservation activists, WWTP industry representatives, and the local government. Every drop from bottle to tap is regulated to some degree, just as drinking water is more regulated than recreational bodies of water. However, these regulations only dictate the acceptable level of pollutants; they do not require specific methods to communicate water treatment results. For example, the EPA requires that water quality results are publicly available in the form of Consumer Confidence Reports (CCR). This is mandated by the Safe Drinking Water Act of 1996 and the Right-to-Know Law of 1998 to protect public health ("Consumer Confidence Report Rule," 2020). However, if those water quality results are not readable and understandable to the common person, then that vital public information is inaccessible and therefore ineffective.

Water quality communication ties into risk communication when a water quality crisis threatens public health. For instance, the 2014 Elk River chemical spill caused over 300,000 Americans to lose access to clean water (Hoback, 2018). City officials and industry representatives struggled to contain the panic and articulate the problem to residents of West Virginia. The lack of general water quality knowledge among the public fueled the flame when officials tried to explain the situation (Hoback, 2018). That same year, residents of Flint, Michigan were faced with severe health issues stemming from the poor water quality after changing the source of their drinking water (Denchak, 2018). Crisis management and risk communication are critical in emergency situations, but the aftermath of these two examples points to another crucial component: better understanding of water quality information outside of times of crisis could have significantly reduced the fear and panic that ensued in these circumstances. For this reason, I am interested in examining the peace-time communication that occurs in annual water quality reports, how these reports are assessed, and any additional factors that impact their success.

There have been several laws passed to try to address this issue, but clear communication often takes a backseat to other compliance requirements. There have been several studies in literature that attempt to quantify the degree of success these Consumer Confidence reports exhibit, namely the Natural Resources Defense Council (NRDC) 2003 study and another 2016 assessment. However, none of these studies account for community factors that affect the audience interaction or understanding of water quality reports. Some local government organizations, such as the New Hampshire Department of Environmental Services (NHDES), recognize these factors and are shifting their focus to educating and engaging the public outside of these reports. This study aims to support that initiative by analyzing water quality reports using methods found in literature and interviewing community members to understand the audience's needs and interactions with these reports. The first step in doing so is reflecting on existing public communication guidelines and exploring the channels of water quality communication at the local level.

Background

CDC's Clear Communication Index

In an effort to promote "transparency, public participation, and collaboration," the Plain Writing Act of 2010 was signed as an executive order by Former President Obama ("Law and Requirements," 2011). Plain writing is defined as clear, concise, and well-organized. By avoiding jargon and ambiguity, communication becomes more accessible and improves public understanding ("Law and Requirements," 2011). As an extension of the Plain Writing Act, the Center for Disease Control and Prevention (CDC) created a Clear Communication Index highlighting techniques to write more clearly. The Index evaluates writing based on seven criteria, which Table 3 below describes in more detail. By focusing on these seven items, the CDC identifies "the most important communication characteristics that enhance clarity and aid understanding of public messages and materials" ("The CDC Clear Communication Index," 2020).

Table 3. Below are the seven categories and explanations given by the CDC to incorporate into all public communication materials ("The CDC Clear Communication Index," 2020).

Item	Definition
Main Message/Call to Action	State the main idea the audience needs to remember
Language	Use active voice and simple words to be more accurate and direct
Information Design	Use lists, headings, short sentences, and paragraphs
State of Science	State sources and acknowledge uncertainty
Behavioral Recommendations	State recommendations and their reasons
Numbers	Use numbers when necessary and explain them
Risk	State threat or harm, along with their factors, outcomes, and likelihoods

According to the 2016 article in the Journal of Water and Health, a group of trained professionals rated 30 CCR drinking water reports using the CDC Clear Communication Index (Phetxumphou, 2016). None of the reports exceeded the minimum passing score of 90%, with a mean score of 50 ± 14% (Phetxumphou, 2016). Respectively, the lowest and highest performing categories were the "State of the Science (3 ± 15%) and Behavioral Recommendations (77 ± 36%) indices" (Phetxumphou, 2016). These conclusions highlight the overall ineffectiveness of these reports, as well as the specific areas that need additional attention. More results revealed the reports were written for the 11th-14th grade level, which may be too complex for the target audience ("Readability Test Tool"). It is recommended that information about public health should be written at the 6th-7th grade level to provide understandable and accessible communication to all.

While the Clear Communication Index provides written guidance and best practices for each of the seven categories, its widget function only generates a numerical score to grade material in an objective way. This objectivity does not account for community factors. So, for this project, the Clear Communication guidelines were used as the basis for my assessment on water quality reports rather than the widget tool's automatic scoring. This allowed me to see the inner workings of these methods and how they evaluate water quality reports on the community level. To better understand the community factors that may affect these water quality reports, I investigated where stakeholders receive water quality information and how that information spreads.

Communication Channels

Observing the flow of water quality information to and from different stakeholders helps to understand how the audience interacts with the reports. Since water quality affects virtually everyone, the circulation of information happens in any direction– although the majority of the time it follows the top-down pattern shown in Figure 40. A top-down flow can stunt growth for water quality communication, as it makes it more difficult to implement community input.

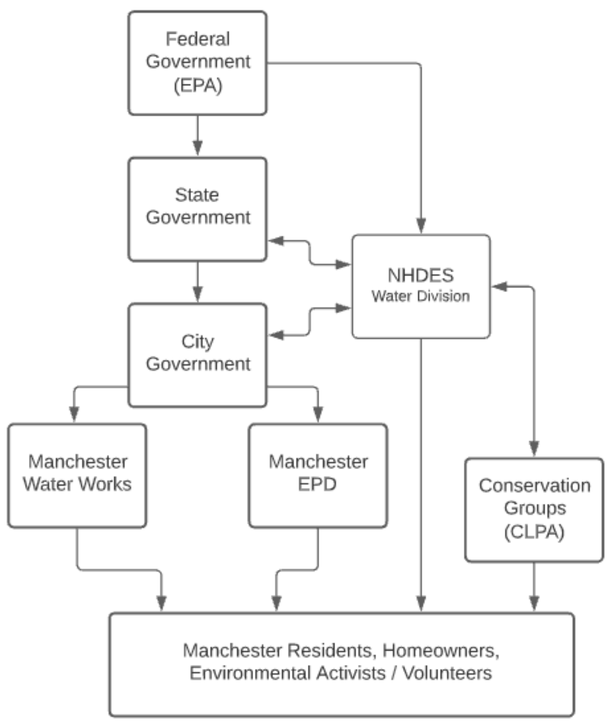


Figure 40. The flow and distribution of water quality information from highest authority (EPA) to lowest authority (city residents). New Hampshire's public water infrastructure makes for a straightforward example of how water quality information flows through different levels of government (Fortier, 2011). Private water systems include additional stakeholders that lead to more convoluted communication channels, since they are not always subject to the same regulations (Kopaskie, 2016). This figure shows just one example of the possible communication channels between stakeholders in water quality and is not meant to be representative of all states or communities.

The height of the stakeholder groups in Figure 40 generally expresses the level of authority of that group. For instance, the Environmental Protection Agency (EPA) holds authority over the state government, which in turn regulates smaller environmental organizations. These statewide organizations include the New Hampshire Department of Environmental Services (NHDES) and two departments of the City of Manchester: the Manchester Water Works, responsible for the drinking water; and the Environmental Protection Division (EPD) ("Water Works FAQ"). The NHDES works alongside city governments on environmental projects, but since it is a regional organization, it falls between state and city government in Figure 40. For this project, the focus is on the lower channels connecting residents to city departments and environmental groups.

As mentioned, through the Safe Drinking Water Act the EPA federally requires annual drinking water reports, often called CCRs or Right-to-Know reports. Homeowners receive these annual reports from the Manchester Water Works department by mail with their quarter-two billing every April ("Water Works FAQ"). Residents can also find Volunteer Lake Assessment Program (VLAP) reports on the Manchester EPD website. VLAP reports represent surface water in New Hampshire, similar to how CCRs report on drinking water. The main goals of VLAP reports include preserving the ecosystem and maintaining recreational activities, such as swimming, boating, or fishing. As volunteer programs, these reports are less regulated and allocated less resources, often relying on part-time employees or partnerships with conservation groups to prosper.

Conservation groups, such as the Crystal Lake Preservation Association (CLPA), contain members with varying levels of water quality expertise, interest, and involvement. These groups help bridge the gap between larger statewide organizations, like the NHDES, and the general public by connecting community stakeholders to experienced professionals. For example, the CLPA is comprised of people who live near Crystal Lake in Manchester, NH or visit regularly, uniting anyone who is interested in habitat conservation or willing to volunteer for the cause. The CLPA organizes beach cleanups and maintenance projects, in addition to providing "additional funding and in-kind services through volunteer monitoring activities" (McMillan, 2009). These monitoring activities include participating in the NHDES Volunteer Lake Assessment Program (VLAP) by collecting water quality samples from local lakes. The CLPA has members trained in this sample collection that regularly communicate with the NHDES VLAP Coordinator who analyzes all water quality samples. Because of this connection, the CLPA serves as a case study for small communities who are actively involved in local water quality communication. This increased participation in the circulation of water quality information allows for informed responses in interviews to come.

Focusing on New Hampshire, the NHDES, and the CLPA, this study explores the methods used to evaluate public health communication along with additional community factors that arise from interviews from water quality experts and volunteers. As CCRs report on drinking water quality pertinent to our health, VLAP reports relay important information about the environment's health. Therefore, it is critical to analyze both forms of communication in addition to drinking water reports to aid understanding of general water quality information.

Methodology

With science and technology changing every day, it can be difficult for people to keep up with the technical language used in public documents. This study aims to evaluate water quality reports using methods found in literature, while exploring community factors that determine the report's effectiveness. To achieve this goal, the following objectives guided my research:

1: Identify communication channels between different stakeholder groups.

2: Evaluate the language used in reports based on the Clear Communication Index.

3: Investigate current methods water quality experts use to communicate results to the public.

4: Explore community understanding and interaction of water quality reports.

To better understand how the communication channels surrounding water quality work, I researched publicly available water quality information for Manchester, NH to find the most readily available content. The annual Consumer Confidence Reports (CCR), also called the Right-to-Know reports, were examined to gain insight on the content and rhetorical moves the public encounter on a regular basis. They were then compared to the laws and regulations the Environmental Protection Agency (EPA) has in place for those water quality reports on a federal level. After studying the structure and content of governmental reports, it is important to understand who receives that information and how they interpret it. Surveying community members helped me gauge understanding and perception of water quality information, as well as how it spreads.

By surveying members of the Crystal Lake Preservation Association (CLPA), I was able to explore the exchanges between different water quality stakeholders in the local community. CLPA members' have increased participation in the exchange and interpretation of water quality information that circulates in the local community. This experience allows for informed responses to my questions in Appendix B. To analyze possible gaps in understanding and interpretation of technical information, a structured survey using Qualtrics was emailed to the CLPA member alias (see Appendix B). This was determined to be the best method to distribute information since it is the primary communication platform of the CLPA. The survey was voluntary, asking for the members' names, and permission to be named and/or quoted in my study at the end of the survey. If participants chose to remain anonymous in the study and/or unquoted, then their responses were only used to interpret trends in the acquired data. The participants also had the option to say whether or not I could follow up with additional questions based on their free responses. This allowed me to ask clarifying questions based on their experience that may improve the quality of the data received.

The survey includes questions such as where they receive water quality information, how clear they thought water quality information was in these reports, and how well they understood certain concepts. Where applicable, I provided examples to aid in clarity. From this data, I was able to determine how information circulates in a small community and how information is interpreted by people of varying levels of scientific knowledge. I was particularly interested in seeing if there were trends between the participants' time in the CLPA, their confidence in their understanding, and where they received water quality information. This may indicate sources with a more successful presentation of water quality information and possible use of best communication practices. These questions were followed by a write-in question asking, "Do you have any ideas about how to make technical information easier to understand?" Although write-in questions are less likely to get a response, I want to give the participants a chance to voice their thoughts given in-person interviews were not possible due to the ongoing COVID-19 pandemic. This form allowed me to reach the largest number of people in the safest manner. The data from these surveys was stored using Qualtrics and deleted at the end of the project, May 2021.

Next, I reached out to three people with varying involvement in water quality reporting to gain insight into their experiences with the whole water quality testing process. These three interviewees were the CLPA Water quality Monitor, a NHDES Compliance Specialist, and the NHDES VLAP Coordinator. These people have an increased scientific or technical background, making their insight valuable for my research.

The CLPA member who volunteers for the Manchester Urban Ponds Restoration Program is trained as a Water Quality Monitor. This person works with the NHDES VLAP Coordinator to collect water samples from Crystal Lake and present water quality results at annual CLPA meetings. As both a Manchester Conservation Commission and CLPA member, this person has the experience to address the knowledge gap of residents during meetings. In my initial email, I stated my project purpose and asked to have a 20 minute or so phone interview. At the start of the semi-structured phone call, I introduced myself and my project purpose again, as well as reminded the interviewee this is voluntary, and I was going to take notes of responses. I asked questions about the possible techniques or procedures they follow to communicate clear and precise information to people who may not be familiar with scientific language (see Appendix A). Since this person is not bound to the same requirements as a city official, answers to these questions helped me better understand simple and effective communication techniques that can work for anybody. From this interview, I was also able to gather important information on public speaking about water quality, as well as gain two additional contacts that are heavily involved in the Volunteer Lake Assessment Program and VLAP reports.

I reached out to these two NHDES personnel by email, stating my project purpose and inviting them to interview with me. I also included a semi-structured questionnaire to these individuals as an alternative means of interviewing (see Appendix A). This method gave the interviewee the flexibility of responding on their own time, as well as writing out informed responses to my questions. If clarification was needed, I was able to follow-up by email. This questionnaire included information about the public nature of my study as well as opt-out options if they wished. At the end of the questionnaire, I also asked for permission to use this person's name and quotes in my study. The questions I was most interested in included what kinds of interpretations, determinations, or recommendations they make based on the water quality testing results, and what methods they use to clearly communicate these results. As I saw in my research, CCR reports and VLAP reports are the two primary communication documents published for the public. Answers to these questions helped me better understand how misinterpretations between experts and the public can occur, and what actions the NHDES is taking to educate the public. The communication techniques discussed were compared to guides found in literature based on public communication.

The following methods allowed me to assess annual CCR and VLAP reports to observe the communication over the years. Two prominent studies I found in literature were the NRDC's "What's on Tap" analysis on the 2001 Manchester, NH CCR report and the nationwide CCR evaluation performed in 2015. To assess the reports, I used a combination of methods given in these studies. The article titled "Assessing clarity of message communication for mandated USEPA drinking water quality reports" (Phetxumphou, 2016) used the CDC's Clear Communication Index to evaluate the clarity of the reports, whereas the NRDC evaluated claims mostly based on EPA compliance. I also utilized the CDC's Everyday Words for Public Health guidelines to assess the complexity of the language used and offer simpler alternative suggestions ("The CDC Clear Communication Index," 2020). I took notice every time the reports utilized the following best practices:

- State the main idea for the audience
- Use active voice and simple words, avoid using jargon and acronyms
- Use lists, headings, short sentences and paragraphs
- State sources and acknowledge uncertainty
- State recommendations and reasonings
- Use numbers and explain their significance
- State threats and health effects
- Avoid false, misleading, unqualified, or buried claims

By utilizing the CDC's Clear Communication Index with the feedback from the CLPA, I hope to highlight areas of success or areas where the guidelines fall short. I specifically analyzed the Manchester Water Works 2010 and 2019 Right-to-Know reports, as well as the Crystal Lake VLAP reports for the years 2010, 2012, and 2019 to show the evolution of these different water quality reports.

Results

2010 Right-to-Know Report Meets Criteria

While analyzing the Manchester Water Works 2010 and 2019 CCR reports, I observed several positive attributes that align with the CDC's Clear Communication guidelines. The 2010 report is seven pages long and utilizes chunked paragraphs with descriptive headings to allow the reader to skim and pick out important information. The information design of this report would fare very well in the corresponding category of the Clear Communication guidelines.

This report also provided explanation or context clues for complex words, such as describing immunocompromised in the example, "immunocompromised persons such as persons with cancer undergoing chemotherapy, persons who have undergone organ transplants, people with HIV/AIDS or other immune system disorders, some elderly, and infants" on page two of the report which can be found in Appendix G ("Water Quality Report").

As for the State of Science category, this report states that it is expected to have some quantity of contaminants in drinking water, and only at certain concentrations are certain contaminants harmful. This is stated on the second page right under the header "Substances That Could Be in Water," a very descriptive header given the content. In an interview with Sara Steiner the VLAP Coordinator at the NHDES, when asked what the most confusing water quality concept is she responded with the following statement:

> "It's hard to understand that there may always be some bacteria present and a result greater than zero is normal. People tend to think if there's bacteria present the water quality is bad or a septic system is failing. Getting them over that hump of it's okay to have bacteria…can be hard."

Recall the State of Science guideline states public health communication must convey any uncertainty in the data. For this case, the uncertainty is that water realistically cannot be pure, and this claim is unattainable. Although this statement may seem obvious, this concept became problematic in the 2014 Elk River chemical spill, when the public voiced concerns that a harmful chemical called MCHM continued to exist in the water even after officials declared the water was safe to drink.

As for other technical information, the report breaks down the treatment process into sections, which helps readability. There are definitions that explain jargon or acronyms on the last page, which is helpful to the reader. Improvements have been made since the 2003 NRDC study that concluded the "EPA rules require the reports to reveal known sources of pollutants in city water, such as factories or Superfund sites. None of the 19 cities surveyed named specific polluters in the right-to-know reports." (Olson, 2003). The 2003 Manchester, NH report was included in this finding. However, in the 2010 report does state some sources as seen in the statement, "Concern was raised over the detection of MTBE, now prohibited, which came from reformulated gasoline" ("Water Quality Report"). When asked what techniques she uses to water quality concepts, Steiner emphasized "explaining the sources, where does it come from and understanding how it gets into the water" (Steiner, 2021) Giving people that context is important to their understanding of common pollutants.

Improvements Made in 2019 Right-to-Know Report

From 2010 to 2019, there were several improvements made to the reports which can be accessed in Appendix G. In the 2010 report, there was a section titled "Substances That Could Be in Water" that listed the contaminants and their descriptions in the one long sentence below:

> Substances that may be present in source water include: Microbial Contaminants, such as viruses and bacteria, which may come from sewage treatment plants, septic systems, agricultural livestock operations, or wildlife; Inorganic Contaminants, such as salts and metals, which can be naturally occurring or may result from urban stormwater runoff, industrial or domestic wastewater discharges, oil and gas production, mining, or farming; Pesticides and Herbicides, which may come from a variety of sources, such as agriculture, urban stormwater runoff, and residential uses; Organic Chemical Contaminants, including synthetic and volatile organic chemicals, which are by-products of industrial processes and petroleum production and may also come from gas stations, urban stormwater runoff, and septic systems; Radioactive Contaminants, which can be naturally occurring or may be the result of oil and gas production and mining activities.

The use of semicolons is not effective from the perspective of the Clear Communication guidelines and important information should be put into a bulleted list whenever possible to make it more visually appealing and improve scannability. The Clear Communication guidelines state, "use lists to break up text in the body of the material and make information easier to scan and read." ("The CDC Clear Communication Index," 2020). Interestingly, in the 2019 report the format for this section was changed to chunked paragraphs with descriptions for each contaminant. Another improvement made in 2019 regarding this section was moving it from page three to page two, following the guidelines by prioritizing important information. Generally, the 2019 report utilized more lists of action items and smaller chunked paragraphs highlighting future treatment facilities. Other improvements included outlining important sections, for example, the section on important health information is now outlined in a bright color to draw the eye.

For content additions, the 2019 report expanded on the testing results paragraph to explicitly say the water quality meets all state and federal requirements. An important claim and main message the audience is looking for. The 2003 NRDC study found many reports left out this statement about passing all water quality standards and tests (Olson, 2003). In the same place, the 2019 report also added a reminder saying, "detecting a substance does not mean the water is unsafe to drink; our goal is to keep all detects below their respective maximum allowed levels." ("Water Quality Report"). This was stated once in the 2010 report, and in 2019 it is stated once in the beginning and again on the same page as the results table. As mentioned previously, Steiner explained how not all chemicals are harmful and "it's important to state that it's a natural occurrence and it's only when numbers get above a certain level that we should be concerned." (Steiner, 2021). The NRDC study concluded that the State of Science category was the least effective category executed in reports nationwide. So, this concept of nonzero contaminants may increase the reader's trust and understanding, which may reduce future panic if a water crisis were to occur.

Another helpful content addition in the 2019 report was adding a section that explains how to analyze the results table on the next page. This helps the test results table seem less intimidating and more approachable to a reader. This report also incorporated the definitions of acronyms and jargon on the same page as the data table itself. With this change, at least the reader can see definitions on the same page rather than scroll or flip to the next like in the 2010 report. This saves the reader time and improves the readability of the table. Overall, the 2019 CCR report showed several improvements after the Plain Writing Act of 2010 and the publication of the CDC's Clear Communication Index.

Evolution of VLAP Reports

The purpose of Volunteer Lake Assessment Program reports is slightly different than the aforementioned CCR reports and knowing this is crucial to analyzing these reports. First, these reports address lake or river water quality as opposed to drinking water, so they are much less regulated. Surface water poses less health risks than drinking water, since it serves recreational purposes only. These reports are created for all lakes or rivers in New Hampshire, but this project focuses on Crystal Lake in Manchester and its conservation group the CLPA. This changes the target audience for these reports. Rather than all residents, these reports cater to those who live near lakes or rivers since they have more stake in that water quality. The audience for VLAP reports generally have more water quality knowledge or expertise than other residents, because of their proximity and desire to maintain or improve the environment. For example, VLAP Coordinator Sara Steiner says, "with the VLAP reports, I put a certain level of expectation on the volunteers to understand the information being presented, which I think is part of their responsibility as a participant" (Steiner, 2021).

However, specifically for the CLPA, members vary in their involvement with the Volunteer Lake Assessment Program. For instance, Todd Connors is the Crystal Lake VLAP monitor who collects samples for the water quality tests and presents the results from the VLAP report annually. In a survey sent to CLPA members, when asked where they receive most of their water quality information, only two people mentioned the VLAP reports directly. Most of these people rely on CLPA meetings and the annual presentation of the VLAP report, rather than reading the report itself. Steiner came to the same conclusion in 2011 when revising the VLAP report template:

> "[Previous] reports were greater than 40 pages in length. In speaking with volunteers during their annual visit, I found that program participants were not reading the entire reports because they were simply too long, so they weren't aware of potential water quality changes that were occurring. I wanted to provide something that was less bulky and that provided the same amount of information."

A group of NHDES personnel and VLAP volunteers workshopped the new template to develop a report that included all the necessary content presented in an attractive two-page format. When inviting volunteers from different lakes Steiner recalls, "their input was the most crucial in the process as they were the audience" (Steiner, 2021). After months of iterations, the VLAP report template was finalized.

The old 2010 VLAP report was fifteen pages total, consisting of pages of text until the last two pages which displayed corresponding tables and figures as seen in Appendix G. The overall organization was difficult to follow since the graphics were not displayed with the corresponding text, and the limited use of descriptive headings with short paragraphs made it difficult to scan.

Using the new template, the 2012 VLAP report consists of a first page with water quality parameter status and watershed land usage information, and a second page containing the observations and recommendations section, as well as a historical trends section. There were a few instances where the report uses complex words that may impede understanding, as explained in the Plain Writing Act. Still, the use of bullets, bolded headers, and sectioned content throughout the report align with the Clear Communication guidelines.

For the 2019 VLAP report, there were several small improvements made to the word choice to improve clarity according to the Plain Writing Act. For example, in the data table on the first page, the 2012 report contained greater than or lesser than symbols to describe the water samples in more detail. A comparison of this can be seen in Figure 41 and 42. Although spelling out the words increases the length of the comments in limited space, it allows for quicker scanning and comprehension of the material.

Parameter	Category	Comments
Phosphorus (Total)	Cautionary	<5 samples and median is > threshold. More data needed.
pH	Good	At least 10 samples with 1 sample but < 10% of samples exceeding
D.O. (mg/L)	Slightly Bad	>10% of samples exceed criteria by a small margin (minimum of 2 exc
D.O. (% sat)	Slightly Bad	>10% of samples exceed criteria by a small margin (minimum of 2 ex
Chlorophyll-a	Good	>/=5 samples and median is < threshold but > 1/2 threshold value
E. coli	Encouraging	>2 samples exist that are > 75% of geometric mean criteria, but not single sample exceedances. More data needed.
Chlorophyll-a	Good	At least 10 samples with 1 sample but < 10% of samples exceedin

Figure 41. The 2012 VLAP report comment section utilized greater than or less than symbols to describe the samples.

Parameter	Category	Comments
Phosphorus (Total)	Cautionary	Limited data for this parameter predicts exceedance of water quality necessary to fully assess the parameter.
pH	Good	Sampling data commonly meet water quality standards or threshold
Oxygen, Dissolved	Very Good	All sampling data meet water quality standards or thresholds for th
Dissolved oxygen satura	Slightly Bad	Data periodically exceed water quality standards or thresholds fo
Chlorophyll-a	Good	Sampling data is better than the water quality standards or thresh
Escherichia coli	No Data	No data for this parameter.
Chlorophyll-a	Very Good	All sampling data meet water quality standards or thresholds for this pa

Figure 42. The 2019 VLAP report revised the comment section to read more clearly without symbols. The entire VLAP reports can be found in Appendix G.

Additionally, notice the parameter section in the 2012 and 2019 reports changing from D.O. (mg/L) to Oxygen, Dissolved.

Another improvement in the 2019 report, is breaking up the Observations and Recommendations section into two sections with descriptive headers. The 2012 report buried the call to action by including the recommendations bullet under all of the observations. According to the Clear Communication guidelines the Main Message and Call to Action should be prioritized at the top of the page. By breaking the section up, it is clearly communicating the purpose. Overall, the VLAP reports in recent years also pass the Clear Communication Index evaluation by following the best practices for public health communication.

Community Factors at Play

According to the last CCR assessment in 2015, none of the 20 Right-to-Know reports across the country passed the Clear Communication Index at a 90% rating. However, when assessing these reports using the best practices given by the CDC, a passing grade seemed reasonable given the justifications above. This leads to the question, do these methods truly measure the effectiveness of water quality reports? Or, rather, are there other factors that influence the effectiveness of water quality communication?

For example, by surveying the members of the CLPA it was discovered that the majority of CLPA members rely on annual presentations of the VLAP results rather than reading the report. This community-based communication channel has a larger impact on residents than a yearly report. As NHDES Compliance Specialist Jen Drociak said, when there is "a personal connection to water bodies, it becomes more important to try to protect these water bodies from despoliation" (Drociak, 2021). Similarly, when that personal connection is tied to a community, that becomes a powerful avenue for communication.

This discovery shows the wider reach of VLAP presentations compared to the report and how verbal communication may have a larger role in community dialogue, which may influence the form of future communications by prioritizing presentations or other forms of media. This highlights a new need for analyzing the effectiveness of reports as a form of communication as a whole, rather than the effectiveness of communication within these reports. By including the CLPA in my analysis, this study goes beyond literature methods assessing the internal communication, and points to other considerations when assessing effectiveness.

Prioritizing personal connection and community ties may also make it easier to create audience-focused water quality reports. In Drociak's experience, questions and concerns vary greatly with who the "customer" is. She mentioned how fishermen, day-trippers, recreationalists, and homebuyers all could be concerned with vastly different aspects of water quality (Drociak, 2021). It is difficult to target the interests of all stakeholder groups in one concise report.

When I asked Todd Connors about how he prepares for annual CLPA presentations, he said would reflect on historical trends, summarize the main results of the report, and offer behavioral recommendations before quickly transitioning to the questions and answer portion of the presentation (Connors, 2021). He said it is easier to communicate more effectively when an audience member asks a question with a certain level of detail, he can match that level of detail in his response (Connors, 2021). For instance, giving too much detail in the initial presentation may lose some of the audience members with less water quality expertise, but this open dialogue allows audiences with greater knowledge to ask more specific questions. In other words, when the reader or audience asks questions or begins the conversation, the message can be tailored to them. This is nearly impossible to do in an annual report.

With a single report recapping a whole year, there is a risk of overwhelming the reader with too much information or presenting too little information for those with more water quality knowledge. To try to combat this, Steiner felt it was imperative to include volunteers' opinions when the new VLAP template was created in 2011 since they were the main audience (Steiner, 2021). The more connected the water quality information is to the audience, the more it will resonate with them.

By surveying the CLPA, I have learned that even an effective report has limitations. The VLAP reports have come a long way in meeting the standard set by the Clear Communication Index for public health communication, yet, according to the survey 90% of people may not be reading them. This indicates there may not even be a communication problem at all, and the problem may lie with engagement. Effective communication in reports play a smaller role when engagement is an obstacle, and the NHDES is starting to realize that. In the interview, Drociak discussed actions the NHDES is taking to improve water quality understanding in New Hampshire residents saying, “we’ve started to shift our focus slightly to educating the public on stormwater runoff, stormwater pollutants, and their effect on water quality” (Drociak, 2021).

There are expectations for communicating water quality, but very few sources that provide that guidance or give a basis for assessment. By investigating the community interaction with the water quality reports, we can understand the full scope of the report’s effectiveness. For the CLPA, the VLAP report serves as the foundation for an annual presentation on Crystal Lake’s water quality. Because the CLPA has members of varying levels of water quality knowledge, presentations may be the best form of communication so the speaker can build upon the information as necessary. Since the building of details and personal connection is challenging for these static water quality reports, it emphasizes the need for a supplementary form of communication to create a more wholistic approach to communication.

By improving water quality understanding, preventative measures are being taken to reduce possible fear and confusion when a water crisis occurs. Given the history of chemical spills and drinking water pollution in the United States, exploring factors that improve water quality communication and understanding is crucial to the health and safety of our country. The CDC’s Clear Communication Index, following the Plain Writing Act, promotes effective public health communication by providing best practices and an assessment tool, but does not go much beyond that. Knowing there is more to this communication than the annual water quality reports is the first step towards improving that dialogue. It is important for professionals to continuously improve these methods of communication through community involvement to be better equipped for water crises in the future.

References

“The CDC Clear Communication Index.” *Centers for Disease Control and Prevention*, Centers for Disease Control and Prevention, 6 Aug. 2020, www.cdc.gov/ccindex/index.html#.

“Consumer Confidence Report Rule and Rule History for Water Systems.” *EPA*, Environmental Protection Agency, 14 Sept. 2020, www.epa.gov/ccr/consumer-confidence-report-rule-and-rule-history-water-systems.

Denchak, Melissa. “Flint Water Crisis: Everything You Need to Know.” *NRDC*, Natural Resources Defense Council, 8 Nov. 2018, www.nrdc.org/stories/flint-water-crisis-everything-you-need-know.

Fortier, Timothy W. “New Hampshire's Water Assets Under Pressure: Public Drinking Water Systems.” *New Hampshire Municipal Association*, Oct. 2011, www.nhmunicipal.org/town-city-article/new-hampshire%E2%80%99s-water-assets-under-pressure-public-drinking-water-systems.

Hoback, Cullen. “What Lies Upstream.” *PBS*, Public Broadcasting Service, 16 Apr. 2018, www.pbs.org/independentlens/films/what-lies-upstream/.

Kopaskie, Andrea. “Public vs Private: A National Overview of Water Systems.” *Environmental Finance Blog*, UNC Chapel Hill, 19 Oct. 2016, efc.web.unc.edu/2016/10/19/public-vs-private-a-national-overview-of-water-systems/#:~:text=Public%20water%20systems%20are%20usually,managed%20by%20investors%20or%20shareholders.

“Law and Requirements.” *Plainlanguage.gov*, United States Government, Mar. 2011, www.plainlanguage.gov/law/.

McMillan, Barbara. “Nonpoint Source Program Success Story.” *City of Manchester, NH*, Sept. 2009.

Olson, Erik D. “What's On Tap?: Grading Drinking Water in U.S. Cities.” *NRDC*, 11 June 2003, www.nrdc.org/resources/whats-tap-grading-drinking-water-us-cities#:~:text=The%20report%20issues%20grades%20to,the%20nation's%20drinking%20water%20supply.

“Readability Test Tool.” *WebFX*, www.webfx.com/tools/read-able/flesch-kincaid.html.

“Safe Drinking Water Act: Consumer Confidence Reports (CCR).” *EPA*, Environmental Protection Agency, 25 Sept. 2020, www.epa.gov/ccr.

"Water Quality Data." *City of Manchester NH Official Web Site*, www.manchesternh.gov/Departments/Environmental-Protection/Pond-Restoration/Water-Quality-Data.

"Water Quality Report." *City of Manchester NH Official Web Site*, www.manchesternh.gov/Departments/Water-Works/Water-Quality-Report.

"Water Works FAQ." *City of Manchester NH Official Web Site*, www.manchesternh.gov/Departments/Water-Works/Water-Works-FAQ.

"Where Can I Find Information about My Local Drinking Water Supply?" *USGS Science for a Changing World*, www.usgs.gov/faqs/where-can-i-find-information-about-my-local-drinking-water-supply?qt-news_science_products=0#qt-news_science_products.

Appendix F: Water Quality Questionnaires

Compliance Specialist, New Hampshire Department of Environmental Services (NHDES)

I am a student from Worcester Polytechnic Institute working on a project to analyze the communication between stakeholders in water quality. This interview is voluntary, and this study will be publicly available on the WPI Library's website. Your responses will help me determine different methods of communication and best practices for relaying water quality information.

1. **Can you tell me about some of your roles and duties involving water quality?**

2. **What are some of your biggest concerns with water quality (for example, E.coli, phosphorus, chloride contamination)?**

3. **What do you think the general public is most concerned with?**

4. **Do water quality testing results require a lot of interpretation? If so, then how do you interpret results— are there procedures you follow?**

5. **What kind of conclusions, determinations, or recommendations do you make based on the testing results?**

6. **In what ways do you communicate results to the public? (such as Right-to-Know reports or VLAP reports)**

7. **What requirements or guidelines are there for reports? (such as EPA guidelines, state requirements, or CDC clear communication index)**

8. **Are there any communication methods or best practices you use when communicating information? (for example, limited use of jargon, plain words, or color coding)**

9. **Do you think improving the communication and understanding surrounding water quality may positively impact the community? What kind of effects would it have?**

10. **May I use your name and/or direct quotes from you in my project?**

Thank you for your time, your responses are appreciated!

VLAP Coordinator, NHDES

I am a student from Worcester Polytechnic Institute working on a project to analyze the communication between stakeholders in water quality. This interview is voluntary, and this study will be publicly available on the WPI Library's website. Your responses will help me determine different methods of communication and best practices for relaying water quality information.

1. **What are some of your roles and duties involving water quality?**

2. **What do you think are the most confusing water quality concepts for the general public?** (Such as phosphorus or E. coli contamination, turbidity, alkalinity, conductivity)

3. **Are there any specific techniques you use to help people understand those concepts? If so, can you give me an example?** (For example, making comparisons, making the information relatable, using examples, explaining the cause and effect of certain actions)

4. **As VLAP Coordinator, can you explain a little bit about how you analyze the water quality samples and create VLAP reports?**

5. **Do you follow any set of guidelines when creating or publishing water quality reports?** (Such as EPA guidelines, NHDES requirements, or refer to the CDC clear communication index)

7. **I noticed around 2011 there was a shift in the structure of VLAP reports, and now the same template is followed year to year for most lakes in New Hampshire. Do you know of any discussion of that change, or could you speak to that at all?**

8. **Are there any communication methods or best practices you use when communicating technical information?** (For example, limited use of jargon, plain words, color coding, tabulating data, using examples or definitions)

9. **Do you think improving the communication and understanding surrounding water quality may positively impact the community? What kind of effects would it have?**

10. **May I use your name and/or direct quotes from you in my project?**

Thank you for your time, your responses are appreciated!

CLPA Water Quality Monitor

I am a student from Worcester Polytechnic Institute working on a project to analyze the communication between stakeholders in water quality. This interview is voluntary, and this study will be publicly available on the WPI Library's website. Your responses will help me determine different methods of communication and best practices for relaying water quality information.

1. **What are some of your responsibilities as a water quality volunteer/monitor for the CLPA?**

2. **Do you analyze the water quality testing results at all or create the VLAP reports? If so, are there procedures or guidelines you follow?**

3. **What do you think are the most confusing water quality concepts for the general public?** (Such as phosphorus or E. coli contamination, turbidity, alkalinity, conductivity, epilimnion, metalimnion, or hypolimnion)

4. **How do you prepare for CLPA presentations?**

5. **How do you explain these water quality concepts to people? Are there any specific techniques you use to help people understand them?** (Such as using examples, comparisons, explaining cause/effect)

6. **Do you think color coding tabulated data is intimidating or helpful for visual people?**

7. **I noticed since 2011 there has been a shift in the structure of the reports, which now follow the same template from year to year. Do you know of any discussion of that change, or could you speak to that at all?**

8. **What are some communication methods you have either used or think are key to successfully communicating water quality information to people, or scientific/technical information in general?**

9. **May I use your name and/or direct quotes from you in my project?**

Thank you for your time, your responses are appreciated!

Appendix G: Water Quality Reports

Right-to-Know Reports

The archive of PDF electronic copies of the CCR can be found on the official Manchester, NH website ("Water Quality Report").

The 2010 CCR can be accessed here.

The 2019 CCR can be accessed here.

VLAP Reports

The archive of PDF electronic copies of the VLAP reports can be found on the official Manchester, NH website ("Water Quality Data").

The 2010 VLAP report can be accessed here.

The 2012 VLAP report can be accessed here.

The 2019 VLAP report can be accessed here.

Appendix H: CLPA Member Questionnaire

Hello! I am a student from Worcester Polytechnic Institute working on a project to analyze the communication between stakeholders in water quality. Your responses will help me determine different methods of communication and best practices for relaying water quality information. This survey is voluntary, all the questions below are optional, and this study will be publicly available on the WPI Library website. Thank you for taking the time to complete this survey.

Are you a member of the Crystal Lake Preservation Association?

- Yes
- No

If yes, how many years have you been a member of the CLPA?

What influenced you to join the CLPA?

How interesting is water quality information to you?

- Extremely interesting
- Very interesting
- Moderately interesting
- Slightly interesting
- Not interesting at all

Where do you receive most of your water quality information?

- ☐ Annual Water Quality Reports (Manchester Water Works)
- ☐ Volunteer Lake Assessment Program (VLAP) Reports
- ☐ CLPA Meetings
- ☐ Other ____________

If applicable, how clear do you think water quality reports are on a scale of 1-10?

Not clear, 1	2	3	4	5	6	7	8	9	Extremely clear, 10
○	○	○	○	○	○	○	○	○	○

If applicable, how closely do you read water quality reports on a scale of 1-10?

Not closely, 1	2	3	4	5	6	7	8	9	Extremely closely, 10
○	○	○	○	○	○	○	○	○	○

How well do you understand the causes and effects pollutants have on water quality? For example, phosphorus, chloride, or E.coli bacteria.

- ○ Extremely well
- ○ Very well
- ○ Moderately well
- ○ Slightly well
- ○ Not well at all

How well do you understand water quality parameters, such as alkalinity, conductivity, hardness, turbidity?

- ○ Extremely well
- ○ Very well
- ○ Moderately well
- ○ Slightly well
- ○ Not well at all

Do you have any ideas about how to make technical information easier to understand, such as color coding results, giving more definitions or examples?

What is your name? If you prefer not to say, you can leave this question blank.

This study will be publicly available on the WPI Library website. Do you give me permission to use your name and/or quote your responses when discussing the results of this survey?

- Yes, I give my permission for both my name and responses to be quoted
- I give my permission to be quoted anonymously
- No, I prefer to stay totally anonymous

Would you allow me to follow up if I have any additional questions?

- Yes
- No

Thank you for your time, your answers and feedback are appreciated!

→