Worcester Polytechnic Institute

Stormwater Management & Design in Framingham, Massachusetts

A Major Qualifying Project

Submitted to the Faculty of

Worcester Polytechnic Institute

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Abstract

Lake Waushakum in Framingham Massachusetts is polluted by various contaminants, including phosphorus, and fecal coliform bacteria. The goal of this project was to determine different stormwater Best Management Practices (BMPs), which help the city to reduce the amount of pollutants entering the lake from Anna Murphy Park, a local park adjacent to Lake Waushakum. Feasible BMPs were analyzed through literature review, wet weather sampling, laboratory testing, schematic design development, map analysis through ArcGIS, hydraulic analysis through HydroCAD, and a decision matrix table.

Capstone Design Statement

Worcester Polytechnic Institute's Civil and Environmental Engineering Department requires that all Major Qualifying Projects contain a capstone design component. Our MQP met the capstone design requirement by designing Best Management Practices (BMPs) to address water quality issues for Catchment Area 2368 entering Lake Waushakum in Framingham, Massachusetts. The design process included water quality sampling, evaluation of topography and land demographics, selection of a BMP, and determination of specifications of the BMP. The design considered the following economic, environmental, sustainability, constructability, ethical, health and safety, and social and political considerations:

Economic: The proposed BMP will be cost-effective for the City of Framingham. The team analyzed all installation and maintenance costs and the BMP can be implemented as needed per the city.

Environmental: This project developed a BMP that improves the stormwater quality entering Waushakum Pond from Outfall 2000203.

Sustainability: The BMP design is sustainable for the site location and improves removal efficiency while staying affordable.

Constructability: The BMP is designed to ensure ease of installation, operation, and maintenance.

Ethical: This BMP complies with the ASCE code of ethics and improves the water quality of Lake Waushakum, which improves environmental justice in the neighborhood and community.

Health and Safety: The proposed BMP design helps limit pollutants entering Lake Waushakum. Once Lake conditions improve, it can be open for the public to use again safely.

Social and Political: The Massachusetts DEP has implemented various rules and regulations for stormwater pollution prevention entering bodies of water. The City of Framingham would like to implement stormwater BMPs around Lake Waushakum to help mitigate stormwater pollution while staying compliant with all DEP regulations.

Professional Licensure

Professional licensure is given by the National Council of Examiners for Engineering and Surveying (NCEES). It is important that an engineer be given a license at the state level by a professional licensing board, because a license establishes a minimum standard of competency. This ensures the protection of the health, safety, and welfare of the public (NCEES, 2021).

To obtain a professional license, there are some criteria that need to be met. First, the prospective professional engineer must have a bachelor's degree from an EAC/ABET-accredited program. The engineer must also have taken and passed the Fundamentals of Engineering (FE) Exam. Next, the prospective professional engineer must have at least 4 years of processive, acceptable, and verifiable work experience (NCEES, 2021). This time requirement may vary by state. Then, the prospective professional engineer will need to pass the Principles and Practice of Engineering (PE) exam to obtain a professional licensure.

A professional licensure is important to a profession because having a license ensures a commitment to providing high quality engineering services in order to improve the lives of the public. It is important to have a license as an individual because it shows your credibility to other companies and peers. Finally, it is important to have a professional licensure to the public because the licensure shows that the public's health, safety, and well-being is always in consideration when developing engineering projects.

Table of Contents

List of Acronyms

BMP - Best Management Practice

BOD - Biochemical Oxygen Demand

CAD - Computer Aided Design

DI - Deionized

DO - Dissolved Oxygen

EPA - Environmental Protection Agency

GIS - Geographical Information System

ICS - Ion Chromatography System

MassDEP - Massachusetts Department of Environmental Protection

MQP - Major Qualifying Project

NPDES - National Pollutant Discharge Elimination System

TMDL - Total Maximum Daily Load

TS - Total Solids

TSS - Total Suspended Solids

WPI - Worcester Polytechnic Institute

Authorship Page

Each member of the team participated in the editing of each section through individual and collaborative editing efforts.

Report Section	**Primary Author (s)**
Abstract	Kali Sander
Capstone Design Statement	Evan Rios & Caitlin Strzegowski
Professional Licensure	Adele Brochu
Acknowledgement	Kali Sander
Executive Summary	Adele Brochu & Kali Sander
1.0 Introduction	Caitlin Strzegowski
2.0 Background	Kali Sander
2.1 Lake Waushakum	Caitlin Strzegowski
2.2 Relevant Stormwater Regulations and Grants	Kali Sander
2.3 Pollution Issues	Evan Rios
2.4 Sampling and Lab Testing	Kali Sander
2.5 Best Management Practices	Adele Brochu
2.6 City Recommended Best Management Practices	Adele Brochu
3.0 Methods	Caitlin Strzegowski

3.1 Catchment Area Characterization	Caitlin Strzegowski
3.1.1 ArcGIS	Caitlin Strzegowski
3.1.2 HydroCAD	Caitlin Strzegowski
3.2 Sampling	Adele Brochu
3.3 Lab Testing	Kali Sander
3.4 Development of BMP Alternatives	Evan Rios
4.0 Results	Kali Sander
4.1 ArcGIS Characterization	Caitlin Strzegowski
4.2 HydroCAD Analysis	Caitlin Strzegowski
4.3 Laboratory and Sampling Testing	Kali Sander
4.4 Treatment Area Analysis	Kali Sander
4.4.1 Treatment Area 1	Kali Sander
4.4.2 Treatment Area 2	Kali Sander
4.4.3 Treatment Area 3	Kali Sander
4.4.4 Treatment Area 4	Kali Sander
4.5 BMP Analysis	Evan Rios
4.5.1 Possible BMPs	Evan Rios

4.5.2 Feasible BMPs	Evan Rios
4.6 Hydraulic Analysis	Evan Rios & Caitlin Strzegowski
5.0 Recommendations	Evan Rios
5.1 Proposed Tree Boxes	Caitlin Strzegowski
5.2 Proposed Rain Garden	Evan Rios & Kali Sander
5.3 Proposed Under-Road Treatment System	Adele Brochu
5.4 Implementation and Construction Plans	Kali Sander
6.0 Conclusion	Adele Brochu
Appendices	All

List of Tables

List of Figures

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Secondly, our team would like to thank Don Pellegrino and Professor Jeanine Dudle, for all of their help teaching us the testing procedures and assisting in analyzing our samples.

Our team also would like to thank Worcester Polytechnic Institutes Civil and Environmental Engineering (CEE) Department. Without the help of all of the professors and staff, we would not have been able to gain the knowledge and resources needed to complete this project.

Finally, our team would like to thank Alison Eliot of The City Framingham MA, as well as Weston & Sampson Engineers and their representatives: Caroline Passalacqua, Jaurice Schwartz, and Thea Reymann. Without Alison and the Weston & Sampson team, this project would not have been possible. Under the guidance of Alison, the team was able to receive supportive and reasonable feedback allowing us to learn a large amount from the project and experience.

Executive Summary

Controlling stormwater runoff has been a pressing issue in the United States since 1948 when the Clean Water Act was enacted. Runoff carries contaminants and bacteria into surrounding bodies of water, which affect aquatic life and public use. To help limit these pollutants, stormwater Best Management Practices (BMPs) were developed. A BMP is a design or practice that will improve the quality of the water and limit the quantity of pollutants that enter surrounding waterways.

The City of Framingham, Massachusetts has had issues with pollutants entering Lake Waushakum, a body of water that lies on the border of both Ashland and Framingham. For the past few years, local beaches have been shut down due to high E.coli levels. It was also determined through testing performed by Weston & Sampson, that there are high levels of phosphorus in the lake. To help maintain compliance with their MS4 permit and to improve the water quality of Lake Waushakum, the City received funding from the 319 Grant to make improvements to their stormwater management practices. The City has been working with Weston & Sampson, a local engineering firm, to improve the areas along the local beach and develop a phosphorus identification report, from which the team determined the best catchment area to focus on for this MQP. The team decided that the best area to focus on would be Catchment Area 2368, which is located in the north central region around Lake Waushakum. This catchment area is composed of a local park and residential properties. The catchment area was ideal for implementing BMPs because the City has the right-of-way over the area which would reduce potential issues with gaining access to private properties.

After determining that Catchment Area 2368 would be the team's main focus, they began researching and developing a list of applicable BMPs. The team developed a spreadsheet of potential BMPs that included characteristics such as removal rates, advantages, disadvantages, maintenance, and applications. Along with this, an ArcGIS map was developed with layers such as the stormwater pipes, streets, topography, tax parcels, soils, and catchment basins. The ArcGIS helped the team analyze the current environmental factors and understand existing structural features of the area. In order to get an accurate representation of the runoff flow and conditions of the existing system, the team used a HydroCAD model. In this model, the team uploaded the design storms for Massachusetts and added other factors such as curve numbers and time of concentrations for each section of the catchment area. The HydroCAD model allowed the team to quantify the flow into each treatment system and to the outfall.

In order to further determine the most accurate, current conditions of the lake, the team needed to collect samples from the catchment area. A sampling plan was developed to determine what pollutants should be sampled for. It also helped determine what area of the storm water piping system that samples should be collected from. This was determined based on research and past sampling events conducted by the City. Materials such as plastic bottles, sterilized bottles, BOD bottles, and a cooler, were gathered before sampling, and rainfall data was analyzed for weeks until a storm with 0.5 inches of rainfall arrived. Once the rainfall conditions were appropriate for sampling, the team sampled with representatives from Weston & Sampson who assisted with performing in-field tests such as chlorine, detergents, and ammonia. Once all samples were collected and infield tests were complete, the samples were brought back to the lab at WPI. In the lab at WPI, more tests such as pH, dissolved oxygen, total suspended solids, nitrate, and total and dissolved phosphorus were completed on the collected samples. These results would be able to help further analyze which BMPs would be the most efficient and feasible for the area.

Using the two software packages and evaluation of alternatives, it was determined that there would be four major areas of focus. The first Treatment Area would be located along the northwest side of the park along Lake Ave. Treatment Area 2 is proposed to be split into two areas located south of the tennis courts. Treatment Area 3 is located along the southwest side of the park on the southside of the playground and picnic area on the corner of Lake Ave and Cove Ave. Treatment Area 4 was considered to be a feasible location for an underground treatment system between the two catch basins prior to the stormwater going to the outfall.

After researching all BMPs that would be applicable to the different areas, and determining which pollutants were most prominent and needed to be effectively removed, the team was able to narrow down the BMPs. The feasibility of the BMPs was analyzed by creating a decision matrix table. In this table there were categories such as cost, maintenance, removal efficiency, and area functionality. Each BMP was given a score of 1-5, 5 being the best and 1 being the worst for each category. The BMPs with the highest scores would continue to be assessed for implementation. The team determined that of the 16 BMPs that were originally ranked, 3 would be presented to the City. These 3 BMPs were a tree box, a rain garden and a Cascade Separator. For each BMP design, details about size, cost, and maintenance have been provided to the City. Finally, the team provided recommendations for future projects at WPI partnering with the City as well as recommendations for the City on how to approach other areas of the lake.

1.0 Introduction

There has been a vast history of maintaining clean water across the United States beginning in 1948 when the Clean Water Act was originally enacted as the Federal Water Pollution Control Act (EPA, 2022). It then became the Clean Water Act in 1972 where it regulated discharges and the water quality of surface waters (EPA, 2022). Regulations such as the Clean Water Act led to the heavy management of stormwater discharge under the EPA and local and state governing agencies.

To ensure stormwater discharges fall within regulations, stormwater treatment practices are put in place to minimize pollutants. A stormwater treatment practice will "improve the stormwater runoff quality, reduce runoff volume, reduce runoff peak flow, or any combination thereof" (Gulliver, 2010). Some examples of stormwater treatment practices include sand filters, rain gardens, tree boxes, vegetated filter strips, dry and wet ponds, and swales. These practices, when designed for a certain area, can limit the number of pollutants that enter the stormwater system by filtering out pollutants and limiting the amount of stormwater that can enter the system. Limiting the amount of water also limits the number of pollutants that can enter the system.

This project focused on using green infrastructure and treatment technologies to help eliminate or minimize pollutants entering Lake Waushakum from one tributary area of Framingham, Massachusetts. Our goal was to develop Best Management Practices (BMPs) for Catchment Area 2368, in the north central region around Lake Waushakum, to reduce stormwater pollutants and runoff that flow into Lake Waushakum. The objectives the team accomplished were:

- Developed a stormwater sampling plan and collected samples to represent sources of pollution accurately.
- Analyzed the collected sample for contaminants and characterize contributing areas and runoff to identify sources of pollution around Anna Murphy Park.
- Developed and evaluated BMPs to address stormwater runoff and developed a BMP recommendation strategy to implement in Anna Murphy Park.

This report details how the team developed BMPs through literature review, wet weather water sampling, laboratory testing, schematic design development, map analysis through ArcGIS, and hydraulic analysis through HydroCAD.

2.0 Background

This section discusses background details on Lake Waushakum and the runoff from Catchment Area 2368, which was researched by the team. The sections also will discuss various stormwater regulations and grants that apply to the City of Framingham and Lake Waushakum specifically, as well as the pollution issues that these parties have been facing. Finally, a review of sampling and lab testing procedures are discussed as well as some examples of previously used Best Management Practices.

2.1 Lake Waushakum

Lake Waushakum or Waushakum Pond is an 82-acre kettle pond located in both Framingham and Ashland Massachusetts. Lake Waushakum is currently listed on the Massachusetts Integrated Lists of Waters due to non-native aquatic plants, chlorophyll-a, dissolved oxygen, total phosphorus, and turbidity (Massachusetts Division of Watershed Management, 2021). Stormwater runoff has been identified as the main contributor to pollutant loading and the inability to meet water quality standards. Runoff mainly flows from roads and impervious surfaces, taking sediments and pollutants with it. The City of Framingham has been working with an engineering consulting company, Weston & Sampson, to retrofit areas around Lake Waushakum to minimize pollutants entering the lake. Efforts have already begun to reconstruct the public beach, although grant funding will be used to finalize design plans, support permitting, and construct green infrastructure to minimize pollutant loading.

The City of Framingham tests Waushakum Pond during the public beach season for Escherichia coli (E.coli). According to the Department of Public Health, 105 CMR 445, minimum standards for a bathing beach include; "no single E.coli sample shall exceed 235 colonies per 100ml and the geometric mean of the most recent five E.coli samples within the sample bathing season shall not exceed 126 colonies per 100ml or no single E.coli sample shall exceed 61 colonies per 100ml and the geometric mean of the most recent five E.coli samples within the sample bathing season shall not exceed 33 colonies per 100ml" (Department of Public Health, 2014). Through 2021, Waushakum Pond was tested 22 times for E.coli. The results reflected a failed score of 20 of the 22 times because the E.coli levels were above the reporting limits. The two passing scores came in June 2021, but the beach was still not open (Framingham, 2021). Waushakum Pond was sampled again in 2022, 22 times. Three of the tests failed the geometric; and one failed the single sample test (Framingham, 2022). The beach was open for most of the summer, however, swimming was not permitted for many weeks.

Framingham City engineers, Department of Public Works, Department of Public Health, Conservation Department, and Parks and Recreation staff have conducted efforts to restore and remediate Waushakum Lake. Partnering with local companies such as Weston & Sampson, city engineers have designed Best Management Practices (BMPs) utilizing green infrastructure, solar, and other climate-resilient solutions (Waushakum Beach Improvements). Government officials and consultants have also taken immediate steps to remediate the lake. Waushakum Pond was treated to temporarily minimize outbreaks of Cyanobacteria which can lead to Algae blooms. Temporary fixes have remediated the immediate need and reduced the risk of harmful toxins, such as cyanotoxins, that are dangerous to humans and animals (Mass.gov., 2019). The City of Framingham samples for cyanobacteria, and when levels are elevated above 70,000 cells per ml (Framingham, 2021) a treatment utilizing copper algaecide is implemented to avoid the bloom. Treatments are notified to the public through blog platforms, social media, and signs on the beach (Framingham Source, June 2022).

While significant efforts are underway at the local city beach, Framingham has been split into Catchment Areas that all flow into the Lake. There are approximately 145, 1-acre catchment areas in Framingham surrounding the lake. Catchment Area 2368, as seen below in Figure 1, is in the North Central part of Lake Waushakum. It is fully in Framingham, MA, and includes a collection system that discharges directly into the lake.

Figure 1. Lake Waushakum with Catchment Area 2368.

Looking closer at Catchment Area 2368, Figure 2, it contains Anna Murphy Park, residential properties, and city-owned streets.

Figure 2. Close up view of Catchment Area 2368.

The Catchment Area, mainly focusing on Anna Murphy Park, was noted as a high priority in the Lake Waushakum PSIR report. The park consists of two tennis courts, a small playground area, and a little league baseball field. Phosphorus loading has already been tested in this area with an estimated phosphorus catchment load of 2.09 lb/year. More information regarding past testing and pollution issues in Catchment Area 2368 can be found in Section 2.3.

2.2 Relevant Stormwater Regulations & Grants

The City of Framingham has received a 319 Grant from the EPA for Waushakum Lake. The grant was established from the 1987 revision to the Clean Water Act to assist Nonpoint Source, or NPS programs to restore impaired waters and protect unimpaired high-quality waters (Yoshikawa, 2013). As of 2022, the available grant funds for the 319 Grant are $178 million, which are distributed by the EPA. Funds are distributed through a state-by-state allocation formula that was developed by the EPA and the states. States must use 50% of the annual proportion funds of the grant to implement watershed projects guided by watershed-based designs. The funds from this grant will allow the City of

Framingham to improve the sustainability of the lake for future generations (City of Framingham, 2021). The City was able to obtain this grant for this project due to prior experience using a 319 grant. The City was familiar with grant processes and had a successful outcome of their other 319 grant projects, so they were able to easily obtain another grant for this project. The 319 grant can also be used to acquire permits (Comprehensive Environmental Inc., 2021).

One permit used in stormwater management is the Massachusetts Municipal Separate Storm Sewer System or MS4 permit. This permit is composed of six different parts that all are used together to help reduce pollution when used together. The six aspects are public education and outreach, public participation, illicit discharge detection and elimination, management of construction site runoff, management of post-construction site runoff, and good housekeeping in municipal operations. Waushakum Pond is located within the City of Framingham's regulated area under the 2016 NPDES MS4 Permit. This permit requires the City to complete a Phosphorus Source Identification Report by 2022 (City of Framingham, 2021). The NPDES Permit is used in accordance with the clean water act. The Clean Water Act prohibits anyone from discharging pollutants through a point source into a body of water unless they have an NPDES permit (US EPA, 2022). A point source is any type of conveyance of water such as a pipe, ditch, channel, or tunnel that can be used to carry water to any body of water. The permit contains limits on what can be discharged, monitoring and reporting requirements, and other provisions to ensure that whatever is being discharged does not hurt the overall water quality or people's health (US EPA, 2022). The permit translates general requirements of the Clean Water Act into specific provisions tailored to the operations of each person discharging pollutants.

In the Commonwealth of Massachusetts, the EPA, and MassDEP co-issue NPDES permits. NPDES permits regulate wastewater discharges by limiting quantities of pollutants that are discharged while imposing monitoring requirements (Massachusetts Department of Environmental Protection, 2022).

2.3 Pollution Issues

When looking into the pollution information on Waushakum Pond, Weston & Sampson developed a Phosphorous Source Identification Report (PSIR) in 2022. The report analyzes the pollutant loadings across the different catchments around the pond. This helped identify the catchments with higher contamination so they could be prioritized for implementing green infrastructures. Dry and wet weather samplings were completed to get a better understanding of the contamination issue. The report also provided potential BMPs for different catchment areas that could benefit stormwater management. Based on the PSIR, our team decided to look at Catchment Area 2368, as the report deemed it a high priority and was mostly city property, therefore the majority of the catchment area was accessible to implement future BMP designs. The catchment includes a park called Anna Murphy park, a local park that includes a little league baseball field, tennis courts, a playground area, and a picnic area. Stormwater structures near Anna Murphy Park, located within Lake Avenue, were sampled in October 2020, by Weston and Sampson during a wet weather event. The results are shown in table 1.

Table 1: Weston and Sampson Lake Ave Test Results October, 2020.

Field Tests	**Results**
Salinity	8.8 ppm
Conductivity	17.1 µS/cm
Ammonia	0.10 mg/L
Surfactants	0.25 mg/L
Laboratory Tests	**Results**
Total Phosphorus	0.26 mg/L
Biochemical Oxygen Demand	5-day analysis did not meet 2mL depletion requirement
Turbidity	3.6 NTU
E. coli	>2419.6. CFU/100mL
Total Suspended Solids	No Data

There is no treatment of the stormwater that is collected within Catchment Area 2368 prior to discharge into the lake.

2.4 Sampling and Lab Testing

There are numerous lab tests that can analyze wet weather samples. Some of the most informative are Dissolved Oxygen (DO), Coliforms (including E. coli), Total Suspended Solids (TSS), Total Phosphorus, Detergents, Ammonia, Chlorine, and pH. Coliform bacteria tests analyze the pollution levels of E. coli in a body of water, which is a major species in the fecal coliform group and is considered the best indicator of fecal pollution and other contaminants. The E.coli regulations for freshwater swimming created by the EPA state that 126 E. coli CFU per 100 mL or above is not swimmable. Dissolved Oxygen (DO) is helpful for maintaining aquatic life and aesthetic water quality. Evaluating the phosphorus levels in the lake is helpful since high concentrations of phosphorus can result from poor agricultural practices or high amounts of stormwater runoff (EPA, 2022). Total phosphorus testing measures all the forms of phosphorus in the sample by digesting the sample to convert all forms into orthophosphate, which is then measured using the ascorbic acid method (EPA 5.6 phosphorus). The phosphorus levels must be less than 10 micrograms per liter for recreation and aesthetic per EPA regulation (EPA, 2000). TSS testing is important because pollutants and pathogens are carried on the surfaces of solids which correlates to water clarity. E. coli testing will help determine the pollution levels, which will be useful for understanding fecal pollutant levels in the discharge. Collecting lake samples could also help determine the effect of the outfall.

2.5 Best Management Practices

The primary method that is used to control stormwater runoff is implementing best management practices, otherwise known as BMPs. Stormwater BMPs are methods, devices, and practices that are used to manage stormwater runoff by controlling peak runoff rate, improving water quality, and managing runoff volume. Important considerations when determining BMPs are site conditions, existing and surrounding land uses, priority stormwater management goals, and additional site development or redevelopment goals. A wide range of BMPs is available, from rain barrels that require little space to constructed stormwater wetlands that require a much larger footprint. The scale of the BMP is directly related to the size of the construction project and to what the specific permitting for the site requires or allows.

Typical approaches include vegetated filter strips, rain gardens, tree box filters, and water quality swales as the most feasible designs. Vegetated filter strips are uniformly graded vegetated surfaces that receive runoff from impervious areas (Massachusetts Department of Environmental Protection). This BMP has very low maintenance, ideal for residential settings, can be used with other BMP designs, and can reduce runoff volumes and peak flows. If the filter strip is 25 ft wide, there is a 10% removal of TSS. If the filter strip is 50 feet wide, there is a removal efficiency of 45%. There is insufficient data of the removal efficiency of nutrients, metals, and pathogens.

Rain gardens are depressions filled with sandy soil, mulch, and vegetation that runoff passes through (Massachusetts Department of Environmental Protection). Some advantages of this BMP is that it can remove phosphorus, can be modified to be used within existing landscapes, and can be used with space constraints. With a vegetated filter strip or equivalent, there is a 90% removal efficiency of TSS. If the soil media is at minimum 30 inches, there is a 30-50% removal efficiency of total nitrogen. There is a 30-90% removal efficiency of total phosphorus, a 40-90% removal efficiency of metals, and insufficient data on the removal of pathogens.

Tree box filters are open concrete barrels filled with soil, gravel, and a tree (Massachusetts Department of Environmental Protection). Stormwater goes through the various layers in the box to the ground. Some advantages of this BMP is that it can be used as a pretreatment device and would be easily implemented by the City. The BMP has an 80% removal efficiency of TSS and removal data for total phosphorus, dissolved inorganic nitrogen, zinc, and pathogens was not reported.

Water quality swales are vegetated open channels that treat required water quality volume and transport runoff (Massachusetts Department of Environmental Protection). Some advantages of this BMP is that it can be used in the place of curbing and it would keep flow away from the street surface. This BMP has a 70% removal efficiency of TSS, 10-90% removal efficiency of total nitrogen, 20-90% removal efficiency of total phosphorus, and insufficient data of the removal efficiency of metals and pathogens.

More typical approaches include grassed channels, dry detention basins, green roofs, baffle boxes, rain barrels, and drainage channels as less feasible designs. Grass channels are swales that provide water treatment with long hydraulic resistance times (Massachusetts Department of Environmental Protection). Some advantages of this BMP is that it can provide pretreatment and it is compatible with low impact development designs. This BMP has a 50% removal efficiency of TSS and -121% removal efficiency of total phosphorus.

Dry detention basins are excavated basins that are used for the detention of stormwater runoff and to control release and peak runoff (Massachusetts Department of Environmental Protection). Some advantages of this BMP is that it is low cost and controls runoff. It has a removal efficiency of <10% for bacteria, 10-30% removal of total phosphorus, 5-50% removal of total nitrogen, and 30-50% removal of metals.

Green roofs are rooftop planting systems that retain precipitation (Massachusetts Department of Environmental Protection). Some advantages of this BMP is that it can reduce volume and peak rates, extend the life expectancy of a roof, and reduce building heating and cooling costs. This BMP removes 40% of annual precipitation, reduces peak flow rates by 50-90%, delays peak discharges by hour, and it increases total phosphorus and total nitrogen.

Baffle boxes are an end of pipe treatment method that is placed at the end of existing stormwater drainage pipes (US EPA, 2005). An advantage of this BMP is that it can serve as a retrofit installation at curb or manhole inlets or it can be installed beneath grates. It has a removal efficiency of 90% for sand and sandy clay and a removal efficiency of 28% for fly ash.

Rain barrels are barrels that store roof runoff that is then reused in gardening or other non-drinkable uses (Massachusetts Department of Environmental Protection). Some advantages of this BMP is that it can reduce demand for non-drinkable water, reduce demand of public water sources, and can reduce stormwater runoff volume. It does not have any primary pollutant removal benefits but it keeps roof runoff out of other water bodies.

Drainage channels are vegetated open channels that are used for non-erosive stormwater transportation (Massachusetts Department of Environmental Protection). Some advantages of this BMP is that it is less expensive than curbing and gutter systems, it is compatible with low impact designs, and it can keep stormwater away from street surfaces. This BMP has a 0% removal efficiency of TSS.

Some final approaches are catch basin inserts, wet basins, sand & peat filters, constructed stormwater wetlands, proprietary media filters, and leaching catch basins as the least feasible designs. Catch basin inserts are an accessory to catch basins that add filtering efficiencies (Massachusetts Department of Environmental Protection). An advantage of this BMP is that it helps catch sediment and other materials before it enters the catch basin. It has a removal efficiency of about 80%.

Wet basins are permanent pools of water that settle sediments and remove soluble pollutants (Massachusetts Department of Environmental Protection). Some advantages of this BMP is that it can remove solid and soluble pollutants as well as nutrients and metals, it is aesthetically pleasing, and it can be used in retrofits. This BMP has a removal efficiency of 80% of TSS with sediment forebay, 10-50% removal efficiency of total nitrogen, 30-70% removal of total phosphorus, 30-75% removal efficiency of metals, and 40-90% removal of pathogens.

Sand & peat filters are filtration basins filled with sand and organic filters underlaid with perforated drains or designed with cells and baffles with inlets or outlets (Massachusetts Department of Environmental Protection). Some advantages of the BMP is that it is applicable for small drainage areas, it has a long design life, and is good for densely populated urban areas. It has a removal efficiency of 80% for TSS, 20-40% for nitrogen, 10-50% for total phosphorus, and 50-90% for total methods.

Constructed stormwater wetlands maximizes pollutants removal through retention, settling, and wetland vegetation uptake (Massachusetts Department of Environmental Protection). Some advantages of this BMP is that it has a low maintenance costs, a high removal efficiency, and it provides wildlife habitat. It has a removal efficiency of 80% for TSS, 20-55% for total nitrogen, 40-60% for total phosphorus, 20-85% for metals, and up to 75% for pathogens.

Proprietary media filters are 2 chambered underground concrete vaults that settle out pollutants and large particles (Massachusetts Department of Environmental Protection). Some advantages of this BMP is that it is specialized for industrial sites and it can be used in redevelopments or ultra-urban settings. The removal efficiency of TSS, total phosphorus, dissolved inorganic nitrogen, zinc, and pathogens depends on the type of media that is used.

Leaching catch basins are pre-cast concrete barrels and risers with an open bottom to infiltrate runoff into the ground (Massachusetts Department of Environmental Protection). Some advantages of this BMP is that it can provide groundwater recharge and it can remove coarse sediments. It has a removal efficiency of 80% for TSS and there is insufficient data on the removal of nutrients, metals, and pathogens.

2.6 City Recommended Best Management Practices

The City has considered other structural BMPs for another area of the city. This area is located along Gilbert street. The designs that the City asked the team to consider for this catchment area was based off of the pilot plans they used when developing their designs for BMPs on Gilbert Street.

The first design the City asked the team to consider is The Cascade Separator® by Contech Engineered Solutions. The specific model the City would like to implement is CS5. Stormwater enters the separator through multiple inlets and/or a grate outlet, where the water then enters and is directed into two separate flumes by the central cylinder (Contech Engineered Solutions, n.d.). Particle settling is then enhanced in the central chamber. The downward spiral of the water pushes sediment into the sump and treated water exits through the outlet. In the event that the flow exceeds flume capacity, the excess water flows over the flume, without re-suspending particles or pollutants. Some benefits of this structure include TSS removal of about 80%, design and installation flexibility, easy maintenance, and much more (Contech Engineered Solutions, n.d.). An image of this design can be seen in Figure 3.

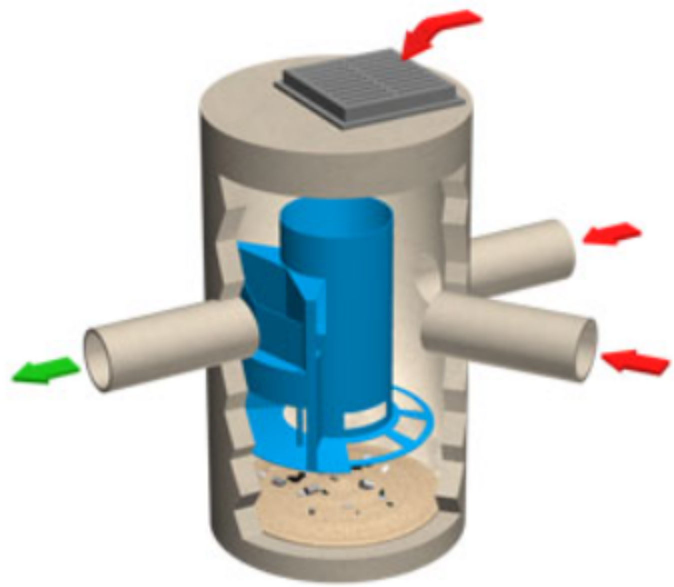

Figure 3: The Cascade Separator®. (Contech Engineered Solutions, n.d.).

The other design that was recommended by the city is the Filterra® Bioretention by Contech Engineered Solutions. Filterra is similar to bioretention areas, as it has similar functions and applications (Contech Engineering Solutions, n.d.). In this design, runoff enters the Filterra system through a curb inlet opening or pipe. The water flows through a filtered media mixture contained in a concrete container that captures and immobilizes pollutants. When the pollutants decompose, they volatilize and become incorporated into the biomass of the Filterra system. The runoff flows through this system and comes out at the bottom of the container where the treated water is discharged. Some benefits of this system is that it adds aesthetic appeal, reduced footprint, and has simple and easy maintenance. It has a median removal efficiency of 86% for TSS, 70% for total phosphorus, 34% for total nitrogen, 55% for total copper, 43% for dissolved copper, 56% for total zinc, 54% for dissolved zinc, and 87% for total petroleum hydrocarbons. Filterra has multiple designs available: Filterra Offline, Filterra Peak Diversion, Filterra Internal Bypass Curb, FIlterra Sediment Chamber (Maryland only), Filterra Bioscape Vault, Filterra Bioscape Vault Basin, and Filterra Bioscape. The Filterra Offline model can be seen in Figure 4.

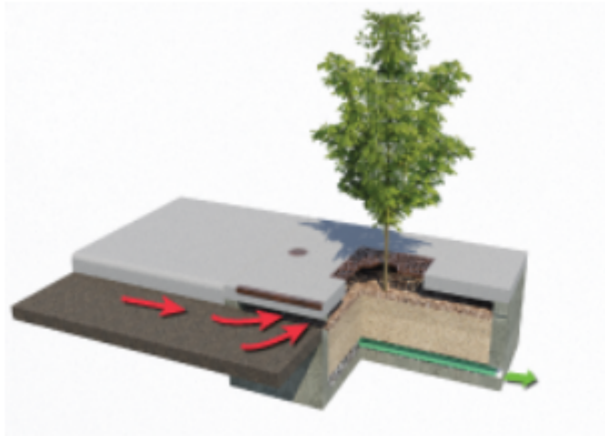

Figure 4: Filterra Offline Model. (Contech Engineered Solutions, n.d.).

The city has a pilot plan to implement the Filterra Offline on Gilbert Street and are already familiar with the designs and applications of this model.

3.0 Methods

Our goal was to develop Best Management Practices (BMPs) for Catchment Area 2368 to reduce stormwater pollutants and runoff that flow into Lake Waushakum. The objectives the team accomplished were:

- Developed a stormwater sampling plan and collected samples to represent sources of pollution accurately.
- Analyzed the collected sample for contaminants and characterize contributing areas and runoff to identify sources of pollution around Anna Murphy Park.
- Developed and evaluated BMPs to address stormwater runoff and developed a BMP recommendation strategy to implement in Anna Murphy Park.

The group completed these objectives by first going over the feasibility of each BMP and how they were narrowed down. Then the Catchment Area was characterized through the use of ArcGIS and HydroCAD. Finally, wet-weather sampling and laboratory testing were conducted and the results were used to select the BMPs chosen for each section of the Catchment Area.

3.1 Catchment Area Characterization

In order to develop treatment processes that are applicable to Catchment Area 2368, the group conducted a thorough analysis of the area using ArcGIS, Google Maps, and HydroCAD. These tools gave an analysis of the area mapping in order to determine basic characteristics. ArcGIS is a public Graphic Information System (GIS) platform that allows the mapping of an area with topographic layers that can be added to analyze the area under different circumstances. The analysis can reveal different relationships between the area, drainage systems, and types of soil. Google Maps, similarly, is a mapping system that allows the user to view close up images of an area for mapping purposes from both an aerial view and a street view. This tool has benefitted the team to visualize what the space looks like for treatment design purposes without being physically onsite. HydroCAD is a Computer Aided Design tool (CAD) that allows the mapping of stormwater runoff. Mapping the area to determine pervious and impervious surfaces can be applied to the HydroCAD software along with rainfall data to calculate runoff in order to appropriately design a BMP.

3.1.1 ArcGIS

A map on ArcGIS was developed in order to analyze Catchment Area 2368 further. First, the group used the Massachusetts ArcGIS database to download shapefiles that were added to a world imagery basemap. The data layers of tax parcels, soils, roads, buildings, water bodies, and city lines were added to the basemap to analyze the Lake Waushakum area. These layers were overlaid together to make a complex GIS map that could be adjusted to look at different criteria. Factors such as slope, environmental structures and the needs of park users were further analyzed by the group to break down the Catchment Area. Breaking down the area allowed the group to explore and understand the different soil types, levels of usage in the park, and proximity to other structures.

After analyzing the layers to understand the boundaries and perimeters, the landscape of the area, and different surface materials, the group gathered more layer data from the City of Framingham. The layers obtained were of the catchment area, drainage system, sewer system, and contours. This allowed the group to predict where water would flow and if the area was impervious or not. To calculate areas and sizes of structures, the group took initial measurements of the park with the measurement tool and geodesic tool. These measurements were utilized for lengths and areas for BMP designs and the HydroCAD analysis.

3.1.2 HydroCAD

A HydroCAD model was developed using information about the rainfall data, pervious and impervious surfaces, and land usage. Using aerial views and the GIS Maps developed, as explained in the section above, the group determined there were three different types of land uses across the Catchment Area. These three land uses were split into three different areas for consideration, the Residential area, the Recreational Park area, and Street. The Street represents all impervious areas that are roads and sidewalks. The Recreational Park represents Anna Murphy Park and has a mix of both pervious and impervious surfaces, for example, the tennis courts are impervious. Finally, the Residential Area is a group of all the other land that makes up the Catchment Area because it is private owned land. The Residential Area is also a mix of pervious and impervious surfaces due to the roofing of houses or the driveway as well as the grassy lawns. The schematic layout of the HydroCAD model broken down into the three different land groups is shown in Figure 5.

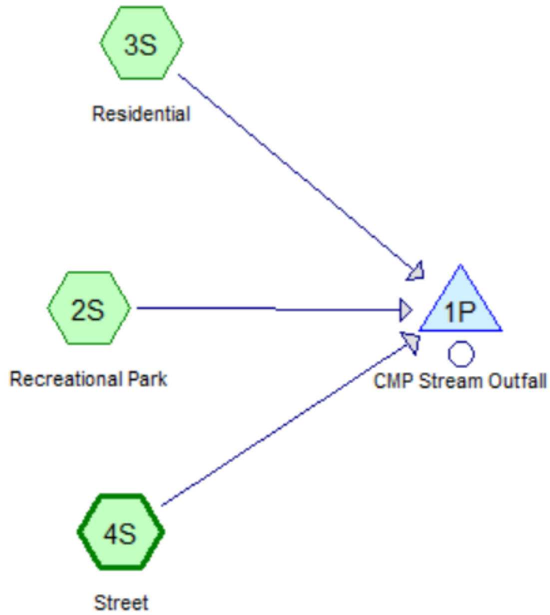

Figure 5. HydroCAD model for stormwater runoff into Lake Waushakum from Catchment Area 2368.

The rain data is based on Massachusetts stormwater standards which state that post developmental flows must be equal to or greater than pre-developmental flows for 2-year, 10-year 24-hour storms. Also taken into consideration and evaluated must be the flow from 100-year 24-hour storms to estimate the amount of flooding that would take place post-development. As per the City of Framingham Drainage Construction Standards, specified design storms are 24-hour storms with rainfall distribution data downloaded from National Oceanic and Atmospheric Administration (NOAA) Atlas 14 (Framingham, 2021). In HydroCAD, runoff was calculated in cubic feet per second (cfs) using the standard method SCS TR-20 to produce a Hydrograph. The group used the HydroCAD data when determining the volume and designs of the treatment systems.

3.2 Sampling

To determine accurate pollutant data at the catch basins and outfall, a stormwater sampling plan needed to be put in place. In order to perform wet weather sampling, certain weather conditions needed to be met; there should be at least 0.25 inches of rain or more within a 24-hour period to meet significant conditions, and the outfall/catch basins must have a flow in order to collect samples. Before sampling occurred, the team gathered appropriate materials for collection. The team collected the following materials before arriving at the catchment area:

- 9, 1-liter plastic bottles from Thermo fisher
- 3, 500mL plastic bottles from Thermo fisher
- 3 glass BOD bottles with stoppers and covers
- Cooler
- Sharpie
- Duct tape
- Tape measure

Once the team was in the field, a PVC rod with a cup attachment was provided by the representatives at Weston & Sampson. This can be seen in Figure 6.

Figure 6. The PVC rod with cup attachment that was used to collect samples. Collection shown is at the catch basin.

Sampling was performed on November 16th, 2022. The team and two representatives from Weston & Sampson were present at the start of sampling. The team first received permission from the property owner where the outfall lies on a previous visit with a City representative. The residents were notified that our team would be on their property and began collection at the outfall, which can be seen in Figure 7. The detailed procedure can be found in Appendix B.

Figure 7. Team member Adele at the outfall collecting samples with the PVC rod and cup attachment.

At the time of sampling, the outside temperature was 41°F. The team first rinsed the PVC cup attachment 3 times with the water coming from the outfall, as a Weston & Sampson representative indicated that it was an EPA recommendation. After rinsing, the team collected enough samples until 2 of the 1-liter bottles were almost full, at least 250mL was collected in the sterilized bottle, and a BOD bottle full of sample water. The flow rate at the outfall was then determined by timing how long it took to fill 250mL of the collection cup. This collection was then used to perform in-field tests. In the field, a multimeter was used to determine the temperature, conductivity, and salinity of the sample. Appendix C contains the procedure for the multimeter tests that were conducted. Chemetrics test kits were used to test for ammonia, detergents, and chlorine.

Next, the team collected samples at catch basin #2008853, just south of the tennis courts. Cones were first placed around the catch basin before it was opened to ensure traffic and pedestrian safety. The catch basin was opened by Weston & Sampson staff with a manhole hook. At the time of collection, there was only flow from one side of the catch basin, from the east side collecting from Cove Ave, so samples were only collected from catch basin connection #2018604. The team first rinsed the PVC cup attachment 3 times with the water coming from the pipe. After rinsing, the team collected enough samples until 2 of the 1 liter bottles were almost full, at least 300mL was collected in the sterilized bottle, and a BOD bottle full of sample water. The flow rate at the pipe was then determined by timing how long it took to fill 300mL of the collection cup. This collection was then used to perform in-field tests. A multimeter was used to determine the temperature, conductivity, and salinity of the same; see Appendix C for the procedures for tests performed in the field. Chemetrics test kits were used to test for ammonia, detergents, and chlorine. The in-field testing can be seen in Figure 8.

Figure 8. Team member Caitlin performing an in-field chemetrics test.

Results from these tests were used to provide a better understanding of the relevant pollutants affecting Lake Waushakum. These results can be seen in Table 2 in Section 4.3. Collecting samples from the outfall was considered the highest priority as it will provide information on pollutant levels going directly into the lake. The flow coming from the catch basin nearest to the outfall was also collected for sampling since all catch basins flow towards that one. Areas with larger contributing flow volumes will have a higher priority when implementing pollution diversion designs.

3.3 Lab Testing

In addition to the tests performed in the field, additional tests were performed in the WPI Environmental Engineering Laboratory for both outfall and catch basin samples. To begin, the pH and the Dissolved Oxygen, or DO levels were measured. To test the pH, a pH probe was used. First, the probe was turned on and calibrated using different buffer solutions of 4, 7, and 10 pH. The probe was then placed into each sample until stabilized. Once stabilized, the pH value was recorded. This same process was repeated for the second sample. A detailed procedure for pH can be found in Appendix D. To test the DO levels, a similar process to the pH meter was used. The DO meter was turned on and calibrated by following the instructions in the manual. Once calibrated, the probe was placed in the sample and stabilized, once stabilized the value on the meter was recorded. Clean the probe and repeat the same process for the second sample. A detailed procedure for DO can be found in Appendix E.

The next test measured the total suspended solids in the samples collected. To do this, a filter paper was cleaned with Deionized water and dried for 1 hour in the furnace at 105°C. After the hour was up, the filter cooled for 30 minutes. Once cooled, the filter was weighed and then placed into the vacuum apparatus as depicted in Figure 9.

Figure 9. Total Suspended Solids Apparatus.

Five hundred milliliters of sample was run through the apparatus until all water was filtered out. This same process was repeated for both samples. Once both samples were filtered, the filters were placed into the furnace again for 1 hour. After an hour, they were cooled for 30 minutes and weighed. The difference between the initial and the second measurement is the total suspended solids in the sample. A detailed procedure for TSS can be found in Appendix F.

Another test that was performed was the Coliform test. To complete this test, Colilert lab kits were purchased through Idexx. To begin the Coliforms test, the incubator was set to 35°C. The two samples collected in sterilized bottles were used for this test. 100mL of each sample was measured and 1 capsule of solution from the Coliert kit was poured into the sample. The sample was shaken until fully dissolved. The sample was placed in the incubator for 24 hours. After 24 hours, if the solution had become yellow, there was E. coli present, and if the solution was fluorescent under UV light, there were fecal coliforms present. This process was repeated for both the outfall and catch basin samples. A detailed procedure for Coliforms can be found in Appendix G.

The last test that was performed on the samples was to test for Dissolved Phosphorus by using Ion Chromatography. Ion chromatography measures concentrations of ionic species by separating them based on an interaction with a resin. The samples were run through a 0.45 micron filter cap. Ionic species separate differently depending on species type and size. Samples pass through a pressurized chromatographic column where ions are absorbed. An eluent runs through the column and the absorbed ions begin separating from the column. The retention time of different species determines the ionic concentrations in the sample.

Total phosphorus also was tested using a spectrophotometer. For this, digestion was performed on 3 standards, a blank and a sample of each the outfall and catch basin. The results of the standards can be seen on the graph in Figure 10. The samples were run through the mass spectrophotometer. A detailed procedure for Total Phosphorus can be found in Appendix H.

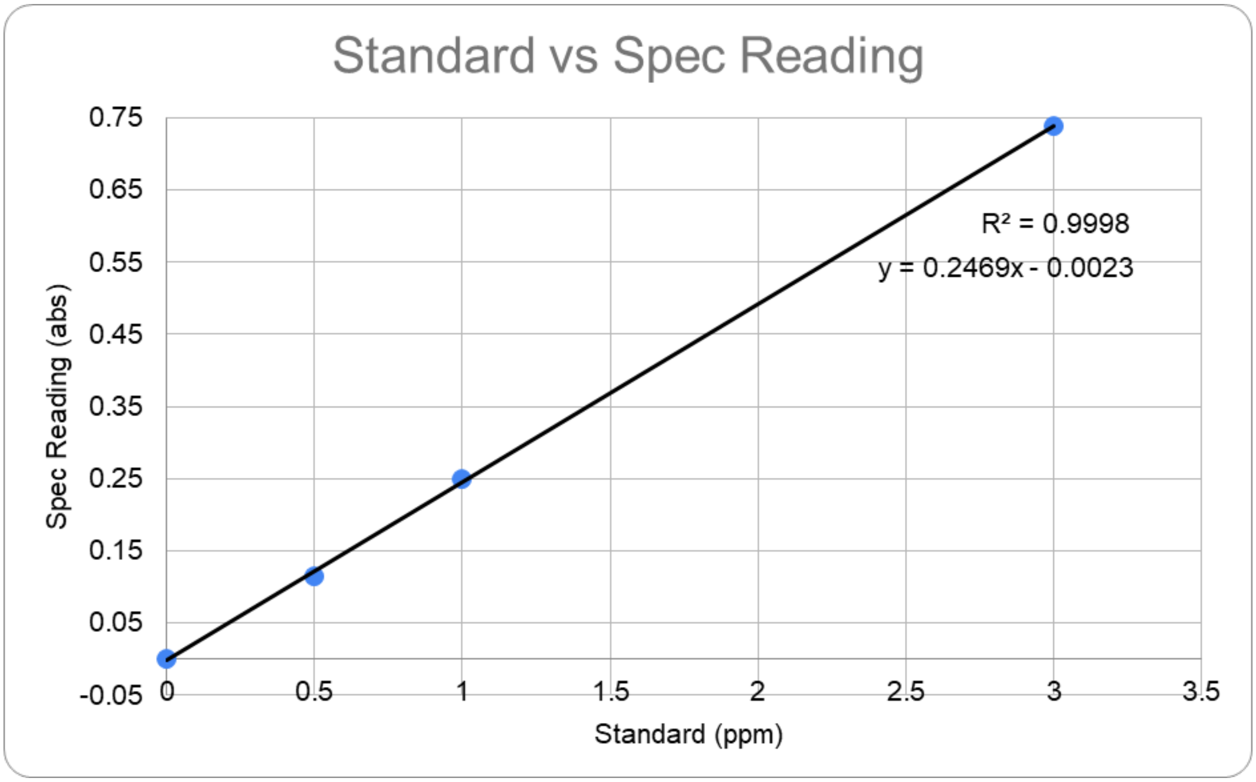

Figure 10. Graph of the standards and spectrophotometer measurements that were used to calculate total phosphorus.

3.4 Development of BMP Alternatives

In order to design a feasible BMP for Anna Murphy park that would reduce stormwater runoff and pollution into Waushakum pond, BMP constraints were considered to narrow down the different design possibilities:

- **Cost**: The City of Framingham has a limited budget considering there are other areas around Waushakum pond that also need stormwater treatment.
- **Maintenance:** The amount of maintenance the BMPs require and if the city has any experiences with maintaining the chosen BMPs.

- **Removal Efficiency**: Considered BMPs would need to have removal efficiencies that will provide quality treatment to the stormwater runoff in the park and on the street following the Massachusetts Stormwater Standards.
- **Area Functionality**: BMPs that cannot function properly in the park were no longer considered, either due to space or appropriateness in an open public park.
- **Design**: Considered BMPs would need to have phosphorus, TSS, chlorine, or fecal bacteria removal for the desired Treatment Area, as well as have minimal disruption to the park and the residencies near Anna Murphy Park.

A decision matrix was used to categorize the feasibility of different BMPs in the park. The matrix accounted for cost, maintenance, the removal efficiency of the BMP, area functionality, and design shown in Figure 11. Each category in the matrix was graded for the individual BMPs from 1-5, 5 being the most feasible for that category, while 1 is unfeasible. The total scores from each BMP were summed, the higher number representing a more feasible BMP for Anna Murphy park.

Decision Matrix

List of BMPs	Cost	Maintenance	Removal Efficiency	Area Functionality	Design	Total	Legend
Vegetated Filter Strips							1 = Poor
Rain Garden							5 = Best
Tree Box Filter							Considering
Water Quality Swale							Maybe Consider
Grassed Channel							Not Considering
Dry Detention Basins							
Green Roofs							
Baffle Boxes							
Rain Barrels/Cisterns							
Drainage Channels							
Catch Basin Inserts							
Wet Basins							
Sand & Peat Filters							
Constructed Stormwater Wetlands							
Proprietary Media Filters							
Leaching Catch Basins							

Figure 11. BMP Decision Matrix Outline.

Once filled out, this decision matrix was used to help the team determine which BMP will be feasible for the given treatment areas. This matrix will be provided to the city of Framingham for their use.

4.0 Results

This chapter provides the results and outcomes of the different analyses the team used throughout the project. Different BMP analysis, lab testing results and software analyses are covered in this section to analyze the most feasible BMPs for Anna Murphy Park.

4.1 ArcGIS Characterization

The ArcGIS mapping provided the group with information about the location of structures, slopes and contours, and boundaries. As seen in Figure 12, Catchment Area 2368 is outlined by the orange line. This parameter was provided by the City of Framingham and gave specific dimensions and boundaries.

Figure 12. Aerial view of Catchment Area 2368 that is outlined by the orange lines.

The group narrowed down the layers utilized to develop a more viewer friendly map. The group removed the soils later because it did not show any contrast across the catchment area. City of Framingham lines and buildings were also removed because they did not add to the map and were still somewhat represented by the Tax Parcel lines. After compiling the layers together, the group developed a final GIS map as seen in Figure 13. The layers utilized were Drain Junction, Roads, Contours, Drain Edge, Tax Parcel, Waushakum Pond, and the Catchment.

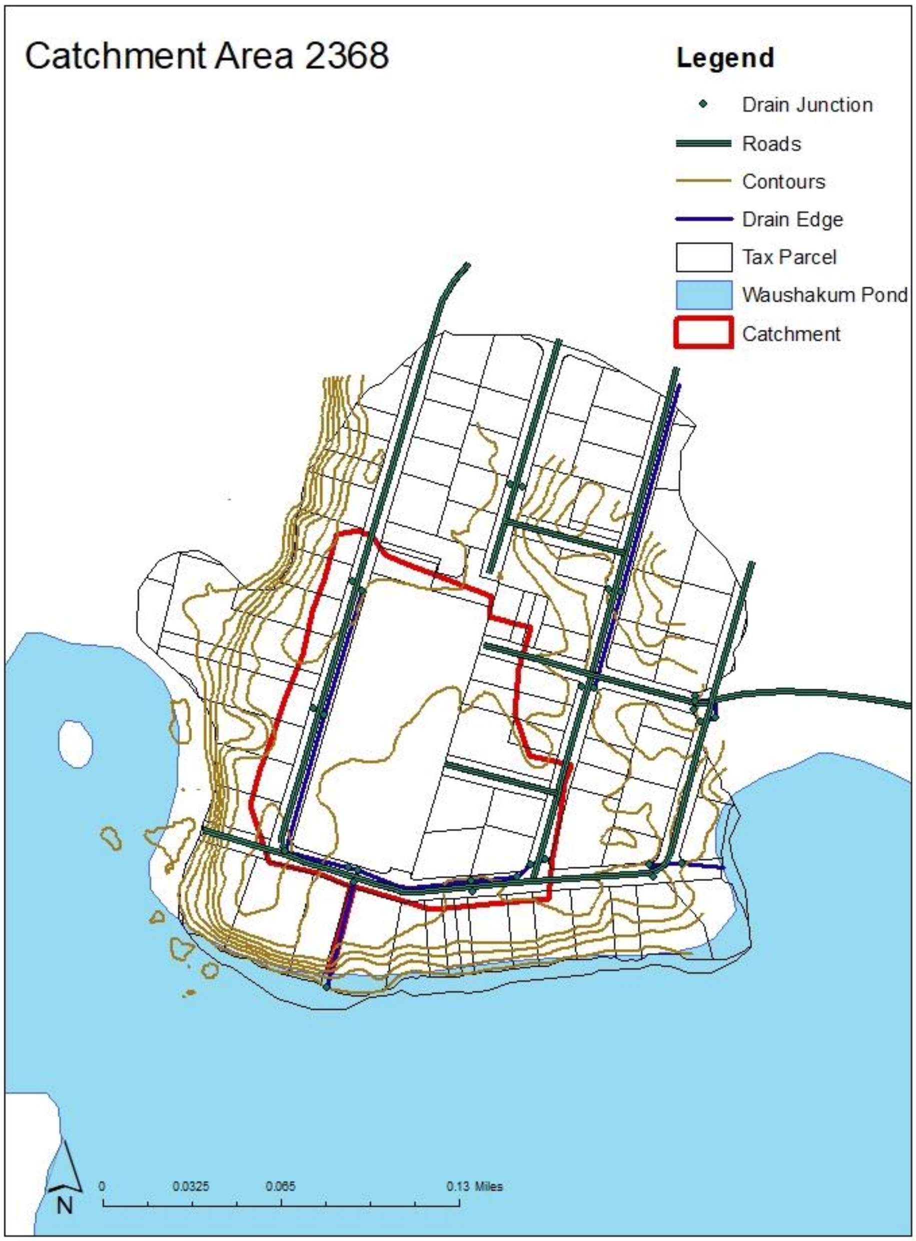

Figure 13. Layers view of Catchment Area 2368.

The Drain Junction, Drain Edge, and Roads significantly lined up and demonstrated the accuracy of layers acquired from both MassGIS and the City of Framingham. The drain junction was utilized to find the point at which the sewer systems meet and go to the outfall. This would be a good position for a BMP because it is the final entry point before the stormwater goes to the outfall. Contour lines show the relative flatness of the catchment area. There is no significant slope and therefore no significant overland flow of water across the area. Using the aerial view along with site visit photos from October 5th, 2022, as seen below in Figures 14 through 16, the group determined there to be significant flooding and pooling around the perimeter of Anna Murphy Park.

Figure 14. Flooding and pooling of water along the baseball field on the northwestern side of Anna Murphy Park.

Figure 15. Flooding and pooling of water along the playground on the southwestern side of Anna Murphy Park.

Figure 16. Flooding and pooling of water along the tennis courts on the southern side of Anna Murphy Park.

This is caused by the slope from different surfaces, the grass to concrete, along with park users parking along the outside of the park. The parking has eroded the grass and soil along the road so the water pools, picks up sediment, debris, and pollutants from cars and the road, and eventually carries it to the storm drains and Lake Waushakum. Therefore, the group determined it is important to treat the stormwater along the west side of Anna

Murphy Park along with the southern edge by the tennis courts. The group split the catchment area into four sections in which to design BMP to address stormwater pollution; Area 1 on the left side of the park lining Cove Ave, Area 2 in the grassy area between the tennis courts and Lake Ave, Area 3 in the bottom left corner of Anna Murphy Park below the playground, and Area 4 running across Lake Ave where the drainage system runs to the outfall. An aerial view outlining the four areas can be seen in Figure 17.

Figure 17. The four catchment areas of focus for a proposed BMP.

As seen in Figure 13 (full GIS Map), there is a drain junction that meets from the left and right side of the catchment area and takes stormwater south to the outfall. Areas 1 and 3 will help to treat stormwater coming to the drain junction from the left and area 2 will treat stormwater coming from the tennis courts and to the right of the junction. Area 4 will treat all stormwater coming from the drain junction before it reaches the outfall. A further description of the BMPs in each area can be found in Section 4.4.

4.2 HydroCAD Analysis

After modeling the area using GIS, the group developed a HydroCAD model to understand runoff and flow. Using the calculated areas of the residential, park, and street areas for both impervious and pervious surfaces and their associated CN values, Figure 18 shows a hydrograph for the whole area based on a Type III 24-hr storm. The 24-hour storm was referenced because it frequently occurs and therefore is used as an example when designing BMPs. This storm data was predicted for the entire catchment area but can be broken down into three different areas. As previously explained, the three areas were broken down to be residential areas, the park, and streets as seen in Figures 19-21.

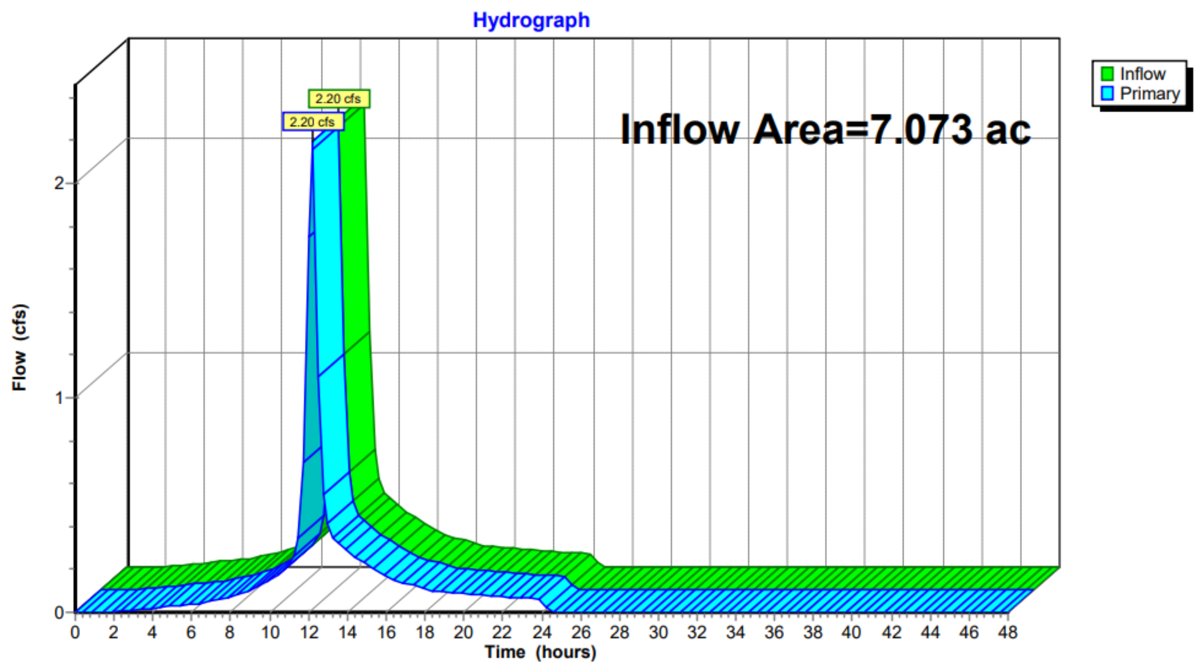

Figure 18. Hydrograph model of the Residential Area showing runoff in cfs.

The three areas had a total area of 7.073 acres, as determined through GIS. The three sections, as shown below in Figures 19, 20, and 21 show the storm analyzed, area, runoff area, runoff volume, runoff depth, time of concentration, and the CN value that was used in stormwater calculations. The CN values were determined through HydroCAD by matching the description of the land and condition to the Soil Type A to get a curve number value. Using the HydroCAD manual, specifically the travel time and time of concentration equations, the team estimated the time of concentration. These values were calculated for each area through HydroCAD which uses the SCS runoff model equation.

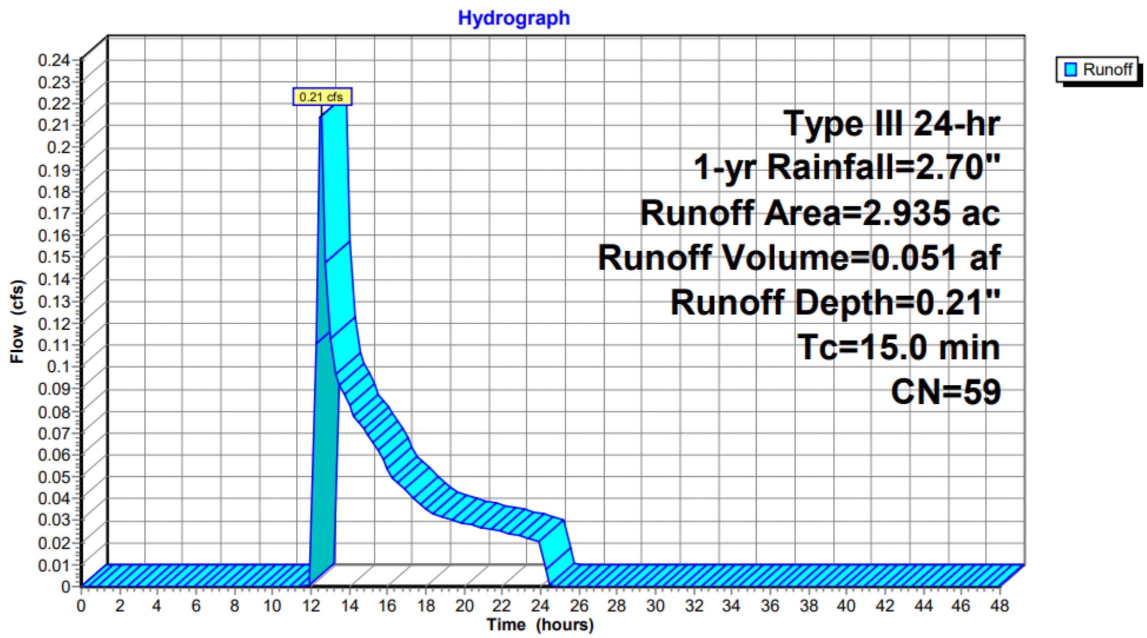

Figure 19. Hydrograph model for the residential area.

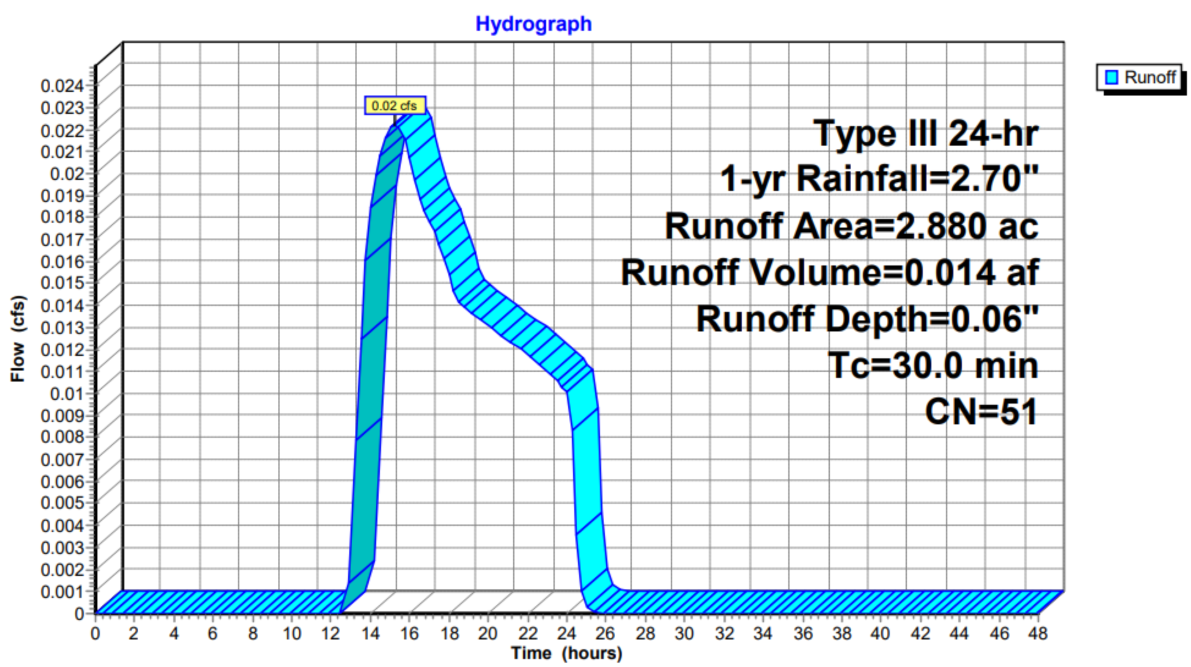

Figure 20. Hydrograph model for the park area.

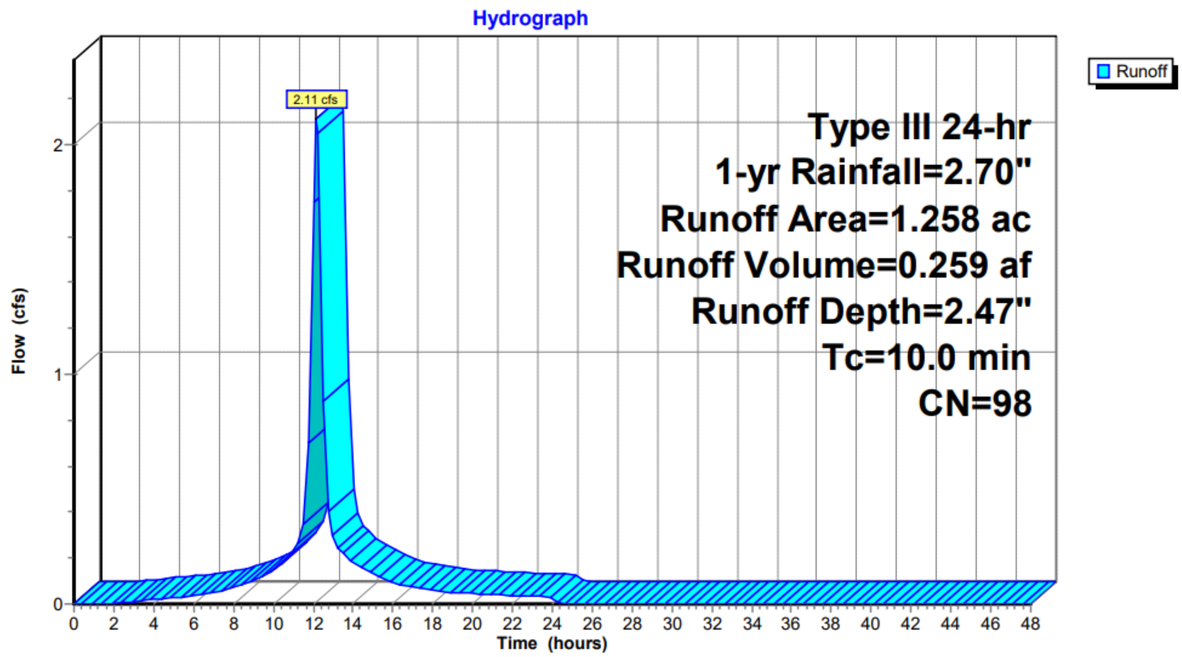

Figure 21. Hydrograph model for the street area.

The street area had the largest runoff volume because it has the largest amount of impervious surface and the highest CN number. The park has the lowest runoff volume because it has the smallest amount of impervious surface and the lowest CN number. These values were used to further narrow down our focus into the four different areas, as seen previously in Figure 4. Area 1 and 2 both focus on street runoff and any residential runoff from the houses on both Cove Avenue and Lake Avenue since that is where a majority of runoff is coming from. The park area is not of major concern since the runoff is so low. Area 3 will account for runoff from the tennis courts, the only major impervious area of the park, as well as any runoff coming down from the park that wasn't absorbed into the ground. Area 4 will still capture all stormwater flow from the catchment area before it enters the outfall. This will include all runoff from the streets, park, and residential areas.

4.3 Laboratory and Sampling Testing

The storm was sampled towards the end of the storm; therefore the actual pollutant flows and event mean concentration entering Lake Waushakum may be higher than reported. It was observed that the flow at the outfall was higher than the flow at the catch basin, however the outfall was also sampled first before the catch basin. Testing and sampling were taken November 16, 2022.

Table 2: Outfall and Catch Basin Field Testing and Laboratory Results

Test Performed	**Outfall Result**	**Catch Basin Results**
Temperature	13 °C	10 °C
Conductivity	14 µs	13.4 µs
Salinity	13.1 ppt	13.1 ppt
Detergents	0.25 ppm	0.25 ppm
Ammonia	0.10 ppm	0.10 ppm
Chlorine	0.03 mg/L	0.18 mg/L
Flow	0.47 gpm	0.18 gpm
pH	6.14	6.05
DO Day 0*	10.53 mg/L	10.81 mg/L
DO Day 5	11.54 mg/L	10.17 mg/L
TSS	6 mg/L	3.6 mg/L
Total Phosphorus**	0.183 ppm	0.196 ppm
Dissolved Phosphate	0.18 ppb	0.19 ppb
Nitrate	0.12 ppb	0.08 ppb

For most Samples, holding times are generally very short - 8 hours for source water compliance samples, 30 hours for drinking water samples, and 48 hours for coliphage samples (EPA, 2023).

*DO Disclaimer:

Samples were not run and read until 7 days after initial collection date

**Phosphorous Disclaimer:

These samples were not read until 68 days after collection due to campus breaks and supply chain issues.

TSS Results:

The results found from TSS removal indicate that the suspended solids concentration is greater at the outfall compared to the catch basin. This could indicate scouring has occurred in the piping between the catch basin and the outfall. Solids were picked up by the stormwater in the pipe which means that maintenance and cleaning of the pipes needs to occur.

Dissolved Phosphorus Results:

Ion Chromatography System (ICS) results show the different compounds that were detected along with their levels. An in-depth table for each compound can be found in Appendix K.

E. coli Results:

After 24 hours in the incubator, the E.coli samples were read. Since both of the samples were yellow, this meant that there was a positive result for E.coli, as seen in Figure 22.

E.coli Disclaimer:

These samples were run approximately 22 days after collection due to Coliert test kits not arriving through the mail. This would result in more coliforms populating and having a high amount when looking at results.

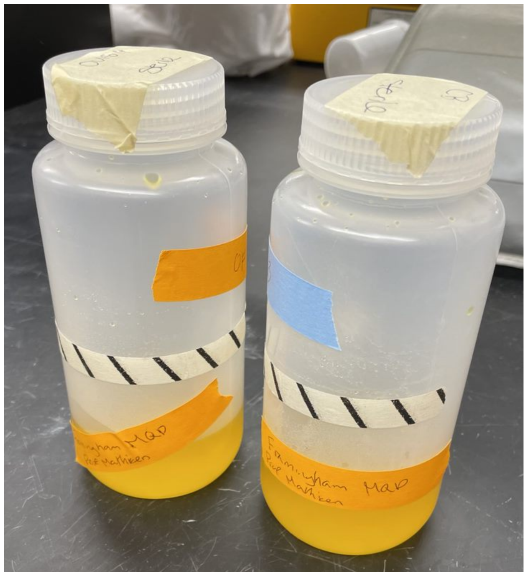

Figure 22. Samples taken turned yellow meaning E. coli was present.

When held under a UV light, the samples were fluorescent, meaning that there were coliforms present in both of the samples. This can be seen in Figure 23.

Figure 23. Samples taken were fluorescent meaning Coliforms were present.

Since there were coliforms present, there is a need for BMPs across the catchment area to treat and minimize stormwater entering Lake Waushakum.

4.4 Treatment Area Analysis

As discussed in Section 4.1, GIS was used to determine the four areas that would be analyzed for the implementation of BMPs.

- Treatment Area 1: Northwest side of the park along Lake Ave
- Treatment Area 2: Two sections south of the tennis courts/basketball court on Cove Ave
- Treatment Area 3: Corner of Lake Ave and Cove Ave, south of the playground
- Treatment Area 4: Underground Lake Ave south of the tennis courts, in between the two catch basins

The sections below discuss the different areas that the group focused on in preparation for final recommendations.

4.4.1 Treatment Area 1

Treatment Area 1 is located along the northwest side of the park along Lake Ave as seen in Figure 24. This area was determined to be important because this area is where anyone who visits the park will park. Over time, the grass has formed large divots and severe puddling occurs. This area also is near a catch basin so a BMP could possibly be connected to the drainage system to help with removal.

Figure 24: Proposed Area 1 on Lake Ave.

4.4.2 Treatment Area 2

Treatment Area 2 is proposed to be split into two areas located south of the tennis courts as seen in Figure 25. This area was chosen because it is close to the catch basin and does not have a lot of foot traffic so that a larger and more effective BMP can be placed here.

Figure 25. Proposed Area 2 on Cove Ave south of the tennis courts.

4.4.3 Treatment Area 3

Treatment Area 3 is located along the southwest side of the park on the south side of the playground and picnic area on the corner of Lake Ave and Cove Ave as seen in Figure 26. This area was chosen because it also is close to the catch basin and does not have a lot of foot traffic so that a larger and more effective BMP can be placed here.

Figure 26: Proposed Area 3 on the corner of Lake Ave and Cove Ave, south of the playground.

4.4.4 Treatment Area 4

Treatment Area 4 was decided to be a very feasible spot for an underground treatment system between the two catch basins as seen in Figure 27. A treatment system here would be able to catch any final pollutants that were not caught beforehand.

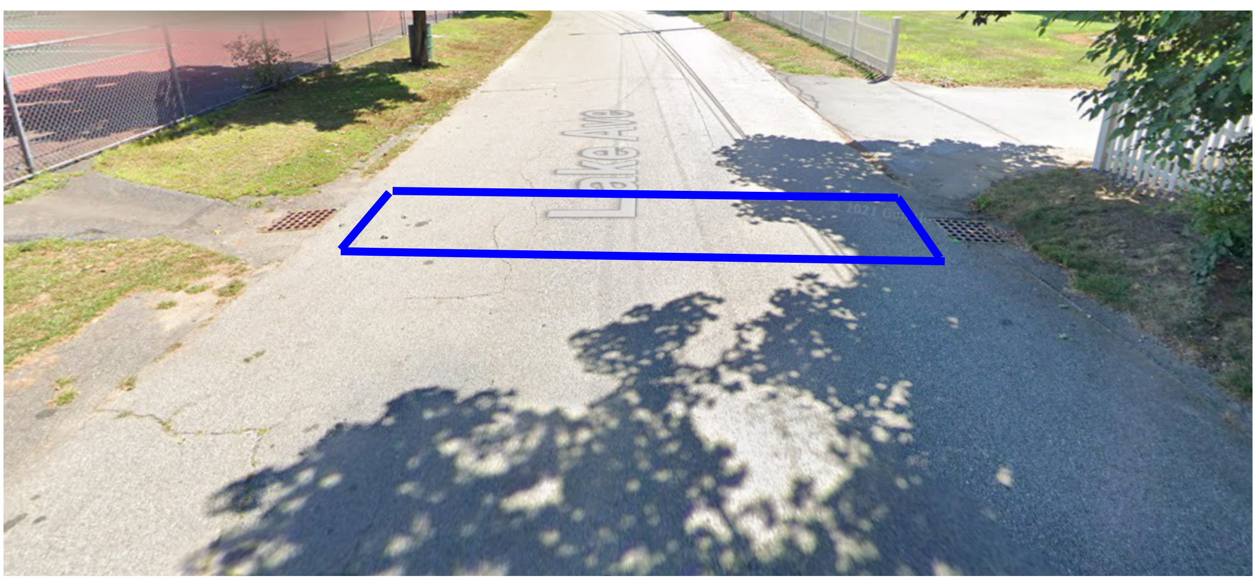

Figure 27: Proposed Area 4 on Lake Ave south of the tennis courts, in between the two catch basins underground (GoogleMaps).

4.5 BMP Analysis

After analyzing the site with GIS and HydroCAD along with the sampled wet weather data, our team was able to narrow down the list of BMPs that could be implemented into Anna Murphy park in order to improve the water quality of Waushakum Pond. The designated areas shown in Figure 4 (Section 4.1) and discussed in Section 4.4 are where the BMPs will be placed. Each area has different designated BMPs that can best benefit the reduction of stormwater pollution.

4.5.1 Possible BMPs

Our team was able to finalize the possible BMPs considered for each area shown in Table 3.

Table 3: BMP Decision Matrix Results

Decision Matrix

	List of BMPs	Cost	Maintenance	Removal Efficiency	Area Functionality	Design	Total	
Considering	Vegetated Filter Strips	4	4	2	4	5	19	Legend
	Rain Garden	4	4	4	3	5	20	1 = Poor
	Tree Box Filter	4	5	3	5	5	22	5 = Best
	Water Quality Swale	4	3	4	4	3	18	
Maybe Consider	Grassed Channel	3	4	1	3	4	15	
	Dry Detention Basins	4	3	2	2	2	13	
	Green Roofs	2	5	1	2	3	13	
	Baffle Boxes	2	2	5	5	3	17	
	Rain Barrels/Cisterns	4	3	5	2	3	17	
	Drainage Channels	3	4	1	3	4	15	
Not Considering	Catch Basin Inserts	3	1	2	4	2	12	
	Wet Basins	1	3	4	1	2	11	
	Sand & Peat Filters	1	3	3	3	2	12	
	Constructed Stormwater Wetlands	1	3	4	2	2	12	
	Proprietary Media Filters	1	2	2	2	3	10	
	Leaching Catch Basins	2	2	2	3	2	11	

Any BMPs with a score of 12 or lower were no longer considered from this point on (marked in red). This was because their ratings for each category were much lower than the other BMPs being considered. BMPs with scores between 13-17 (marked in yellow) had some feasibility issues but were still considered when planning which areas of the park would implement BMPs due to having higher scores in some categories. The BMPs with a score of 18 or more (marked in green) were highly considered during the planning phase of the project as they were the most well-rounded and had high scores in most categories.

4.5.2 Feasible BMPs

When identifying the 4 Treatment Areas, the team considered more than one option for each area. All considered BMPs provide high TSS removal.

Tree boxes were considered most feasible for Area 1 as there are already trees scattered in that area, which would fit the aesthetic of the park. It also would not affect any public use of the park. Vegetated filter strips and water quality swales were also options due to the large amount of space Treatment Area 1 has to offer, but they could affect the public access to the field on the north side of the park. Wet water quality swales also provide phosphorus removal which can help reduce the high phosphorus tested levels of 0.183 ppm from the outfall given by the spectrophotometer test.

Due to the small size of Treatment Area 2, along with it being an area where minimal people would walk on, our team considered a rain garden. Rain gardens also provide high phosphorus removal which will reduce the phosphorus load currently flowing through the catch basins. Tree. boxes were also considered, but rain gardens are more affordable than tree boxes and can come in more diverse sizes, making it a more feasible BMP option. Tree boxes also have high chloride removal rates which will decrease the chloride results taken from the ICS lab test.

For Treatment Area 3, our team considered a similar solution to Treatment Area 1, where tree boxes were deemed most feasible which would match the aesthetic for the park and provide more shade near the playground area. The tree boxes would also stop cars from parking on the grass in the park which would reduce the divots created from cars causing puddles during the rainy season.

For Treatment Area 4, a baffle box was considered where it would be implemented in the street, laying in between the 2 catch basins that flow to the outfall. Since it would be difficult to implement any BMPs near or on the outfall (the outfall resides on private property), our team believed this would be the next best solution. Another option for Treatment Area 4 that our sponsor recommended was a Cascade Separator system, which would provide similar benefits to the baffle boxes, with the benefit of the city having designed and constructed similar systems in past projects.

4.6 Hydraulic Analysis

When considering the flow after BMP construction, how much flow would be removed by each treatment system will affect the final flow exiting the outfall. This value will affect the dimensions and final designs of each BMP to appropriately treat the catchment area. Flow removals from each treatment system can be seen in Table 4. It was assumed that the rainfall amount was 3.33 in/24 hour for both the tree box filter and rain garden for a 2-year storm event (US Department of Commerce, 2005). All calculations were completed based on the designs in Section 5 and can be found in Appendix J. The tree box filter removes an average flow of 0.004 cfs. The park area was not considered for the calculation of flow entering the tree box because the pervious nature of the park has limited runoff as seen in the HydroCAD analysis. The rain garden storage potential is 405 $cubic\ feet$. Rain garden designs are expected to be designed to hold rainwater without overtopping (Iowa Stormwater). With an expected percolation rate of 1 in/hr (Iowa Stormwater), and the rainfall event occurring at 0.14 in/hr, there is enough time for the water to percolate into the rain garden (1in/hr>>0.14 in/hr). Therefore the flow removal for the rain gardens is the amount of rainwater that is expected to enter both the rain gardens during an average rain event, 0.091 cfs. The underground treatment system has no flow removal because it primarily removes pollutants such as TSS and does not significantly affect the stormwater flow. A summary of flow reductions for each treatment system are located in Table 4.

Table 4: Flow Reduction for each Treatment System

BMP	**Flow Removal (cfs)**
Tree box Filter	0.004
Rain Garden	0.091
Underground Treatment System	0.000

If the tree box filter and rain garden BMPs are implemented into their respective treatment areas, they will reduce the amount of flow and/or pollutants going to the underground treatment system. The flows will be further discussed regarding how they apply to the design of each BMP in the following section.

5.0 Recommendations

This section discusses our recommendations for BMP designs in Anna Murphy park that will help reduce stormwater pollution in Lake Waushakum. The designs are applicable for the areas in Figure 28 and discussed in past chapters that take into account cost, removal efficiency, management, and size. Our recommendation will allow the City of Framingham to stepwise implement the BMPs which will improve the overall water quality of the lake. Implementation and construction scheduling are also recommended to help with the planning process. Table 5 gives an overview of our recommended treatment systems.

Table 5: Treatment Area Overview

Treatment Area Overview	
Treatment Area	Recommended BMP
Area 1	Tree box Filter
Area 2	Rain Garden
Area 3	Tree box Filter
Area 4	Underground Treatment System

Figure 28. GIS Map with the proposed areas.

5.1 Proposed Tree Boxes

Tree boxes are being recommended for both Areas 1 and 3 because of the small size, location, and flow removal. The City of Framingham is currently piloting Contech Filterra boxes, therefore for the ease of design, construction, and maintenance, the group is recommending continuing using the Filterra upon assumption of a successful pilot test. The pilot is taking place on Gilbert Street in Framingham, where the City has plans to put in two Filterra systems in order to reduce stormwater flow from the road and treat the existing stormwater. The Filterra will treat stormwater and can handle large flow rates up to 175 inches per hour (Contech, 2022), while still maintaining the aesthetic of the park, a key factor for the City of Framingham. Based on lab results, as discussed in Section 4.3, there were high levels of TSS and Total Phosphorus, both of which have removal efficiencies ranging between 70% to 86% (Contech, 2022). Specifically, TSS has a removal efficiency of about 86% and Total Phosphorus has an efficiency of about 70% (Contech, 2022). The

Filterra system will be built into the existing stormwater system, as seen below in Figure 29 provided by Contech.

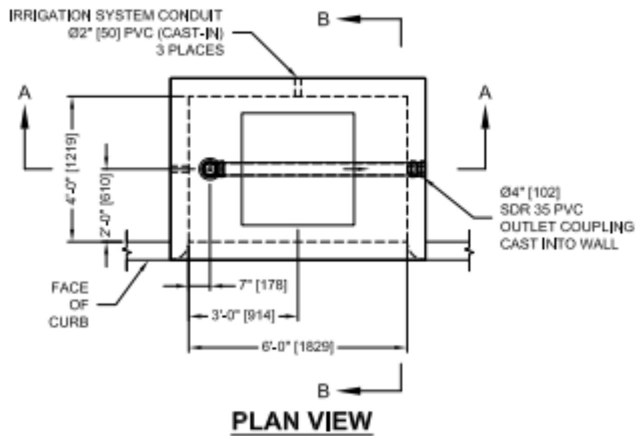

Figure 29. Overhead plan view of the Filterra system with the existing stormwater pipes running through.

The side views in Figure 30 from Contech represent how the piping system will run through the soil and crushed rock layers and the stormwater will continue through toward the outfall. The stormwater entering the Filterra will flow through the top grate and percolate through the soil layers to the pipe system.

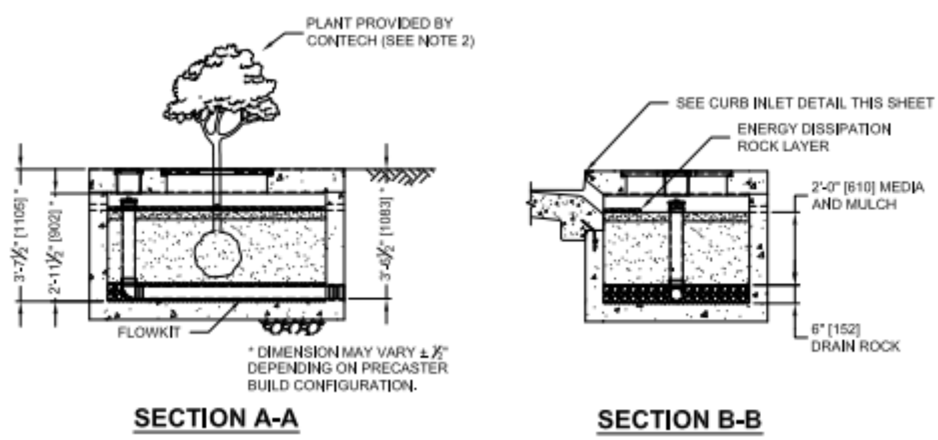

Figure 30. Side views of the Filterra system from Contech.

A similar system in Figure 31 shows the soil makeup of the tree box. The proposed Filterra system will have a topsoil layer, bioretention soil layer, and crushed rock layer. A 6'x4' tree box is the recommended size for optimizing pollutant removal. There will be a 4" topsoil layer above a 3' bioretention media and a 6" pea gravel bedding that the stormwater pipes will run through. There will be a tree or plant, for example a Deciduous tree like the trident maple or blackhaw viburnum, through the grate that will be provided by the manufacturer, Contech.

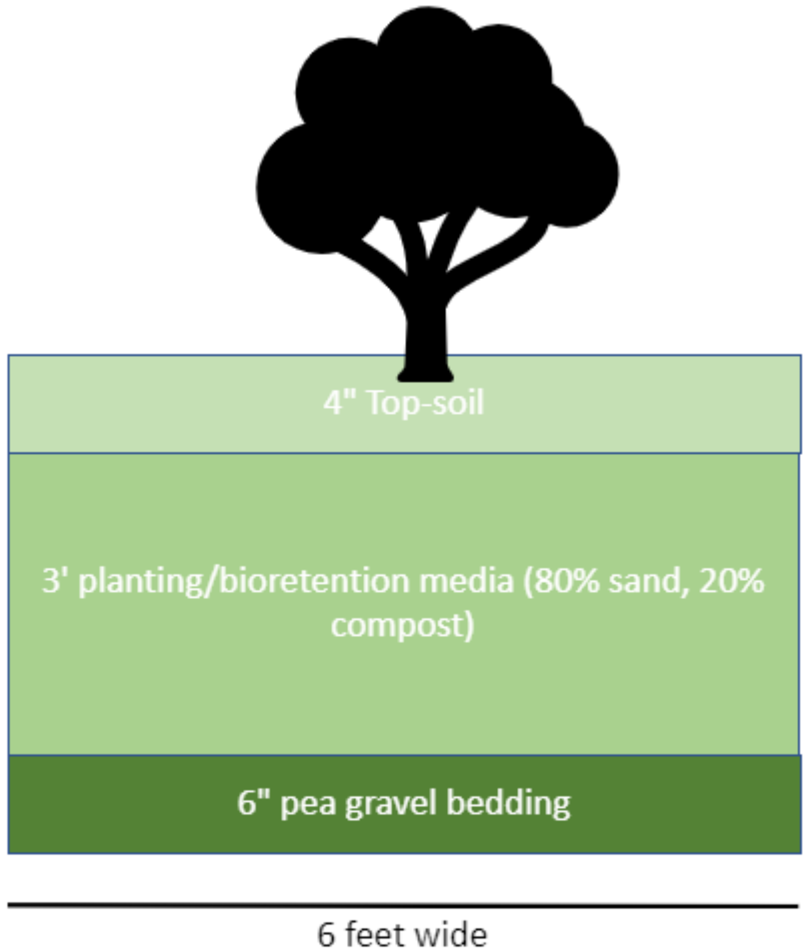

Figure 31. A detailed image of a tree box demonstrating the different matter layers. The stormwater pipe will run through the pea gravel layer.

The system will be built along the side of the road in the grassy or sandy area. In Areas 1 and 3, the Filterra will be built between the fence and the road. This placement will avoid the electrical box and fire hydrant along the west side of the park. The box will be placed within the length of the fence so there is still an opening to enter the park, however the Filterra will still be able to be walked on without damage to the system. The grate covering the box allows water to flow through but is made of galvanized steel and can withstand stress (Contech). The Filterra placement will ensure accessibility to the playground and baseball field while also maintaining the integrity and aesthetic of the park.

The price of each Filterra system, estimated based on previous projects from the City of Framingham, will cost roughly $16,000 for construction, totaling $32,000 for both tree boxes including construction costs. Since both tree boxes can be installed at the same time, there may be savings in construction and installation costs. There is minimal maintenance required except a few additional yearly costs such as leaf blowing and cleaning off the top grate which can be completed along with routine catch basin cleanings. In addition, it is recommended to replace the mulch layer after removing trash or debris annually.

The parameters for the Filterra system as follows:

Size of the Filterra box: 6x4 ft

One tree box accounts for about ¼ acre of impervious area (Low Impact Development Center, 2007)

Estimate of total area potentially treated by tree boxes (value from HydroCAD) = 0.480 acres (residential park area) + 0.5 acre (residential area) +1 acre (street) = 1.98 acres

[This value was calculated based on the area flowing into the catch basins from the western side of the catchment area because Areas 1 and 3 are along Cove Ave. and the western end of Lake Ave.]

1.98 acres of impervious area *1/2 tree box/acre impervious area = 4 tree boxes for the drainage area

Considering cost and construction feasibility, our group is recommending the City of Framingham begin by implementing two tree boxes for the catchment area. It is important to also consider that the group overestimated the size of the potential area treated by the tree box so that it would account for larger precipitation events. Also, the rain garden will be treating a large portion of this drainage area and will account for some of the runoff that does not go into the tree boxes, as discussed in Section 5.2. However, the City of Framingham has requested our proposed treatment system have the ability to be added or implemented in steps based on the budget of the City. In the future, after the two original tree boxes are added, two more tree boxes can be added along Cove Ave and Lake Ave as deemed necessary based on funding and pollutant contamination.

5.2 Proposed Rain Garden

Our recommendation for a feasible BMP in Area 2 are rain gardens. Since Area 2 has a residing tree in the center of the grass area, the team recommends implementing two smaller rain gardens adjacent to the tree, parallel to the tennis courts and the street Lake Ave. Rain gardens provide an easy design and lower cost compared to other BMPs. Rain gardens can remove up to 90% TSS, 30-50% Total Nitrogen, 30-90% Total Phosphorus, and 40-90% metals (mass.gov). Figure 32 proposes the dimensions of both rain gardens in context of the park layout, along with a list of the most practical plants.

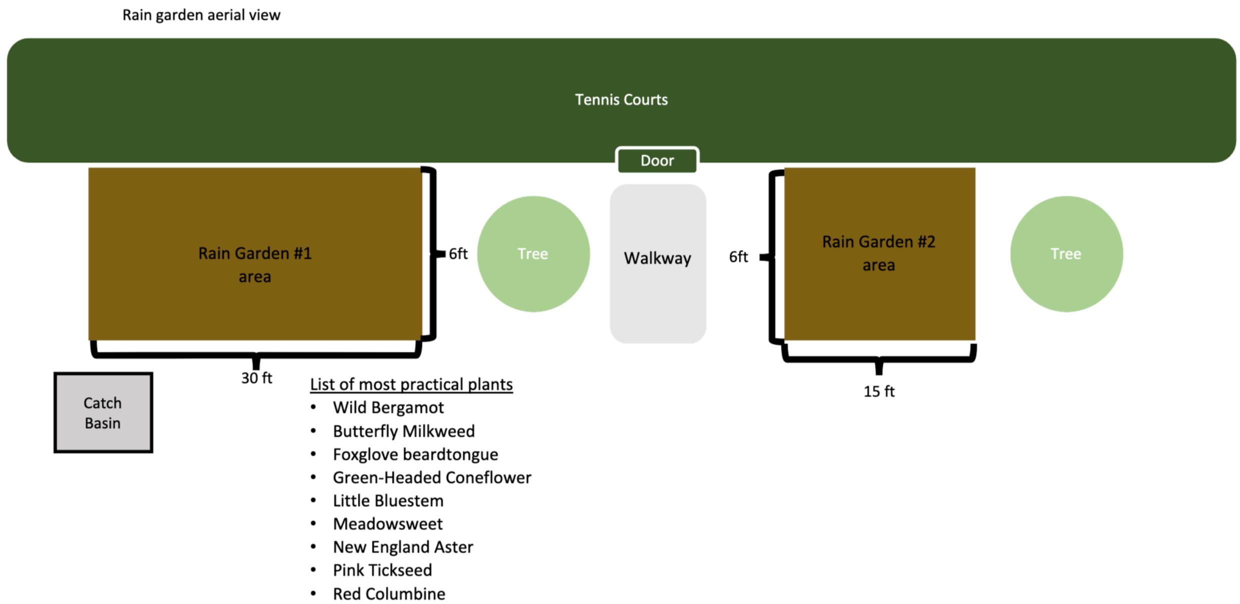

Figure 32: Proposed aerial view of rain garden.

The list of most practical plants are all feasible rain garden plants in Massachusetts (Massachusetts Office of Coastal Zone Management (CZM)). Our team chose these plants mainly based on their visual appearance and if they were capable of living in a moderate-moisture environment. These plants are also tolerant to salt spray and wind, which is beneficial during the winter seasons when the roads are salted. All of the chosen plants are considered perennials and grasses. The recommended size of rain garden #1 is 6 feet in width, 30 feet in diameter, and 18 inches in depth whereas rain garden #2 is 6 feet in width, 15 feet in length, and 18 inches in depth. The rain gardens have different sizes due to the communal walkway and the tree on the right side of the figure. The dimensions shown above allow for construction to occur in these areas, without affecting any park access or trees. Figure 33 goes in depth on the different components that are necessary to build a functioning rain garden.

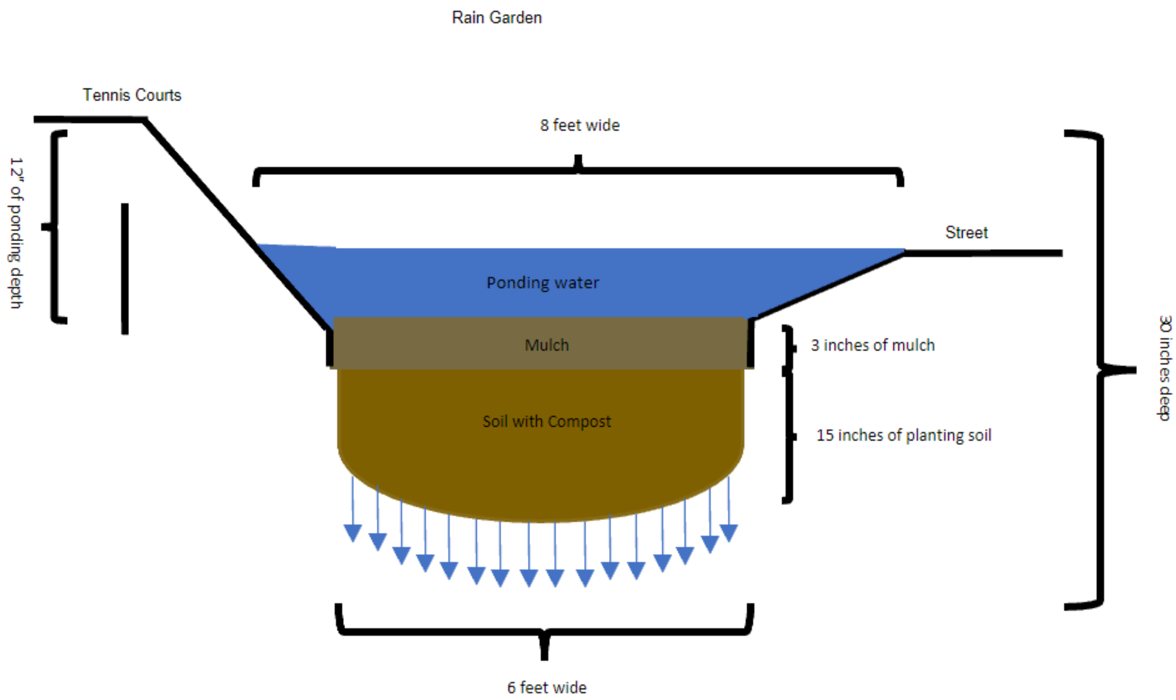

Figure 33: Proposed side view of rain garden.

Currently, the tennis courts have a higher elevation compared to the street. The current grass patch that resides where the rain gardens are recommended to be placed will need to be landscaped to create a flatter surface area, as rain gardens are designed to have water permeate through its soil. Since the rain garden would be implemented adjacent to Lake Ave, the City of Framingham will need to maintain the structure of the rain garden by adding signs to inform people not to park in this area. Maintenance in the winter will also need to be considered as plows should not be directing any snow into the rain gardens, which could compact the soil or damage the plants (Planting FAQs).

For the cost of the two rain gardens totaling 270 sq ft, the team estimated that it would cost $7,920 for Rain Garden #1 and $3,960 for Rain Garden #2. This takes into account installation ($40/sq ft) and maintenance ($4/sq ft). The cost for implementing the rain gardens, including a percolation test ($150) and a soil test ($90) is $12,120 (Terrascope 2024). Even so, this cost is an estimate on standard rain garden implementations from Terrascope which does not include excavation of the designated rain garden areas, or any additional challenges. The team recommends a 20% contingency, which would add an additional $2,424 to the total cost. The estimated total cost for implementation of the rain gardens is $14,544

5.3 Proposed Under-Road Treatment System

The Cascade Separator system that the City previously designed for Gilbert Street was ultimately not considered as a final choice due to issues with local residents. The area where the Cascade Separator system would have been constructed had previous issues with flooding and there was difficulty regarding city access and easement agreements with residents. The city instead went with the filterra designs because they felt it would be more feasible and would ultimately remove more TSS. This insight ultimately aided the team in selection of the proposed under-road treatment system.

Since the area that the Cascade Separator would be placed in was not known to be a highly flooded area, the team decided that this Cascade Separator would be good to place at catch basin #2008854, which can be seen in Figure 34.

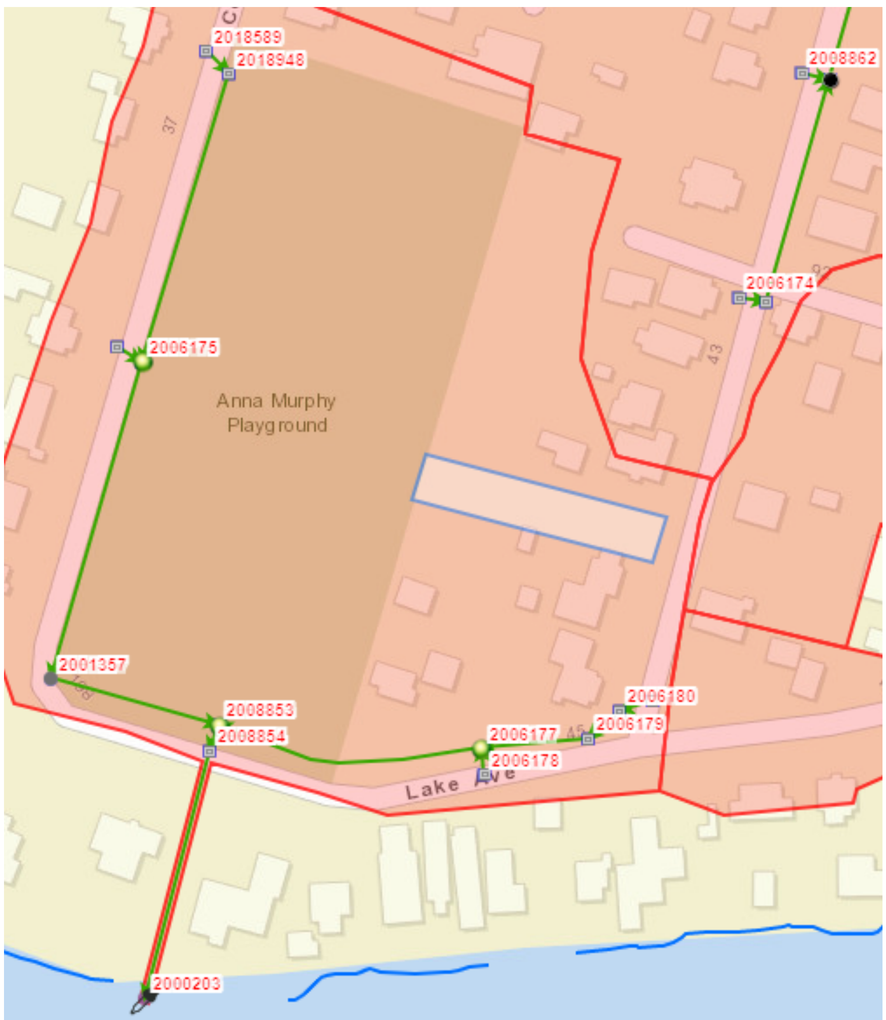

Figure 34: Catch basins within the catchment area.

Since the treatment system is underground, the city owns the right-of-way which will limit legal fees and easement issues when construction begins or maintenance is needed. The placement of this separator would allow for TSS to be collected before it reaches the outfall which will help meet the city's goal of lowering the level of suspended solids in Lake Waushakum. This design will also be easy for the city to maintain. There is no requirement to enter the unit, meaning the city can use a vacuum truck to maintain the structure (Contech Engineered Solutions, n.d.). Contech also has its own network for maintenance providers that can be used to provide maintenance to this structure.

Implementing this design is estimated to cost about $25,000. This value was given to the team by the City of Framingham and reflects the cost to implement this same pilot model on Gilbert Street. This value includes the cost of the model, excavation costs, and any associated installation costs. The specific model that will be used is the CS-5, which can be seen in Figure 35.

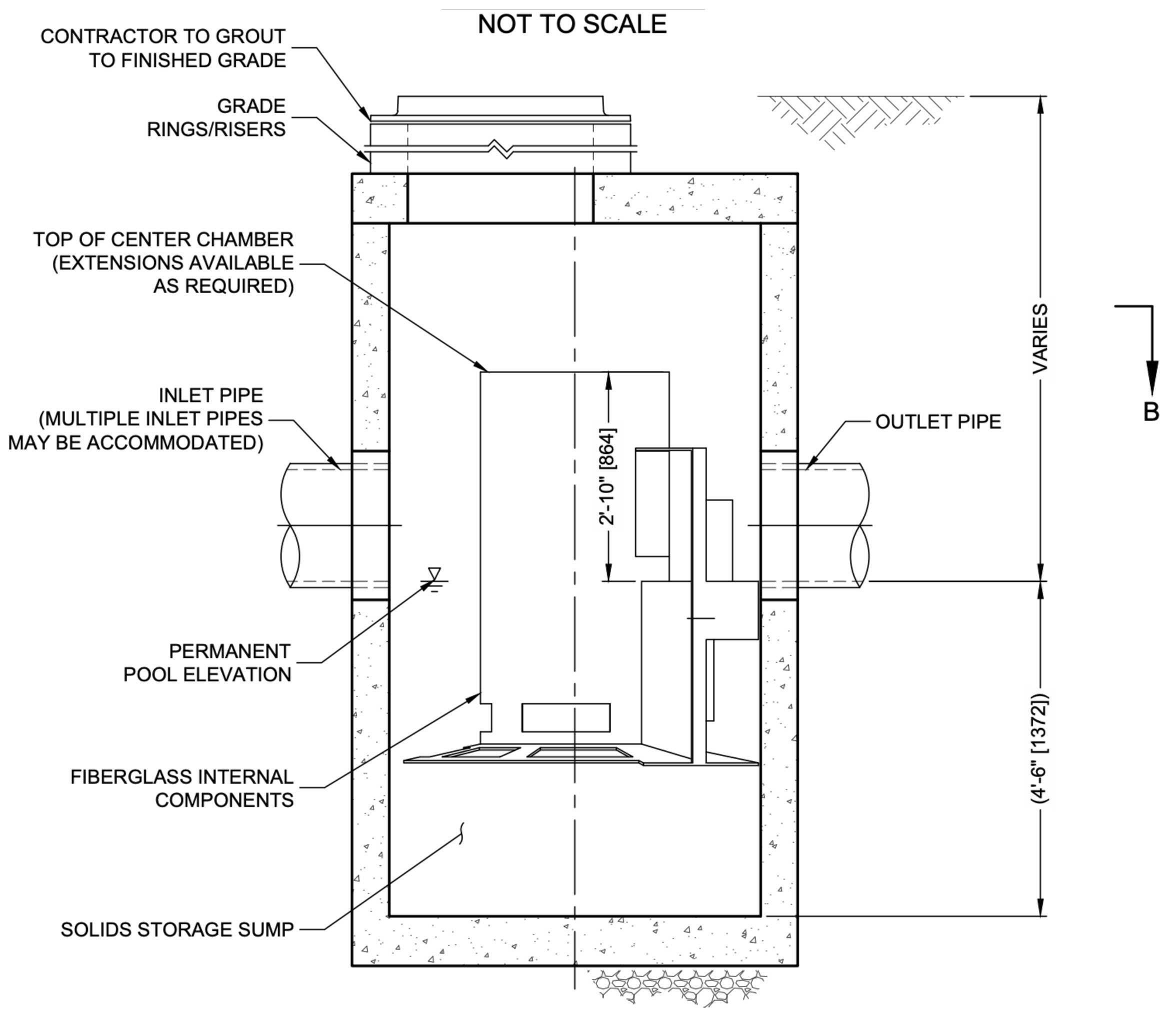

Figure 35: CS-5 Cascade Separator Standard Detail. (Contech Engineered Solutions, 2019).

Catch basin #2008854 is made out of precast concrete. It has a base elevation of 159.76’ to the bottom of the inlet pipe and a surface elevation of 166.76’. The catch basin is 7’ deep with no sump and has a 3’ diameter.

The half of the separator that is below the inlet and outlet pipes is set to a standard 4’6”. The half of the separator above the bottom of the inlet and outlet pipes varies based on the size of the catch basin. Therefore, the dimension of the top half of the separator would be 7’. The total height of the system would be 11’6”.

If the city would like to change this dimension, the team recommends raising the height of the inlet and outlet pipes. This would allow the separator to be raised up and be shorter than a total height of 11’6”. Moving the pipes would cause an in increase in cost. If any rehabilitation to the catch basins in this area were to be considered in the future, moving the pipes to a higher elevation should be considered.

5.4 Implementation and Construction Plans

After determining each of the specific BMPs for each Treatment Area, our group determined a stepwise approach to implementing and constructing the BMPs would be best. The city has a limited budget for stormwater projects that is heavily reliant on grants. Adding the BMPs to Catchment Area 2368 as deemed feasible by the city allows them to have control over their budget, but still make changes to improve the water quality in Lake Waushakum. Implementing BMPs specifically in Anna Murphy Park will reduce the amount of stormwater pollution flowing into the lake via the park’s outfall.

The first BMP that should be implemented into the catchment area should be the Filterra Tree Boxes into Treatment Areas 1 and 3. These should be implemented before any of the other treatment BMPs because they have high removal rates and have been utilized by the City in similar stormwater projects. If there is a long time period between the construction of additional BMPs, having the tree boxes will still be providing more removal than there is currently.

The second BMP that should be constructed is the rain garden in Treatment Area 2. The rain garden BMP will provide high removal of pollutants in an area of the park that currently go straight into the lake. There would be a need for excavating the area where the rain garden will be placed due to the ground not being fully level currently. An approach to constructing and implementing rain gardens at a lower cost to the city would be using local volunteer organizations such as Boy Scouts, Girl Scouts, or local youth groups. States such as West Virginia and Tennessee have already been implementing these practices through Land Trust and Environmental Classroom projects.

Finally, the underground treatment system, the Cascade, should be implemented last in Treatment Area 4. It is the most expensive treatment system because it requires the most construction and disturbance to the area. However, the Cascade only has removal of TSS with no significant removal rates for nutrients. The road would need to be removed and then repaved after the installation of the system. The stormwater piping system would be removed to fit the Cascade along with soil removal and disposal or displacement.

Overall, the group is recommending the order of the installation of BMPs to be Treatment Area 1 and 3 together, Treatment Area 2, and then Treatment Area 4, referenced in figure 28 in Section 5.0. This recommendation is based on removal rates, costs, and construction requirements. The city can construct the BMP that best suits their needs and budget, and then perform additional testing to see if the necessary removal rates were achieved.

6.0 Conclusion

This project included a stormwater sampling plan, laboratory analysis of collected samples, ArcGIS characterization, HydroCAD analysis, BMP feasibility matrix, and recommendations on which BMPs to implement with coordinating locations. Results from TSS, Total Phosphorus, E. coli and Dissolved Oxygen showed that there were high levels of chlorine and coliforms in the samples collected. Both HydroCAD and ArcGIS were used to provide further details on the underlying conditions of the area and were used to determine the most feasible areas that BMPs can be implemented. Tree box filters, rain gardens and an underground treatment system were the 3 BMPs that were recommended to the City.

The City is working to implement BMPs similar to the ones discussed in this report in other catchment areas surrounding Lake Waushakum. To ensure moving forward the City of Framingham is continuously making an effort to actively lower the amount of pollutants entering Lake Waushakum, the team recommends that further investigation be completed at each outfall and catchment area. This would involve field testing and observation as well as laboratory analysis. A priority of each catchment area and outfalls would be developed and analysis similar to the one in this project would be performed. In order to fund these types of projects, our team recommends the City continue to apply for available grants and funds for stormwater management projects and improvements. Overall, there are many ways to design and implement different Stormwater BMPS into different areas. It is important to do our best efforts as engineers to protect the public health and welfare of our local communities. Our team recommends working closely with The City of Framingham to assist with future MQP projects near or at Lake Washakum.

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Appendices

Appendix A: Proposal

Stormwater Management & Design

in Framingham, Massachusetts

Stormwater Management & Design in Framingham, Massachusetts

A Major Qualifying Project Proposal

Submitted to:

Sponsor: Alison Eliot: Framingham DPW

Project Advisors: Suzanne LePage and Paul Mathisen

Submitted by:

Adele Brochu

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Kali Sander

Caitlin Strzegowski

Date Submitted:

10/13/2022

Table of Contents

CAPSTONE DESIGN STATEMENT

Worcester Polytechnic Institute's Civil and Environmental Engineering Department requires that all Major Qualifying Projects contain a capstone design component. Our MQP meets the capstone design requirement by designing a Best Management Practice (BMP) to address water quality for Parcel 2368 entering Lake Waushakum in Framingham, Massachusetts. The design includes water quality sampling, evaluation of topography and land demographics, selection of BMP, and determination of specifications of the BMP. The design considers the following economic, environmental, sustainability, constructability, ethical, health and safety, and social and political considerations:

Economic: The proposed BMP will be cost-effective for the City of Framingham. We will analyze this through a cost-benefit analysis of all installation and maintenance costs.

Environmental: This project will develop a BMP that improves the stormwater quality entering Waushakum Pond from Outfall 2000203.

Sustainability: The BMP design will be sustainable for the site location, improving removal efficiency and life span while staying affordable.

Constructability: The BMP will be designed to ensure ease of installation, operation, and maintenance.

Ethical: This BMP will comply with the ASCE code of ethics and improve the water quality of Lake Waushakum, which will improve environmental justice in the neighborhood and community.

Health and Safety: The proposed BMP design will help limit pollutants entering Lake Waushakum. Once Lake conditions improve, it can be open for the public to use again safely.

Social and Political: The Massachusetts DEP has implemented various rules and regulations for stormwater pollution prevention entering bodies of water. The City of Framingham would like to implement stormwater BMPs to help mitigate stormwater pollution in Lake Waushakum while staying compliant with all DEP regulations.

1.0 INTRODUCTION

Lake Waushakum or Waushakum Pond is an 82-acre kettle pond located in both Framingham and Ashland, Massachusetts. There are approximately 145, 1-acre catchment areas in Framingham surrounding the lake. Lake Waushakum is currently listed on the Massachusetts Integrated Lists of Waters, for total phosphorus, turbidity, dissolved oxygen, and aquatic plant impairments. The public beach at Lake Waushakum is consistently closed due to high levels of E.coli and sometimes does not open for months at a time. Stormwater runoff has been identified as the main contributor to pollutant loading and the inability to meet water quality standards. The City of Framingham will retrofit Waushakum's public beach with green infrastructure, enhance the riparian buffer at the City's property with vegetation, and expand its public outreach and education programs. Grant funding will be used to finalize design plans, support permitting, and construct green infrastructure at the public beach. The poor water quality has intensified as the City experiences more extreme rain events and impacts from climate change.

This project will use a combination of both structural and non-structural BMPs to improve water quality in Lake Waushakum. Our goal is to develop Best Management Practices (BMPs) for the Catchment Parcel 2368 to reduce stormwater pollutants and runoff that flow into Lake Waushakum. Three different objectives will accomplish this:

- Develop a stormwater sampling plan and collect samples to represent sources of pollution accurately.
- Analyze the collected sample for contaminants and characterize contributing areas and runoff to identify sources of pollution around Anna Murphy Park.
- Develop and evaluate BMPs to address stormwater runoff and develop a BMP strategy to implement in Anna Murphy Park.

2.0 BACKGROUND

In this section, we will discuss background details on Lake Waushakum and previous steps that the City of Framingham has taken to test contaminants. The 319 Grant and all associated permitting such as the NPDES, and MS4 permits that are required to conduct work will be addressed. Finally, previous Best Management Practices (BMPs) utilized by Framingham and surrounding Massachusetts cities to address similar problems will be analyzed.

2.1 LAKE WAUSHAKUM

Lake Waushakum (Waushakum Pond) is an 82-acre kettle pond located in Framingham and Ashland, Massachusetts. It is listed on the Massachusetts Integrated Lists of Waters as Category 5 for "Waters requiring a TMDL (Total Maximum Daily Load)", or the total amount of a pollutant that can enter a waterbody, for total phosphorus, turbidity, dissolved oxygen, and aquatic plant impairments. The lake has been closed consistently for the past three years due to high levels of E. coli (lab data citation). According to the Environmental Protection Agency (EPA), Waushakum Pond is impaired due to non-native aquatic plants, chlorophyll-a, dissolved oxygen, phosphorus, total, and turbidity (Massachusetts Division of Watershed Management, 2021). Stormwater runoff has been identified as the main contributor to pollutant loading and the inability to meet water quality standards. Stormwater is a Nonpoint Source pollutant (NPS) meaning it is diffused from many different sources. For example, rainwater can carry fertilizers, bacteria from pet waste, oils and grease from roadways, and sediment from construction or pathways (Framingham Source, May 2022). These pollutants end up in the water system through sewers and eventually spill into lakes such as Waushakum Pond.

The City of Framingham tests Waushakum Pond regularly for Escherichia coli (E.coli). According to the Department of Public Health, 105 CMR 445, minimum standards for a bathing beach include; “no single E.coli sample shall exceed 235 colonies per 100ml and the geometric mean of the most recent five E.coli samples within the sample bathing season shall not exceed 126 colonies per 100ml or no single E.coli sample shall exceed 61 colonies per 100ml and the geometric mean of the most recent five E.coli samples within the sample bathing season shall not exceed 33 colonies per 100ml” (Department of Public Health, 2014). Through 2021, Waushakum Pond was tested 22 times for E.coli. The results reflected a failed score of 20 of the 22 times because the E.coli levels were above the reporting limits. The two passing scores came in June 2021, but the beach was still not open (Framingham, 2021). Temporarily, the beach opened on June 17th, 2021; however, swimming was still not permitted. Waushakum Pond was sampled again in 2022, 22 times. Three of the tests failed the geometric; meanwhile one failed the single sample test (Framingham, 2022). The beach was open for most of the summer, however, swimming was not permitted for many weeks.

Town engineers, DPW staff, and parks and recreation staff have begun efforts to restore and remediate Waushakum Pond to prevent summer-wide closures. Partnering with local companies such as Weston & Sampson, city engineers have designed Best Management Practices (BMPs) utilizing green infrastructure, solar, and other climate-resilient solutions (Waushakum Beach Improvements).

Government officials and consultants have taken immediate steps to remediate the lake. Waushakum Pond was treated to temporarily minimize outbreaks of Cyanobacteria which can lead to Algae blooms. Temporary fixes have remediated the immediate need and reduced the risk of harmful toxins, such as cyanotoxins, that are dangerous to humans and animals. Side effects of consuming water contaminated with blue-green algae include diarrhea, nausea or vomiting, skin, eye, or throat irritation, and difficulty breathing (Mass.gov., 2019). Commonly found in surface water bodies, such as the lake, harmful algae blooms (HABs) typically occur in late summer and early fall in Massachusetts (Mass.gov., 2019). The City of Framingham samples for cyanobacteria, and when levels are elevated above 70,000 cells per ml (Framingham, 2021) a treatment utilizing copper algaecide is implemented to avoid the bloom. Treatments are notified to the public through blog platforms, social media, and signs on the beach (Framingham Source, June 2022).

2.2 PROJECT GRANTS

The City of Framingham has received a 319 Grant from the EPA for Waushakum Lake. The grant was established from the 1987 revision to the Clean Water Act to assist Nonpoint Source, or NPS programs to restore impaired waters and protect unimpaired high-quality waters (Yoshikawa, 2013). As of 2022, the available grant funds for the 319 Grant are $178 million, which are distributed by the EPA. Funds are distributed through a state-by-state allocation formula that was developed by the EPA and the states. States must use 50% of the annual proportion funds of the grant to implement watershed projects guided by watershed-based plans. The funds from this grant will allow the City of Framingham to improve the sustainability of the lake for future generations (City of Framingham, 2021). The City was able to obtain this grant for this project due to prior experience using a 319 grant. The City was familiar with grant processes and had a successful outcome of their other 319 grant projects, so they were able to easily obtain another grant for this project. The 319 grant can also be used to acquire permits (Comprehensive Environmental Inc., 2021).

2.3 PERMITTING

One permit used in stormwater management is the Massachusetts municipal separate storm sewer system or MS4 permit. This permit is composed of six different parts that all are used together to help reduce pollution when used together. The six aspects are public education and outreach, public participation, illicit discharge detection and elimination, management of construction site runoff, management of post-construction site runoff, and good housekeeping in municipal operations.

Waushakum Pond is located within the City of Framingham's regulated area under the 2016 NPDES MS4 Permit. This permit requires the City to complete a Phosphorus Source Identification Report by 2022 (City of Framingham, 2021). The NPDES Permit is used in accordance with the clean water act. The Clean Water Act prohibits anyone from discharging pollutants through a point source into a body of water unless they have an NPDES permit (US EPA, 2022). A point source is any type of conveyance of water such as a pipe, ditch, channel, or tunnel that can be used to carry water to any body of water. The permit contains limits on what can be discharged, monitoring and reporting requirements, and other provisions to ensure that whatever is being discharged does not hurt the overall water quality or people's health (US EPA, 2022). The permit translates general requirements of the Clean Water Act into specific provisions tailored to the operations of each person discharging pollutants. One structural BMP must also be installed by June 2024 as a demonstration project targeting a catchment with high phosphorus load potential.

In the Commonwealth of Massachusetts, the EPA, and MassDEP co-issue NPDES permits. NPDES permits regulate wastewater discharges by limiting quantities of pollutants that are discharged while imposing monitoring requirements (Massachusetts Department of Environmental Protection, 2022)

2.4 PARCEL 2368- ANNA MURPHY PARK AREA

An area noted as a high priority in the Lake Waushakum PSIR report was Catchment ID 2368, with the region focusing on Anna Murphy Park which can be seen in Figure 2.. The park consists of two tennis courts, a small playground area, and a little league baseball field. Phosphorus loading has already been tested in this area with an estimated phosphorus catchment load of 2.09 lb/year. There are no current BMP stormwater design plans for the park which will be the main focus of this project.

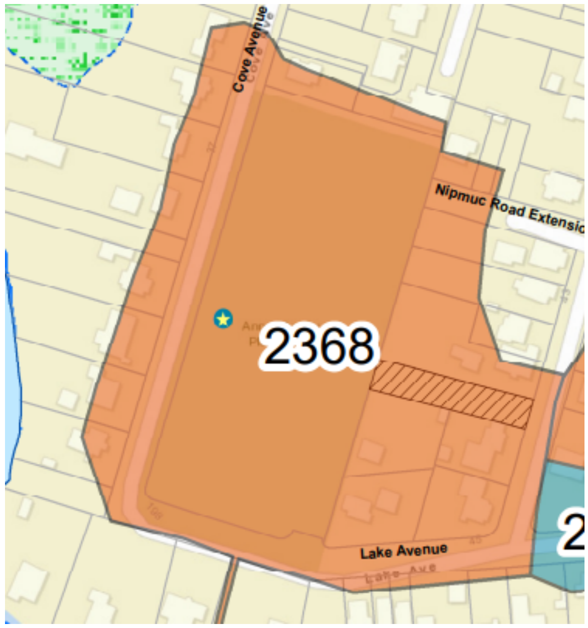


Figure 2. Catchment Area

An area around Anna Murphy Park, 60 Lake Park Ave, was tested in Mat of 2022, by both Weston and Sampson during a wet weather event. In the field, there were 4 tests performed: salinity, conductivity, ammonia, and surfactants. The results were as follows, salinity was measured at 8.8ppm, conductivity was measured at 17.1 µS/cm, ammonia was read at 0.01 mg/L, and surfactants were measured at 0.25 mg/L. Samples that were collected in this area were then laboratory tested for Total Phosphorus, BOD, Turbidity, E.coli, and Total Suspended Solids. Total Phosphorus for the area measured 0.26 mg/L, BOD results showed that the 5-day analysis did not meet the 2mL depletion requirement for any sample taken that day, Turbidity measured 3.6 NTU, E. coli read >2419.6 CFU/100mL but the sample was read past the run time, and finally, TSS results had No Data. Many of the tests performed at this site will need to be performed again so our group is able to get more accurate and updated data.

To gain a better understanding and obtain a better visual of the parcel, GIS and Hydro CAD will be used for modeling. These applications will allow visualization of the topography, types of vegetation, and other parcel conditions that can be used to select the appropriate BMP designs.

2.5 ENVIRONMENTAL LABORATORY TESTING

Before designing a stormwater BMP for the Waushakum Pond, researching different methods to gain a better understanding of pollution levels will need to be done. A BMP Accounting and Tracking Tool (BATT Tool) produced by EPA was used by Weston & Sampson to calculate the pollutant levels of the lake as well as the expected BMP bacteria reduction. The

BATT Tool is a spreadsheet-based tool that tracks pollutant load reductions over time (EPA, 2016). The expected amount of TSS, phosphorus, and nitrogen removal from any implemented BMPs should be 1293 lb./year, 3.34 lb./year, and 41.7 lb./year, respectively. Our goal for BMP removal should reduce pollutant levels by 65% (City of Framingham, 2021).

Environmental engineering tests were researched to get a better understanding of water quality and regulations. Total coliform bacteria tests analyze pollution levels of E. coli, which is a major species in the fecal coliform group and is considered the best indicator of fecal pollution and other contaminants. E. coli testing analyzes fecal pollutant levels in bodies of water. Biochemical Oxygen Demand (BOD) testing is another common method used in wastewater treatment plants to determine the degree of organic pollution in water. Dissolved oxygen (DO) is helpful for maintaining aquatic life and aesthetic water quality which can be analyzed through BOD tests. Phosphorus data has already been taken in Waushakum Pond. Evaluating the phosphorus levels in the lake is helpful since high concentrations of phosphorus can result from poor agricultural practices or high amounts of stormwater runoff (EPA, 2022).

2.6 STORMWATER BEST MANAGEMENT PRACTICES

The primary method that is used to control stormwater runoff is implementing best management practices, otherwise known as BMPs. Stormwater BMPs are methods, devices, and practices that are used to manage stormwater runoff by controlling peak runoff rate, improving water quality, and managing runoff volume. Important considerations when determining BMPs are site conditions, existing and surrounding land uses, priority stormwater management goals, and additional site development or redevelopment goals. A wide range of BMPs is available, from rain barrels that require little space to constructed stormwater wetlands that require a much larger footprint. The scale of the BMP is directly related to the size of the construction project and to what the specific permitting for the site requires or allows.

There are three different kinds of BMPs: point BMPs, Linear BMPs, and Area BMPs. A point BMP is used to capture upstream drainage at a specific location and combines detention, infiltration, evaporation, settling, and transformation to manage the flow and remove pollutants. Point BMPs are the most common. A linear BMP has narrow linear shapes adjacent to stream channels that provide filtration for runoff, nutrient uptake, and ancillary benefits of stream shading, wildlife habitats, and overall aesthetic value. Finally, an area BMP is a land-based management practice that affects an impervious area, land cover, and pollutant input.

BMPs for stormwater near water include bioretention zones, artificial stormwater wetlands, wet basins, and sand and organic filters, among others (Boston Water & Sewer, 2013). Before stormwater is absorbed or discharged, it is treated in Bioretention areas using soil, vegetation, and microbes. Rain gardens, also known as Bioretention zones, are small, vegetated areas that are covered in mulch and dirt. Using sheet flow or piping, stormwater runoff is channeled into the cell. An impermeable liner and an underdrain are part of a filtering Bioretention area that stops runoff before it reaches the water table. An underdrain in an exfiltrating Bioretention area is intended to improve the exfiltration of runoff into the groundwater (Massachusetts Department of Environmental Protection, 2022).

Through wetland vegetation, retention, and settling, constructed stormwater wetlands are systems that maximize the removal of pollutants from stormwater runoff. Built-in stormwater wetlands temporarily store runoff in small pools that provide favorable circumstances for the development of wetland vegetation. Constructed stormwater wetlands must be used with additional BMPs, such as sediment forebays, just as extended dry detention basins and wet basins (Massachusetts Department of Environmental Protection, 2022).

Wet basins' main method of stormwater treatment involves a stationary body of water. The pool eliminates soluble contaminants while allowing sediments, especially fine particles, to settle. To limit peak discharge rates, wet basins need more dry storage space. Depending on how large the permanent pool is in comparison to the runoff from the nearby watershed, wet basins have a moderate to high capacity to remove the majority of urban contaminants.

Sand and peat filters, as well as organic filters, are made up of self-contained beds of these materials, either with perforated underdrains underneath them or with cells and baffles that have inlets and outputs. The sand serves as a filter for stormwater runoff, which in some designs may be prone to biological uptake. To receive additional treatment, runoff is released or sent to another BMP (Massachusetts Department of Environmental Protection, 2022).

3.0 APPROACH

The goal of this project is to develop Best Management Practices (BMPs) for Parcel 2368 to reduce stormwater pollutants and runoff that flow into Lake Waushakum. Our work will aid in limiting the phosphorus load and other pollutants that flow into Lake Waushakum each year.

In the following sections, we discuss each objective in turn.

Our objectives are as follows:

1. Develop a stormwater sampling plan and collect samples to represent sources of pollution accurately.
2. Analyze the collected sample for contaminants and characterize contributing areas and runoff to identify sources of pollution around Anna Murphy Park.
3. Develop and evaluate BMPs to address stormwater runoff and develop a BMP strategy to implement in Anna Murphy Park.

3.1 SAMPLING PLAN

A sampling plan includes analysis of the watershed to understand the topography and what types of soil and grasses are on the surface as well as how to carry out a sampling event. The group will work with the City of Framingham staff to determine a storm for sampling during which the group will sample for pH, TSS, Dissolved Oxygen (DO), temperature, nutrients, E.coli, and flow rate. Samples will be taken from outlet 2000203, as seen in Figure 2, or nearby catch basins in the Parcel. All samples will be tested in WPI's Environmental Laboratory in Kaven Hall.

3.1.1 ANALYZING THE WATERSHED AND TOPOGRAPHY

To understand the watershed and topography, the group will conduct a site visit on 10/5/2022 to take pictures of the parcel and each catch basin and do a preliminary analysis of the structures present. The team will meet with Alison Eliot, an Engineer for the City of Framingham, to answer questions about the parcel, what actions have been taken, and what they would like to see done through this project. ArcGIS topography maps, soils, and land use will be analyzed to understand the grading of the park and parcel. It will give an understanding of the entire parcel, including all residential areas the group may not have access to during the site visit.

3.1.2 SAMPLING PLAN

Prior to any sampling event, the group will coordinate with the City of Framingham to determine which storm is most suitable for sampling. The storm should last a few hours to give ample time for sampling and we will need to allow enough time to have a representative from the City with us. The storm must produce more than 0.5 inches of rain and occur during daylight. In order to be able to collect and analyze the samples, the group will complete training on sampling and proper laboratory skills on October 6th, 2022 at Gateway Park provided by Worcester Polytechnic Institute.

The team will collect wet weather samples to accurately represent all contaminants entering Lake Waushakum through Outfall 2000203. Figure 1 below shows that the Parcel is labeled for each of the 11 catch basins. The team will first attempt to sample Outfall 2000203 because it directly enters the lake and is an accumulation of all catch basins. However, this falls on residential property, so if the outfall is inaccessible or does not produce flow, the group will attempt to sample Catch Basin 6 in wet weather to develop an understanding of total loads throughout the entire year entering Lake Waushakum from Outfall 2000203. The team will prioritize sampling Catch Basin 6 because it is closest to Outfall 2000203 to accurately represent the whole parcel.

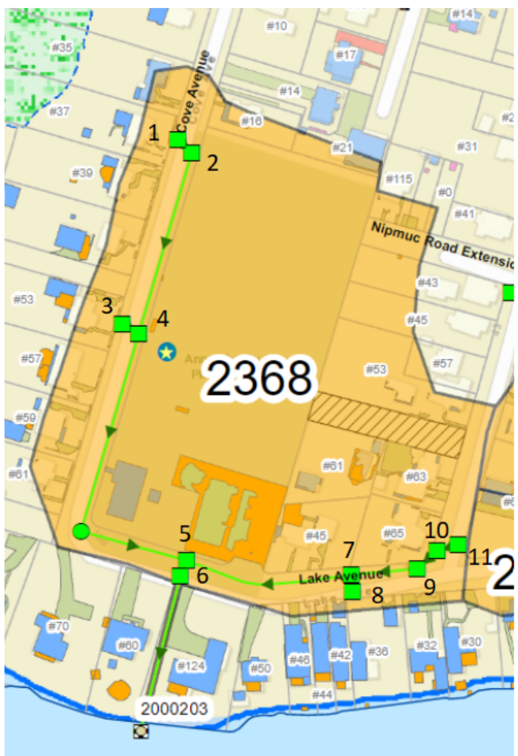


Figure 2. Parcel 2368 with numbered catch basins (1-11).

According to the MS4 permit, a wet weather sampling event occurs when 0.25” of rainfall has occurred. The group will attempt to wet weather sample incrementally 3 times during the rain event: during the first 30 minutes of rainfall, about 15 minutes after the first sample, and another 15-20 minutes after the second sample. This will ensure the sample is representative of what is entering the catch basin and will flow to the outfall. It will also capture all contaminants that may enter the catch basin before they have been washed away throughout the rain event.

During the sampling event at Parcel 2368, the team will take pictures, make visual observations, and complete a google form created to manage the sampling event and have all collected information stored in one place. It is on google drive and will be completed by one group member at the sampling event. It requires information such as weather, the condition of the structure, and what samples were taken. Samples will be taken and analyzed for pH, metal content, TSS, Dissolved Oxygen (DO), temperature, nutrients, E.coli, and flow rate. 4 bottles will be collected for each test time from the outfall or catch basin, totaling 12 bottles for each basin because temperature and flow will be analyzed on-site. Two plastic bottles will be used for all pH, nutrients, and TSS. A glass bottle will be used for DO and a disinfected bottle will be used for E.coli. The temperature will be measured through a probe in one of the bottles and flow will be measured with a flow meter or a bucket. The bucket will be filled to a known volume throughout which the time will be measured. Then the group will divide the volume by the time to get the flow rate. A list of bottles, materials, and what each bottle was used for will be included in the final report along with sampling event documentation.

The group will analyze one storm sampling event through one catch basin or outfall due to constraints. There are many samples to take during an event with limited time to do so, so the group will focus on one catchment basin or the outfall. Parcel 2368 is also about 40 minutes away from WPI so driving time must be taken into consideration along with the busy schedules of the group members. Two group members must be at the sampling event, so coordinating with schedules may only allow for one sampling event to be done. The second objective will discuss how we analyze these samples and determine trends.

3.2 ANALYZE LAB DATA

Collected samples will be analyzed for pH, TSS, Dissolved Oxygen (DO), temperature, nutrients, E.coli, and flow rate. BOD testing is important because it directly affects the amount of dissolved oxygen in streams (EPA, 2012). DO will be measured via the Winkler method or a meter and probe. High levels of BOD saturation will be considered an issue due to the lack of DO in the lake or stormwater catch basins. Phosphorus and nitrogen are found naturally in bodies of water and through stormwater runoff from contributing land areas. If there is an excessive amount, algae levels will increase, damaging the water source and decreasing the oxygen levels in the water, negatively impacting aquatic life. Total phosphorus testing measures all the forms of phosphorus in the sample by digesting the sample to convert all forms into orthophosphate, which is then measured using the ascorbic acid method (EPA 5.6 phosphorus). The phosphorus levels must be less than 10 micrograms per liter for recreation and aesthetic per EPA regulation

(EPA, 2000). TSS testing is important because pollutants and pathogens are carried on the surfaces of solids which correlates to water clearness. E. coli testing will help determine the pollution levels, which will be useful for understanding fecal pollutant levels in the discharge. Collecting lake samples could also help see the effect of the outfall. The E.coli regulations for freshwater swimming created by the EPA state there 126 E. coli CFU per 100 mL or above is not swimmable.

Results from these tests will provide a better understanding of the relevant pollutants affecting Waushakum Pond. Each catch basin will have its own sample analysis so the team can design the best stormwater BMPs across the parcel. All existing BMPs in parcel 2368 are type 1 catch basins utilized for pipe systems less than 5 feet below the surface. Collecting samples from the outfall will be considered the highest priority as it will provide information on pollutant levels going directly into the lake. The catch basin nearest to the outfall will also be collected for sampling due to all the basins being daisy-chained towards it. Areas with larger contributing flow volumes will have a higher priority when implementing BMP designs. HydroCAD modeling will need to be completed to map the current piping system to better understand flows and loading entering the pond.

3.3 DEVELOP AND SELECT BMPS

The development and selection of BMPs include developing a broad list, evaluating testing results, addressing water quality, conforming to City needs, and modeling the data. The team will develop a list of potential BMPs for this project. BMPs will be chosen from prior WPI MQP reports, advisors' ideas, City requests, and other established stormwater management BMPs. The data from testing will determine the most effective BMP options that will be focused on.

Another way the team will determine which BMPs to use is by determining the effect the BMPs will have on water quality. Ideally, the team would want to select a BMP that has the best removal of pollutants and improves the water quality of Lake Waushakum. Some other restrictions, such as City needs and cost, may not allow for some BMPs to be selected. A cost-benefit analysis will need to be performed on the proposed BMP designs to determine which will best fit the City’s budget. The City may also have requests for what they're looking for in a BMP, which will be considered.

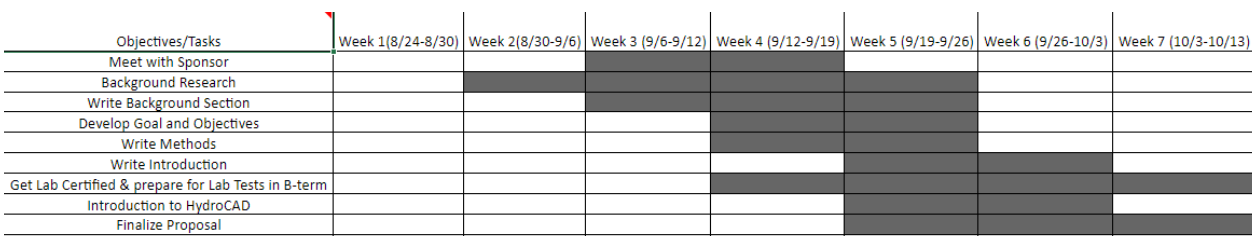
The team will also create an assessment matrix. This matrix will help to weigh all BMP design options against one another. It will compare cost, water quality impacts, constructability, and any constraints that need to be addressed. This matrix will help to easily identify the final BMP designs that will be considered. Another tool that may be used to select BMPs is the EPA BMP Accounting & Tracking Tool (BATT).

The selected BMP from the matrix will then be modeled in Hydro CAD and GIS. If the team is deciding between two different BMP designs, the modeled data will help visualize which BMP will be more effective and help to narrow down the appropriate BMP design. These applications will allow a better visualization of how the BMP designs will affect the water quality. Once all constraints have been addressed, appropriate BMPs will be selected and proposed to the city for their approval. The team will modify or change their selection based on any feedback from the City and the advisors of this MQP.

3.4 DELIVERABLES

At the conclusion of this project, the team will have developed and presented deliverables to the City of Framingham and the project Advisors. The project will analyze the watershed, land topography, and various BMPs. A BMP design will be created based on the needs of the city and all constraints around the project. The BMP will address pollutants in stormwater runoff in a cost-effective manner that will overall help limit pollution into Lake Waushakum. A Gantt chart following the timeline of our work can be seen below, broken down through three terms, A, B, and C.

A term:



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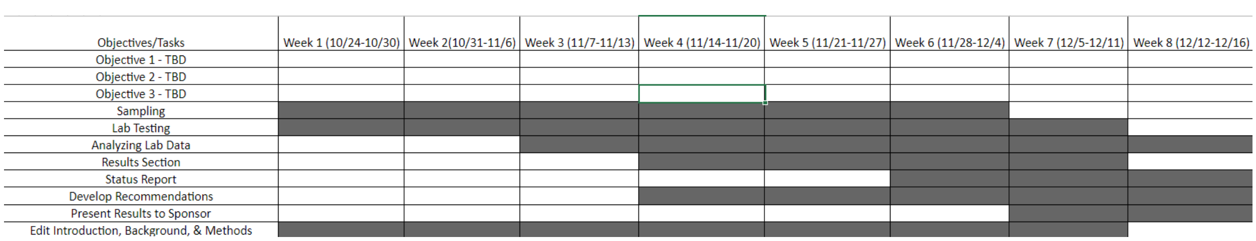
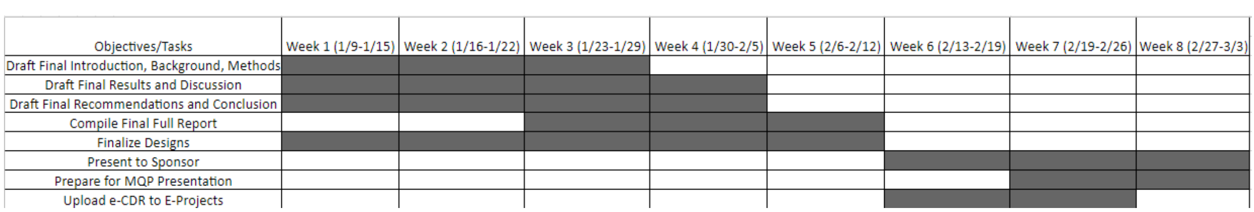


C term:



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Appendix B: Sampling Procedure

Materials Used

- 9 plastic bottles
- 3 sterilized bottles (for bacteria)
- 3 BOD bottles
- Cooler
- Sharpie
- Duct tape
- Tape measure
- PVC rod with cup attached to collection end

Collection at Catch Basin

1. Remove the catch basins cover with a manhole cover remover
2. Place cones around the area of the catch basin
3. Lower the PVC rod with the cup attached to the pipe opening.
4. Per EPA guideline, rinse the cup 3 times with the water from the pipe
5. Place the PVC rod with cup attachment below the pipe and collect a sample and time how long it takes.
6. Using the volume and time of collection, determine the flow rate.
7. To collect any more samples, repeat steps 5-6
8. Repeat steps 1-7 for other catch basins.

Collection at Outfall

9. Place the PVC rod with the cup attachment below the outfall.
10. Rinse the cup 3 times, per EPA standards.
11. Place the PVC rod with cup attachment below the pipe and collect a sample and time how long it takes.
12. Using the volume and time of collection, determine the flow rate.
13. To collect any more samples, repeat steps 11-12

Appendix C: Sampling Event Test Kit Procedures

Hatch Multimeter tests

1. Turn the Hatch Multimeter on
2. Remove the cap from the sensor
3. Rinse the sensor and cap with water
4. Poor the sample into the cap
5. Put the cap back on the sensor
6. Keep the cap on the sensor and record the measurements given for temperature, salinity, and conductivity
7. To measure another sample, repeat steps 3-6

Chlorine Tests

8. Rinse the Hach Colorimeter test kit test tube 3 times with sample water
9. Add 10mL of sample to the test tube
10. Add one Hach Chlorine reagent packet to the test tube
11. Put the cap on the test tube and mix
12. Place the test tube inside the colorimeter, place the cover over the tube, and hit read
13. After 3 minutes, record the concentration of chlorine.
14. If more samples need to be analyzed, repeat steps 8-13

Ammonia Tests

This procedure was modified from the "Ammonia CHEMets® Kit K-1510/R-1501: 0 - 1 & 1 - 10 ppm N" procedure

15. Fill the sample cup to the 25 mL mark with the sample to be tested.
16. Add 2 drops of A-1500 Stabilizer Solution. Stir to mix the contents of the cup.
17. Place the CHEMet ampoule, tip first, into the sample cup. Snap the tip. The ampoule will fill leaving a bubble for mixing
18. To mix the ampoule, invert it several times, allowing the bubble to travel from end to end.
19. Dry the ampoule. Obtain a test result 1 minute after snapping the tip.
20. Obtain a test result using the appropriate comparator. Use the Low Range Comparator Place the ampoule, flat end first, into the comparator. Hold the comparator up toward a source of light and view from the bottom. Rotate the comparator until the best color match is found.

Detergent Tests

This procedure was modified from the CHEMetrics "Detergents CHEMets Kit K-9400/R-9400: 0 - 3 ppm" procedure

21. Rinse the reaction tube with the sample to be tested, and then fill it to the 10mL mark with the sample.
22. While holding the double-tipped ampoule in a vertical position, snap the upper tip using the tip breaking tool
23. Invert the ampoule and position the open end over the reaction tube. Snap the upper tip and allow the contents to drain into the reaction tube
24. Cap the reaction tube and shake it vigorously for 30 seconds. Allow the tube to stand undisturbed for 1 minute.
25. Make sure that the flexible tubing is firmly attached to the CHEMet ampoule tip.
26. Insert the CHEMet assembly (tubing first) into the reaction tube making sure that the end of the flexible tubing is at the bottom of the tube. Break the tip of the CHEMet ampoule by gently pressing it against the side of the reaction tube. The ampoule should draw in fluid only from the organic phase (bottom layer).
27. When filling is complete, remove the CHEMet assembly from the reaction tube.
28. Remove the flexible tubing from the CHEMet ampoule and wipe all liquid from the exterior of the ampoule. Place an ampoule cap firmly onto the tip of the CHEMet ampoule. Invert the ampoule several times, allowing the bubble to travel from end to end.
29. Obtain a test result by placing the ampoule, flat end first, into the comparator. Hold the comparator up toward a source of light and view from the bottom. Rotate the comparator until the best color match is found.

Appendix D: pH Methods

Standardize the pH Probe

1. Remove the pH probe from the storing solution
2. Rinse the probe with Deionized (DI) water
3. Place the probe in the 4-pH buffer solution
4. Press the STD button and wait for the screen to stabilize.
5. Once the screen stabilizes, press the STD button again to accept the conditions.
6. Remove the probe from the 4-pH buffer solution and rinse the probe with DI water.
7. Place the probe into the next buffer solution. Repeat steps 2-6 for each buffer solution

Measuring pH

8. After completing steps 1-7, rinse the probe with DI water
9. Place the probe into the sample. (make sure there is enough sample to cover the end of the probe)
10. Wait for the probe to stabilize and record the pH

Appendix E: Dissolved Oxygen

Procedure

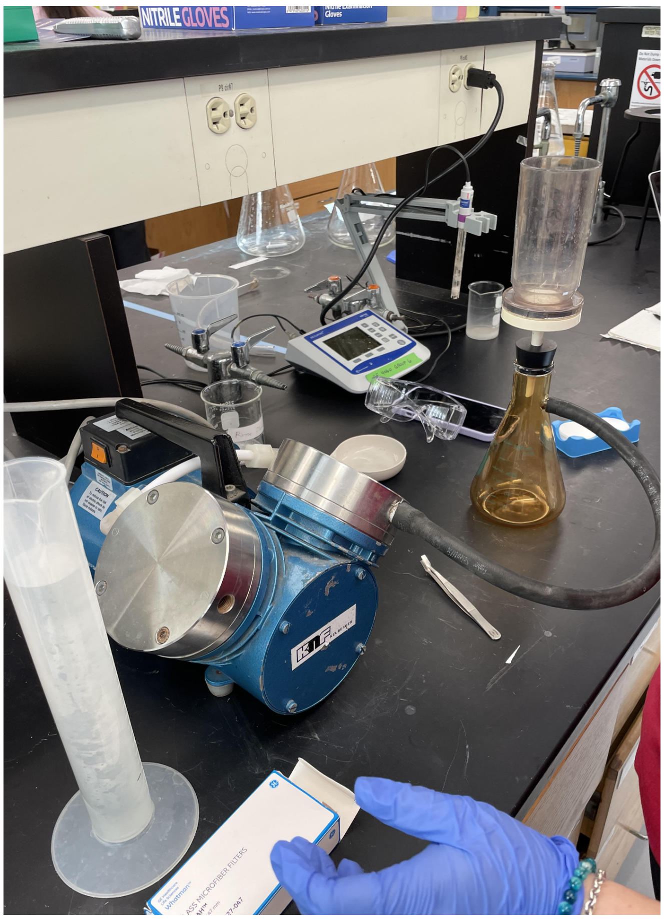
1. The DO probe should be running on a stir plate in a solution of water and air.
2. Calibrate the DO probe as it is in the solution
3. Remove the probe and rinse it off with DI water
4. Place the probe into the BOD bottle filled with your sample.
5. Click read
6. Once the reading stabilizes, record the DO value.
7. Rinse the DO probe and return it to the storing solution.
8. To read more samples, repeat steps 2-7.

Appendix F: TSS Methods

Materials needed:

- Reagent grade water
- Porcelain dish
- Whatman 934-AH glass microfiber filter sheets
- Sample water

1. Set the oven to 104 degrees Celsius.
2. Set up the vacuum apparatus with a flask and Whatman Glass Microfiber Filter (934-AH, diameter=47mm) (as seen in the picture below).



3. Wash the porcelain dish.
4. Turn on the vacuum. Pour 120 mL of reagent grade water onto the filter through the funnel. Turn off the vacuum. The filter paper should be clean.
5. Remove the cone and the filter and place the filter into the porcelain dish.
6. Place the porcelain dish with filter paper into the oven for 1 hour to dry it out.
7. Remove the porcelain dish with the filter from the oven and place on the work bench for 30 minutes to cool.

8. Zero the scale with the porcelain dish. Place the filter paper in the dish to weigh the filter paper. Record the weight.
9. Place the filter paper back into the vacuum apparatus beneath the cone.
10. Turn on the vacuum. Through the cone, add 500mL of the sample stormwater so that it runs through the filter (the filter paper should look dirty, if it still looks clean run more sample water through). Turn off the vacuum. Remove the filter paper and place it back in the porcelain dish.
11. Place the porcelain dish with the filter paper in the oven (104 degrees Celsius) for 1 hour to dry it out.
12. Remove the porcelain dish with the filter paper from the oven and place on the work bench for 30 minutes to cool.
13. Using tweezers, remove the filter paper from the porcelain dish and place on the scale. Measure and record the weight.
14. Subtract the filter paper weight without solids from the filter paper weight with solids (second weight-first weight) to measure the TSS in g/500mL
15. Repeat steps 3-14 for each sample.

Appendix G: Coliforms and E. coli Testing Procedure

Materials Needed:

100mL Graduated cylinder

2 sterilized bottles

Colilert IDEXX testing kit

1. Set the incubator to 35°C
2. Wash and sterilize 2 bottles
    a. Label each (orange - outfall, blue - catch basin)
3. Measure 100mL of the sample stormwater from the outfall and pour into the orange sterilized bottle.
4. Measure 100mL of the sample stormwater from the catch basin and pour into the blue sterilized bottle.
5. Using the Colilert IDEXX sampling kits, pour one capsule of solution into the outfall 100mL of sample water.
6. Shake until the solution is completely dissolved.
7. Repeat for the catch basin sample.
8. Place both sterilized bottles in the incubator for 24 hours.
9. After 24 hours, remove the samples from the incubator.
10. Determine if there are Coliforms present (if the solution has become yellow)
11. Determine if there is E.coli present (fluorescence with UV light)

Appendix H: Total Phosphorus Testing Procedure

*This procedure was taken from the WPI Department of Civil & Environmental Engineering

Total Phosphorous (TP)

- Clean glassware (100ml beakers, 100ml volumetric flasks, 25ml volumetric flasks) = soak in acid bath overnight, rinse 3 times with tap water, rinse 3 times with DI water.
- Label 100 mL beakers with blank, standards and samples IDs
- Make standards
  - Take out the labeled bottle (large, brownish) of standard from the refrigerator
  - Get 100 ml volumetric flasks
  - Label flasks for standards
  - Pipette standard amounts according to sheet
  - Fill flasks with DI water from e-pure tap, then use a spray bottle to fill flask to the line
  - Add parafilm to the flasks
  - Invert flasks 5 times each
- Pour blank, standards, samples into 25 mL vol. flask
  - Rinse before filling = add a little, swirl, dump out (do twice)
  - Use disposable, plastic pipette if over line
  - Pour into corresponding beaker, rinse flask with spray bottle twice
- Digest samples = about 1 mL of standards and samples will be left in the beakers.
  - Add 5ml of nitric acid and 1ml of sulfuric acid to each beaker
  - Heat on hot plate until ~1ml left or start fuming
  - Add drops of H_2O_2 if too much organics in the sample (cloudy and colored)
- Turn on spectrophotometer (don't need to wait hours before using)
- Make sure the wavelength is set to **400 nm** (change by pressing Manual Program)

  Single Wavelength
- Filter samples (don't have to for all samples, depends on how cloudy/sediment amount)
  - #4 filter paper, Whatman
  - Funnels
- Get 3 solutions
  - Phenolphthalein: 1,000 mL, white/clear bottle, clear solution
  - Molybdovanadate: 1,000 mL, white/clear bottle, yellow solution
  - NaOH: 6.25N, white bottle, clear solution

1

- Get supplies for each solution
    - (2) Disposable dropper, 100 mL (small) beaker
    - 1 mL – pipette and tip (1-5 mL, large tips in drawer);
- Get DI water (in squirt bottle), paper towels, gloves, "my" cell from the water lab, large waste beaker
- Transfer **blank** solution from beaker into cell; rinse with DI water to get all of sample
- Add 1 drop of Phenolphthalein
- Add NaOH with dropper until sample turns pink
- Add E-pure water to the line on the cell with squirt bottle
- Add/pipette 1 mL of Molybdovanadate
- On the spec. press timer, set to 3 minutes
- Place the cell in the machine (kimwipe first), with the white line mark facing outwards, when the timer hits zero
- Press Zero
- Rinse cell into large waste beaker
- Repeat steps 12-20 for the rest of the samples and standards, except press Read for step 19
- Dispose the waste into hazardous waste bottle for Total phosphorous

Standard solution preparation:

Target conc., ppm	Target volume, ml	Added volume of stock solution 0.1mg/ml, ml
0.1	100	0.1
0.2		0.2
0.5		0.5
1.0		1
2.0		2
3.0		3

Calculations:

Slope-intercept equation: $y=0.2469x-0.0023$ (taken from Spectrophotometer graph)

TP1 → 0.043 abs

$$0.043=0.2469x-0.0023$$

$$x=0.183 \text{ ppm}$$

TP2 → 0.046 abs

$$0.046=0.2469x-0.0023$$

$$x=0.196 \text{ ppm}$$

Appendix I: BMP Tables

BMP	General Description	Materials Used	Advantages	Disadvantages	Maintenance	Removal Efficiency	Applications	Design Considerations	Other Notes	Website Link
Vegetated Filter Strips	Uniformly graded vegetated surfaces, recieve runoff from impervious areas (concrete), treat small concentrated areas, distribute flow along whole strip, slow runoff velocities, trap sediment, promote infiltration, reduce runoff volume	Grasses that are permeable, salt tolerant, can withstand high flow velocities	Reduce runoff volumes and peak flows, low maintenance, pretreatment for bioretention cells, natural, ideal for residental settings (road runoff), can be used with other BMPs	Variability in removal efficiencies, poor option with large land requirements, effective with <6% slopes	Inspect for sediment buildup, erision, bare spots and overall health every 6 months during first year and annually after, mow the grass as needed, remove sediment and reseed bare spots as needed	TSS (25-50 ft for strip width)=10-45% removal, Nutrients, metals, pathogens (insufficient data)	Effective pretreatment for runoff from roads or driveways, must have proper grading (2-6% slope)	Depth of the soil must extend below frost line, avoid peat or compost which freeze during the winter and become impermeable and ineffective, locate in an area with low clay content (or other materials with limited infiltration), contributing drainage area is less than 1 acre, flow depth must be <0. 5inches, >25feet for TSS removal, 2 feet above seasonal high groundwater and 2-4 ft above bedrock	Work best along roadways	https://www.mass.gov/doc/massachusetts-stormwater-handbook-vol-2-ch-2-stormwater-best-management-practices/download
Rain Garden	Depressions filled with sandy soil, mulch and native vegetation, runoff percolates through the media as a filter, treats with soil, plants and microbes	Needs pretreatment, for areas with small slopes, must be 5-7% of the area draining to it, must be 2-4 feet deep, pea gravel/sand/filter fabric must be first laid after excavation, soil mix (40% sand, 20-30% topsoil, 30-40% compost) must be uniform, free of stones/stumps/roots and have low clay levels, soils with 1.5-3% organic content, all native vegetation	Removal of phosphorus, can modify existing landscape, maintains natural look, can be used with space constraints	Requires maintenance and landscaping, not suitable for large drainage areas	Inspect and remove trash (monthly), mow (2-12 times per year), mulch/fertilize/remove dead vegetation/prune (annually)	TSS (90% with vegetated filter strip), Phosphorus (30-90%), metals (40-90%), pathogens (insufficient data)	Good for urban areas, come in multiple sizes, can be built into parking lots, islands, along the outsides of roads	Needs pretreatment, for areas with small slopes, must be 5-7% of the area draining to it, must be 2-4 feet deep, pea gravel/sand/filter fabric must be first laid after excavation, soil mix (40% sand, 20-30% topsoil, 30-40% compost) must be uniform, free of stones/stumps/roots and have low clay levels, pH between 5.5-6.5 for microbial activity and soils with 1.5-3% organic content	Prevent snow from entering the biorentention area, if neccessary look at the chart for plant specifications	https://www.mass.gov/doc/massachusetts-stormwater-handbook-vol-2-ch-2-stormwater-best-management-practices/download
Dry Detention Basins	Excavated basin for detention of stormwater runoff, controlled release, control peak runoff	Permeable soil, gravely soils, impervious layer, vegetation (buffers)	Controls runoff, low cost	Negligible removal of TSS, clogs frequently, requires large land area	Inspect basins (annually), mow (twice a year), remove debris//trash (twice a year), remove sidement (as necessary)	Bacteria (<10%), Total Phosphorus (10-30%), Total Nitrogen (5-50%), Metals (30-50%)	Need large parcel area (10 acres), can be used in smaller situations with pretreatment	Need 50 ft from septic system leach field, 25 ft from septic system tank, 50 ft from private well, 10 ft from property lines; depth (3-12 ft), store volume to fit 2, 10-year, 24-hour storms, emergency spillway, minimum slope of the bottom of 2%, impervious linings, side slopes 3:1 (flatter prevents erosion), vegetative buffers (erosion control)	Can control peak discharges for 2- and 10-year storms	https://www.mass.gov/doc/massachusetts-stormwater-handbook-vol-2-ch-2-stormwater-best-management-practices/download
Green Roofs	Rooftop planting system that retains precipitation (less runoff off roofs), extensive (minimal maintenance and restricted variety of plants, resistant to frost, flat or low slop roof deck), intensive (regular maintenance, more variety of plants, richer soil), water proof membranes (modified asphalts, synthetic rubber, hypolan, reinforced PVC)	Lightweight soil with water retention capacity (perlite, clay shale, pumice, chrushed terracotta, no more than 5% organic material), hardy, low growing, drought-resistant perennials or annuals (stonecrop, delospermum, sempervivium, etc)	Reduces volume and peak rate, reduces heating/cooling costs in the building, sound insulation, extend life expectancies of roof	Precipitation is not recharged to groundwater, may require irrigation, may require structural strengthening	Irrigation, weeding, mulching, pruning (as needed)	Increases Total Phosphorus/Total Nitrogen, removes 40% annual precipitation, peak flow rates reduced by 50-90%, delays peak discharges by an hour	When reducing stormwater runoff, where combined sewer overflows or flooding compromises water quality, not to be used where groundwater recharge is a priority	About 15% slope max, drainage layer, synthetic waterproof membrane, soil layer, light-weight plants, waterproof membrane, can retain water volume of 0.5-1 inch, irregation system	Less efficient in cold climates, potential for leaks	https://www.mass.gov/doc/massachusetts-stormwater-handbook-vol-2-ch-2-stormwater-best-management-practices/download
Catch Basin Inserts	Catch Basin Inserts are a BMP accessory recently developed to add filtering efficiency to traditional catch basins. These proprietary BMPs are capable of removing a range of pollutants, from trash and debris to fine sediments and oil/grease and metals depending upon the filtering medium used	They typically have three components: • an insert that fits in into the catch basin • absorbent material (can be a single unit or a series of filters) • a housing to hold the absorbent material: made of steel or metal	helps to catch sediment and other non-stormwater material before going into the catchbasins	manufacturer's specifications must be followed, which may include modifications to the catch basin. Catch Basin Inserts are typically designed for and used for smaller volume applications. Additionally, larger sized sediment can clog and significantly reduce the effectiveness of some Catch Basin Insert filtering media.	Since Catch Basin Inserts are usually proprietary devices, the manufacturer should be asked to ensure that the device will work in the type of catch basin in which it is installed. Flow characteristics and sediment loading should be evaluated and any resulting modifications to the catch basin made before installation of the insert.	about 80% at best	Catch Basin Inserts can be useful for specialized applications, such as targeting specific pollutants other than TSS, at Land Uses with Higher Potential Pollution Loads, for oil control at small sites, for retrofits of existing catch basins with no or undersized sumps, to add TSS capability to areas with higher sediment loading, or to improve existing conditions at size-constrained sites	typically designed for smaller flows and smaller basins		https://www.mass.gov/doc/massachusetts-stormwater-handbook-vol-2-ch-2-stormwater-best-management-practices/download
wet basins	: Wet basins use a permanent pool of water as the primary mechanism to treat stormwater. The pool allows sediments to settle (including fine sediments) and removes soluble pollutants. Wet basins must have additional dry storage capacity to control peak discharge rates. Wet basins have a moderate to high capacity to remove most urban pollutants, depending on how large the volume of the permanent pool is in relation to the runoff from the surrounding watershed.	whatever is in the area, grass, trees, sediment, makes a pool	Capable of removing both solid and soluble pollutants • Capable of removing nutrients and metals • Aesthetically pleasing BMP. • Can increase adjacent property values when properly planned and sited. • Sediment generally needs to be removed less frequently than for other BMPs. • Can be used in retrofits	More costly than extended dry detention basins. • Larger storage volumes for the permanent pool and flood control require more land area. • Infiltration and groundwater recharge is minimal, so runoff volume control is negligible. • Moderate to high maintenance requirements. • Can be used to treat runoff from land uses with higher potential pollutant loads if bottom is lined and sealed. • Invasive species control required	Inspect wet basins to ensure they are operating as designed At least once a year. Mow the upper-stage, side slopes, embankment and emergency spillway. At least twice a year. Check the sediment forebay for accumulated sediment, trash, and debris and remove it. At least twice a year. Remove sediment from the basin. As necessary, and at least once every 10 years	• Total Suspended Solids (TSS) 80% with sediment forebay • Total Nitrogen 10% to 50% • Total Phosphorus 30% to 70% • Metals (copper, lead, zinc, cadmium) 30% to 75% • Pathogens (coliform, e coli) 40% to 90%	Generally, dry weather base flow and/or large contributing drainage areas are required to maintain pool elevations. The minimum contributing drainage area must be at least 20 acres, but not more than one square mile. Sites with less than 20 acres of contributing drainage area may be suitable only if sufficient groundwater flow is available. Use wet basins at residential, commercial and industrial sites. Because wet basins remove soluble pollutants, they are ideal for sites where nutrient loadings are expected to be high.	Volume and geometry are the critical parameters in a wet basin design; the relationship of the volume in the permanent pool to the contributing runoff volume directly affects pollutant removal rates. Generally, bigger is better; however, after a certain threshold level, increasing the pool size results in only marginal increases in pollutant removal. The permanent pool must be sized at a minimum to hold twice the water quality volume (this is equivalent to a VB/VR of 2) when a wet basin is designed to provide peak rate attenuation in addition to water quality treatment. The peak rate volume is an additional volume above the permanent pool. The permanent pool volume must not be counted as part of the volume devoted to storage associated with peak rate attenuation. When designing a wet basin to also accommodate peak rate attenuation, a multiple stage outlet must be included as part of the design.		https://www.mass.gov/doc/massachusetts-stormwater-handbook-vol-2-ch-2-stormwater-best-management-practices/download
sand and peat filters	Also known as filtration basins, sand and organic filters consist of self-contained beds of sand or peat (or combinations of these and other materials) either underlaid with perforated underdrains or designed with cells and baffles with inlets/outlets. Stormwater runoff is filtered through the sand, and in some designs may be subject to biological uptake. Runoff is discharged or conveyed to another BMP for further treatment	sand and other organic materials	Applicable to small drainage areas of 1 to 10 acres, although some designs may accept runoff of up to 50 acres. • Good retrofit capability. • Long design life if properly maintained • Good for densely populated urban areas and parking lots with high intensity use	Pretreatment required to prevent the filter media from clogging. • Frequent maintenance required. • Relatively costly to build and install. • Without grass cover, the surface of sand filters can be extremely unattractive. • May have odor problems, which can be overcome with design and maintenance. • May not be able to be used on certain sites because of inadequate depth to bedrock or high groundwater • May not be effective in winter	Inspect filters and remove debris ,After every major storm for the first few months after construction is complete to ensure proper function and every 6 months thereafter.	tss 80%,nitrogen 20-40%, total p 10-50%,metals,50-90%	Sand filters are suitable for cold climates, but surface or perimeter filters will not be effective during the winter months. Using an alternative conveyance measure such as a weir system between the settling chamber and filter bed may avoid freezing associated with the traditional standpipe. Where possible, the filter bed should be below the frost line. Some sand filter variations (e.g., organic filters) should not operate during the winter, as organic media can become completely impervious when frozen. Using a larger underdrain system to encourage rapid draining in winter may help limit freezing of the filter bed	Sand filters are not appropriate for large drainage areas, do not provide flood control and generally do not protect stream channels from erosion. Sand filters that do promote groundwater recharge are not suitable in areas with high groundwater tables. In addition, sand filters need frequent maintenance, and underground and perimeter versions are out of sight so can be easy to forget.,surface sand filters can cost around 56,000 and underground filters can cost around 64,000	Sand filters are suitable for sites with mild to moderate slopes, as they generally require 4 to 8 feet of head (elevation drop) to promote flow through the system.	https://www.mass.gov/doc/massachusetts-stormwater-handbook-vol-2-ch-2-stormwater-best-management-practices/download
tree box filter	The Tree Box Filter consists of an open bottom concrete barrel filled with a porous soil media, an underdrain in crushed gravel, and a tree. Stormwater is directed from surrounding impervious surfaces through the top of the soil media. Stormwater percolates through the media to the underlying ground. Treated stormwater beyond the design capacity is directed to the underdrain where it may be directed to a storm drain, other device, or surface water discharge.	concrete, soil, gravel,tree	May be used as a pretreatment device • Provides decentralized stormwater treatment • Ideal for redevelopment or in the ultra-urban setting	• Treats small volumes	Check tree Annually. Expected tree life is 5-10 years. Rake media surface to maintain permeability Twice a year Replace media When tree is replaced	Total Suspended Solids (TSS)- 80% presumed for regulatory purposes • Total phosphorus (TP)- Not Reported • Dissolved Inorganic Nitrogen- Not Reported • Zinc- Not Reported • Pathogens (coliform, e. coli)- Not Reported	can be used as a pretreatment device and reduces volume rate of runoff	Design at a minimum to capture and treat the required water quality volume,Design to drain in less than 72 hours,Tree box filters are typically designed in layers		https://megamanual.geosyntec.com/npsmanual/treeboxfilters.aspx , https://www.mass.gov/doc/massachusetts-stormwater-handbook-vol-2-ch-2-stormwater-best-management-practices/download
constructed stormwater wetlands	maximize pollutant removal through wetland vegetation uptake, retention, and settling. Temporarily stores runoff in shallow pools that support wetland growth and conditions	gravel, sediments, varrying plants, pipes	low maintenance costs, high removal efficiency, removes nitrogen, phosphorus, oil, and grease, aesthetically pleasing, provides wildlife habitat.	Can require lots of land. The vegetation must be well established before a high removal efficiency can be achieved. There are high construction costs. It is hard to maintain in dry periods. There is no recharge. Can become a mosquito breeding habitat. There are other safety issues that may need to be considered.	Wetlands must be inspected for 2 times a year for the first 3 years of construction. The forebays must be cleaned out once a year. Sediments must be cleaned out once every 10 years.	Total Suspended Solids (TSS) have an 80% removal efficiency with pretreatment. Total Nitrogen has a removal efficiency of 20% to 55%. Total Phosphorus has a removal efficiency of 40% to 60%. Metals (copper, lead, zinc, cadmium) have a removal efficiency of 20% to 85%. Pathogens (coliform, e coli) have a removal efficiency of up to 75%	Site constraints that can limit the suitability of constructed stormwater wetlands include inappropriate soil types, depth to groundwater, contributing drainage area, and available land area. Soils consisting entirely of sands are inappropriate unless the groundwater table intersects the bottom of the constructed wetland or the constructed stormwater wetland is installed over the sand to hold water. Where land area is not a limiting factor, several wetland design types may be possible. Consider pocket wetlands where land area is limited.	Do not locate constructed stormwater wetlands within natural wetland areas.		https://www.mass.gov/doc/massachusetts-stormwater-handbook-vol-2-ch-2-stormwater-best-management-practices/download
baffle boxes	Baffle boxes are an end of pipe treatment method and are placed at the end of existing stormwater drain pipes	concrete or fiberglass boxes, typically 10 to 15 feet long and 6 to 8 feet high	Baffle box designs can be modified to serve as a retrofit installation at curb or manhole inlets or beneath grates	needs regular maintenance to remain effective	Regular maintenance that depends on how much it rains	Removal efficiency of up to 90 percent for sand or sandy clay at entrance velocities of up to 6 feet per second. 28 percent removal efficiency for fly ash at the same velocity.	can remove floating debris	would only be able to implement if we had permission to install on outfall that is on private property		https://www.epa.gov/sites/default/files/2015-09/documents/urban_guidance_0.pdf
proprietary media filters	2 chambered underground concrete vaults. Large particles settle out in the first chamber. Stormwater flows into the second chamber through the specific media. Specific media can be modified depending on what pollutants are being targeted	concrete chambers	Specialized for applications like industrial sites, for specific target pollutants Preferred for redevelopments or in the ultra urban setting when LID or larger conventional practices are not practical	May require more maintenance. Performance varies depending upon the media used. TSS removal depends on what media is used. "Wet" systems that are designed to retain water can cause mosquito and vector problems.	Inspect for standing water, sediment, trash and debris and clogging 2 times per year. Accumulated trash and debris must be removed during every inspection. Inspect to determine if the system drains in 72 hours once a year during the wet season after a large storm. Inspect filtering media for clogging; replace if clogged according to the manufacturer's instructions	Total Suspended Solids (TSS) removal efficiency varies upon the media that is used. Total phosphorus (TP) removal efficiency varies upon the media that is used. Dissolved Inorganic Nitrogen removal efficiency varies upon the media that is used. Zinc removal efficiency varies upon the media that is used. Pathogens (coliform, e. coli) removal efficiency varies upon the media that is used.	The first chamber is usually a pretreatment settling basin. The second chamber is a filter bed containing either sand or other filtering media or an array of media-containing cartridge filters. After larger particles (e. g., TSS) settle out in the first chamber, stormwater flows through the specific filter media in the second chamber, and a portion of the target pollutants are sorbed to the filter media.	Media Filters are most efficient when designed to operate off-line.		https://www.mass.gov/doc/massachusetts-stormwater-handbook-vol-2-ch-2-stormwater-best-management-practices/download

BMP	General Description	Materials Used	Advantages	Disadvantages	Maintenance	Removal Efficiency	Applications	Design Considerations	Other Notes	Website Link
Leaching catch basins	A leaching catch basin is a pre-cast concrete barrel and riser with an open bottom that permits runoff to infiltrate into the ground.	A stand-alone barrel/riser and a Barrel/riser combined with a deep sump catch basins that provides pretreatment.	Provides groundwater recharge. Removes coarse sediment.	Needs frequent maintenance. Can become a source of pollutants via resuspension if not properly maintained. Cannot effectively remove soluble pollutants or fine particles. Do not provide adequate treatment of runoff unless combined with a deep sump catch basin. It is an entrapment hazard for amphibians and other small animals.	Inspect units and remove debris annually or more frequently as indicated by structure performance. Remove sediment when the basin is 50% filled. Rehabilitate the basin if it fails due to clogging, as needed.	Total Suspended Solids (TSS) have a removal efficiency of 80% if combined with a deep sump catch basin and if designed to be off-line. Nutrients (Nitrogen, phosphorus) have insufficient data on removal efficiency Metals (copper, lead, zinc, cadmium) have insufficient data on removal efficiency. Pathogens (coliform, e coli) have insufficient data on removal efficiency.	Because leaching catch basins discharge runoff to groundwater, do not use them in areas of higher potential pollutant loadings (such as gas stations) without adequate pretreatment such as an oil grit separator.	Use stone material with a void ratio of 0.39 or less. Make the depth to groundwater at least 2 feet below the bottom of the leaching catch basin. When designing structural components, design for dead and live loads as appropriate. Include provisions for overflows such as redundant devices and paved chutes. The basin inlet cover is an important component. The openings must be no larger than 1 inch square to prevent coarse debris larger than 1 inch from entering the basin. The inlet grate must fit tightly into the underlying steel frame to prevent it from being dislodged by traffic. Do not weld the inlet grate to the underlying frame. The riser section shall be mortared, grouted, gasketed, or otherwise sealed, to prevent exfiltration through the joint. Leaching catch basins shall contain no weep holes. Do not perforate the barrel section.		https://www.mass.gov/doc/massachusetts-stormwater-handbook-vol-2-ch-2-stormwater-best-management-practices/download
Rain Barrels/Cisterns	Cisterns and rain barrels store roof runoff which is then reused it for gardening and other non-drinkable uses reused or infiltrated into a safe area.	Barrel made of wood, heavy plastic, or cans	Can reduce water demand for any non-drinkable uses. Residents can save money on water bills by storing runoff. Less demand of public water sources. Can reduce stormwater runoff volume.	Can be a mosquito-breeding habitat if not properly maintained. Not usable in winter as water can freeze and break the barrel	Inspecting the unit twice a year for mosquito control, removing and draining the barrel before freezing temperatures to prevent cracking, and replace and repair when necessary.	No primary pollutant removal benefits but keeps roof runoff out of other water bodies. Roof runoff assumed clean.	Cisterns and rain barrels used mainly in commercial or residential properties where there is a gutter and downspout system that can direct runoff into the barrel. Can be used in urban areas as they do not take up a lot of space. Good in any circumstance.	Rain barrels are best used with a drip irrigation system. Make sure barrels are not easily accesible by children or animals. Use mosquito netting in open areas to keep properly sealed.		https://www.mass.gov/doc/massachusetts-stormwater-handbook-vol-2-ch-2-stormwater-best-management-practices/download
Water Quality Swale	Water quality swales are vegetated open channels. They treat required water quality volume and transport runoff for 10-year storms without erosion occurances. There are 2 types of swales: Dry Swales and Wet Swales. Both are designed to treat the required water quality volume can include features that can reduce specific pollutants.	Vegetation mix, seedlings, mulch.	Can replace curb and gutter systems. Can keep stormwater flows away from street surface. Compatible with low impact development designs. Can be used to improve drainage or grass channels. It is also animal friendly,	High degree of maintenance required than for curb and gutter systems. Subject to damage from car parking, snow removal, and winter deicing. Can erode during large storms. Less feasible in areas with very flat grades, steep topography or poorly drained soils. Can become a mosquito breeding area.	Inspect swales for vegetation and erosion, repair if needed. Check for rilling and gullying. This should occur twice a year. Mow dry swales, wet swales less so, depending on vegetation as needed. Sediment and debris should be removed once a year. Re-seed when necessary.	Total Suspended Solids: 1. Dry Swale 70% 2. Wet Swale 70% Total Nitrogen = 10% to 90% Total Phosphorus = 20% to 90%	Dry swales mainly used in residential and institutional land with low to moderate density impervious areas of land is low. Wet swales usually not good for residential areas, such front lots because they contain standing water, attracting mosquitoes.	When designing a water quality swale it is important to know the soil characteristics, flow capacity, erosion resistance, and vegetation where the swale would be implemented. Site conditions and design specifications usually limit the use of swales.		https://www.mass.gov/doc/massachusetts-stormwater-handbook-vol-2-ch-2-stormwater-best-management-practices/download
Grassed Channel	Grassed Channels/biofilter swales provide water treatment with long hydraulic residence time compared to drainage channels. Removal methods are sedimentation and gravity separation, rather than filtration. Pretreatment of sediment forebay or equivalent must be provided for TSS removal.	Geotextile and grass lining are used to protect channel structure.	Can provide pretreatment. Open drainage system makes it easier for maintanence. Compatible with low impact development designs as well as animal friendly.	Short retention time leads to inefficient gravity separation. Limited filtration provided by grass lining. It also needs to be carefully designed to achieve low water quality flow rates and can become a mosquito habitat due to standing water.	Sediment from forebay and grass channel should be removed anually. It shouled be mowed once a mont while areas should be repaired from erosion and vegetation but no less than once a year.	Total Suspended Solids = 50% Total phosphorus = -121%	Grass channels are designed to fully drain after a storm. They also end up exporting phosphorus (why is why total phosphorus is negative). Not suitable for stormwater with phosphorus issues.	Grass channels are designed to maximize contact with vegetation and soil surface which helps with better gravity separation of solids during storms. Velocity of channel should not exceed 1 foot per second during a 24-hour storm. Water depth should not exceed 4 inches.		https://www.mass.gov/doc/massachusetts-stormwater-handbook-vol-2-ch-2-stormwater-best-management-practices/download
Drainage Channels	Drainage channels are traditional vegetated open channels that are used for non-erosive stormwater transportation. They provide no infiltration or TSS removal.	Soil amendments are used to improve vegetation. Vegetation mix will need to be made specifically for the site. Seeding will require mulching.	Transports stormwater efficiently. They are less expensive than curb and gutter systems. They are compatible with low impact designs. Roadside drainage channels can keep stormwater flows away from street surface	More maintenance is required than for curb and gutter systems. Roadside channels can be damaged from car parking or snow removal. It provides limited pollutant removal compared to water quality swales. It is less feasible in areas with flat grades, steep topography or poorly drained soils.	Inspect channels to make sure vegetation is adequate and for signs of rilling and gullying. Repair is necessary as inspection should occur during the first few months of construction then 2 times a year thereafter. Mow as necessary. Remove sediment and debris manually at least once a year. Reseed when necessary.	Total Suspended Solids = 0%	Drainage channels feasible for residential and institutional areas with low/moderate density. Area needs to be mainly pervious to infiltration for drainage channel to work properly. They can also be used in parking lots to break up areas of impervious cover.	Drainage channel should be designed for maximum capacity while minimizing any possible erosion. The greatest flow retardance occurs when there is high vegetation growth. Land availability, maintenance requirements and soil characteristics should also be considered when designing the drainage channel.		https://www.mass.gov/doc/massachusetts-stormwater-handbook-vol-2-ch-2-stormwater-best-management-practices/download
porous pavement	pavement that has a higher than normal percentage of air voids. Allows water to pass through and infiltrate the subsoil	durable, load-bearing, pervious surface overlying a stone bed that stores rainwater before it infiltrates into the underlying soil.	• Reduce stormwater runoff volume from paved surfaces • Reduce peak discharge rates. • Increase recharge through infiltration. • Reduce pollutant transport through direct infiltration. • Can last for decades in cold climates if properly designed, installed, and maintained • Improved site landscaping benefits (grass pavers only). • Can be used as a retrofit when parking lots are replaced.	• Prone to clogging so aggressive maintenance with jet washing and vacuum street sweepers is required. • No winter sanding is allowed. • Winter road salt and deicer runoff concern near drinking water supplies for both porous pavements and impervious pavements. • Soils need to have a permeability of at least 0.17 inches per hour. • Special care is needed to avoid compacting underlying parent soils.	cleaning, reseeding, exfiltration assessment, and monitoring as needed. Surface inspections anually.	80% removal efficiency of TSS		Porous paving must not receive stormwater from other drainage areas, especially any areas that are not fully stabilized. Use porous paving only on gentle slopes (less than 5%). Do not use it in high-traffic areas or where it will be subject to heavy axle loads.		

Appendix J: Tree box & Rain Garden Flow Calculations

The dimensions used in both the tree box and rain garden calculations can be seen in Sections 5.1 and 5.2, respectively.

Tree box:

Area of tree box: 6ft * 4ft = $24ft^2$ = 3456 in^2

Area of street entering tree box: 6m* 65m *10.72ft2/m2 *144in2/ft2 = 602,035.2 in^2

Influent entering the tree box: (Iowa Stormwater) 3.33 in/24hr = 0.13875 in/hr * (3456+602,035.2) in^2 *1hr/3600s= 23.33664 in^3/sec

The park area was not considered for the calculation of flow entering the tree box because the pervious nature of the park has limited runoff as seen in the HydroCAD analysis.

About 30% of water is removed through the tree box media (Iowa Stormwater, 2018)

Removal: 0.30 * 23.33in^3/sec * 1 ft^3/1728 in^3= 0.00405 ft^3/s

Rain Garden:

Volume of rain garden 1 = (30in deep *360in long*72in wide) = 777,600in^3

Volume of rain garden 2 =(30in deep*90in long*72in wide) = 194,400in^3

Total volume of rain garden =194,400in^3 + 777,600in^3= 972,000in^3

Rainfall = 3.33 in/24hr = 0.13875 in/hr

Assume percolation rate = 1 in/hour

Surface Area (1) = 30 ft * 6 ft = 180 ft^2 = 25,920 in^2

Surface Area (2) = 15 ft * 6 ft = 90 ft^2 = 12,960 in^2

Total Surface Area = 12,960 in^2 + 25,920 in^2 = 38,880 in^2

Area of tennis courts and half basketball court: [(44m *47m)2068 + (16m *17m)272] *10.72$ft^2/m2$ *144in^2/ft^2= 3,612,211.2 in^2

Area of street entering rain garden: (47m*6m) *10.72$ft^2/m2$ *144in^2/ft^2= 435,317.76 in^2

Rainfall entering the rain gardens= 0.13875 in/hr * (38880+3,612,211.2+435,317.76) in^2 = 566,989.243/hr * 1 ft^3/1728 in^3 * 1hr/3600s= 0.091 ft^3/s

Rain garden storage potential = (30 ft * 6 ft * 1.5 ft) + (15 ft * 6 ft * 1.5 ft) = 405 ft^3

Additional ponding area allows for rain garden overflow. There is room in the soil medium before ponding on top if the precipitation rate is larger than the percolation rate

Appendix K: Anion Report

Logged on User: User1
Instrument: ICS_2100
Sequence: Fram. Storm Water M QP

Anion Summary Report

No.	Name	Time min ECD_1 Flouride	Area µS*min ECD_1 Flouride	Rel.Area % ECD_1 Flouride	Height µS ECD_1 Flouride	Rel.Height % ECD_1 Flouride	Amount ECD_1 Flouride
1	Blank	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
2	Blank	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
3	200ppb	4.211	0.1765	7.23	1.14	17.37	21.7858
4	400ppb	4.214	0.3615	7.69	2.50	18.59	44.6342
5	800ppb	4.217	0.7089	7.81	5.09	19.21	87.5230
6	1200ppb	4.217	1.0407	7.86	7.53	19.30	128.4945
7	2000ppb	4.221	1.6469	7.72	12.15	19.26	203.3375
8	4000ppb	4.224	3.1889	7.40	22.93	18.76	393.7256
9	1	4.174	0.0478	0.77	0.34	1.70	5.8983
10	2	4.181	0.0460	0.75	0.33	1.67	5.6853
11	3	4.184	0.0365	0.45	0.27	0.88	4.5046
12	4	4.184	0.0350	0.43	0.26	0.85	4.3176
13	Blank	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
14	Blank	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
15	Blank	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	Sum:	42.025	7.289	48.112	52.525	117.575	899.906
	Average:	4.203	0.729	4.811	5.252	11.757	89.991
	Rel.Std.Dev:	0.463 %	139.643 %	75.477 %	140.166 %	76.929 %	139.643 %

No.	Name	Time min ECD_1 Chloride	Area µS*min ECD_1 Chloride	Rel.Area % ECD_1 Chloride	Height µS ECD_1 Chloride	Rel.Height % ECD_1 Chloride	Amount ECD_1 Chloride
1	Blank	7.880	0.0148	12.14	0.03	8.32	2.9918
2	Blank	7.864	0.0164	6.48	0.06	6.74	3.3126
3	200ppb	8.094	0.5347	21.91	2.15	32.80	108.3342
4	400ppb	8.107	1.0607	22.57	4.54	33.75	214.8998
5	800ppb	8.111	2.0213	22.27	8.84	33.39	409.5042
6	1200ppb	8.114	2.9993	22.66	13.15	33.71	607.6362
7	2000ppb	8.111	4.8505	22.73	21.46	34.01	982.6858
8	4000ppb	8.101	9.8845	22.94	42.92	35.11	2002.5587
9	1	7.864	3.3715	54.44	15.16	75.33	683.0515
10	2	7.881	3.3750	54.82	15.13	75.75	683.7558
11	3	7.887	5.8218	71.56	26.07	86.12	1179.4790
12	4	7.897	5.8594	71.97	26.22	86.34	1187.0903
13	Blank	7.920	0.0235	3.38	0.09	2.68	4.7685
14	Blank	7.924	0.0202	3.40	0.08	2.74	4.0861
15	Blank	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	Sum:	111.753	39.854	413.255	175.877	546.793	8074.155
	Average:	7.982	2.847	29.518	12.563	39.057	576.725
	Rel.Std.Dev:	1.410 %	103.687 %	80.412 %	103.423 %	77.507 %	103.687 %

No.	Name	Time min ECD_1 Nitrite	Area µS*min ECD_1 Nitrite	Rel.Area % ECD_1 Nitrite	Height µS ECD_1 Nitrite	Rel.Height % ECD_1 Nitrite	Amount ECD_1 Nitrite
1	Blank	9.777	0.0020	1.62	0.00	1.21	0.6223

2	Blank	9.770	0.0082	3.24	0.02	1.72	2.5739
3	200ppb	10.141	0.3614	14.81	1.05	16.08	113.8000
4	400ppb	10.154	0.7093	15.09	2.25	16.70	223.3394
5	800ppb	10.154	1.4141	15.58	4.57	17.26	445.2345
6	1200ppb	10.157	2.0547	15.53	6.58	16.88	646.9418
7	2000ppb	10.154	3.2147	15.06	10.28	16.29	1012.1465
8	4000ppb	10.134	6.2498	14.51	18.20	14.89	1967.7733
9	1	9.791	0.0587	0.95	0.13	0.64	18.4709
10	2	9.807	0.0596	0.97	0.08	0.42	18.7805
11	3	9.760	0.0468	0.58	0.05	0.18	14.7451
12	4	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
13	Blank	9.857	0.0279	4.00	0.06	1.80	8.7905
14	Blank	9.857	0.0260	4.38	0.05	1.96	8.1921
15	Blank	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	Sum:	129.513	14.233	106.320	43.326	106.024	4481.411
	Average:	9.963	1.095	8.178	3.333	8.156	344.724
	Rel.Std.Dev:	1.826 %	168.159 %	82.723 %	164.969 %	97.229 %	168.159 %

No.	Name	Time min ECD_1 Sulfate	Area µS*min ECD_1 Sulfate	Rel.Area % ECD_1 Sulfate	Height µS ECD_1 Sulfate	Rel.Height % ECD_1 Sulfate	Amount ECD_1 Sulfate
1	Blank	11.400	0.0012	1.01	0.00	0.77	0.3345
2	Blank	11.597	0.0015	0.59	0.00	0.35	0.4093
3	200ppb	12.321	0.4214	17.26	0.94	14.30	115.1292
4	400ppb	12.371	0.7605	16.18	1.73	12.85	207.7864
5	800ppb	12.401	1.4769	16.27	3.43	12.95	403.5480
6	1200ppb	12.421	2.1938	16.58	5.10	13.07	599.4328
7	2000ppb	12.431	3.5582	16.67	8.44	13.38	972.2269
8	4000ppb	12.424	7.3629	17.09	17.36	14.20	2011.8120
9	1	11.821	0.8638	13.95	1.84	9.16	236.0198
10	2	11.864	0.8270	13.43	1.77	8.84	225.9633
11	3	11.907	0.9577	11.77	2.06	6.82	261.6681
12	4	11.947	0.9646	11.85	2.07	6.81	263.5758
13	Blank	11.927	0.0036	0.52	0.01	0.21	0.9893
14	Blank	11.934	0.0032	0.54	0.01	0.21	0.8794
15	Blank	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	Sum:	168.763	19.396	153.718	44.749	113.935	5299.775
	Average:	12.055	1.385	10.980	3.196	8.138	378.555
	Rel.Std.Dev:	2.813 %	143.002 %	63.781 %	146.776 %	69.647 %	143.002 %

No.	Name	Time min ECD_1 Bromide	Area µS*min ECD_1 Bromide	Rel.Area % ECD_1 Bromide	Height µS ECD_1 Bromide	Rel.Height % ECD_1 Bromide	Amount ECD_1 Bromide
1	Blank	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
2	Blank	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
3	200ppb	19.501	0.2062	8.45	0.37	5.58	96.5435
4	400ppb	19.524	0.4251	9.05	0.77	5.71	199.0098
5	800ppb	19.517	0.8732	9.62	1.54	5.81	408.7809
6	1200ppb	19.511	1.2777	9.65	2.28	5.86	598.1428
7	2000ppb	19.474	2.0772	9.73	3.78	5.99	972.3887

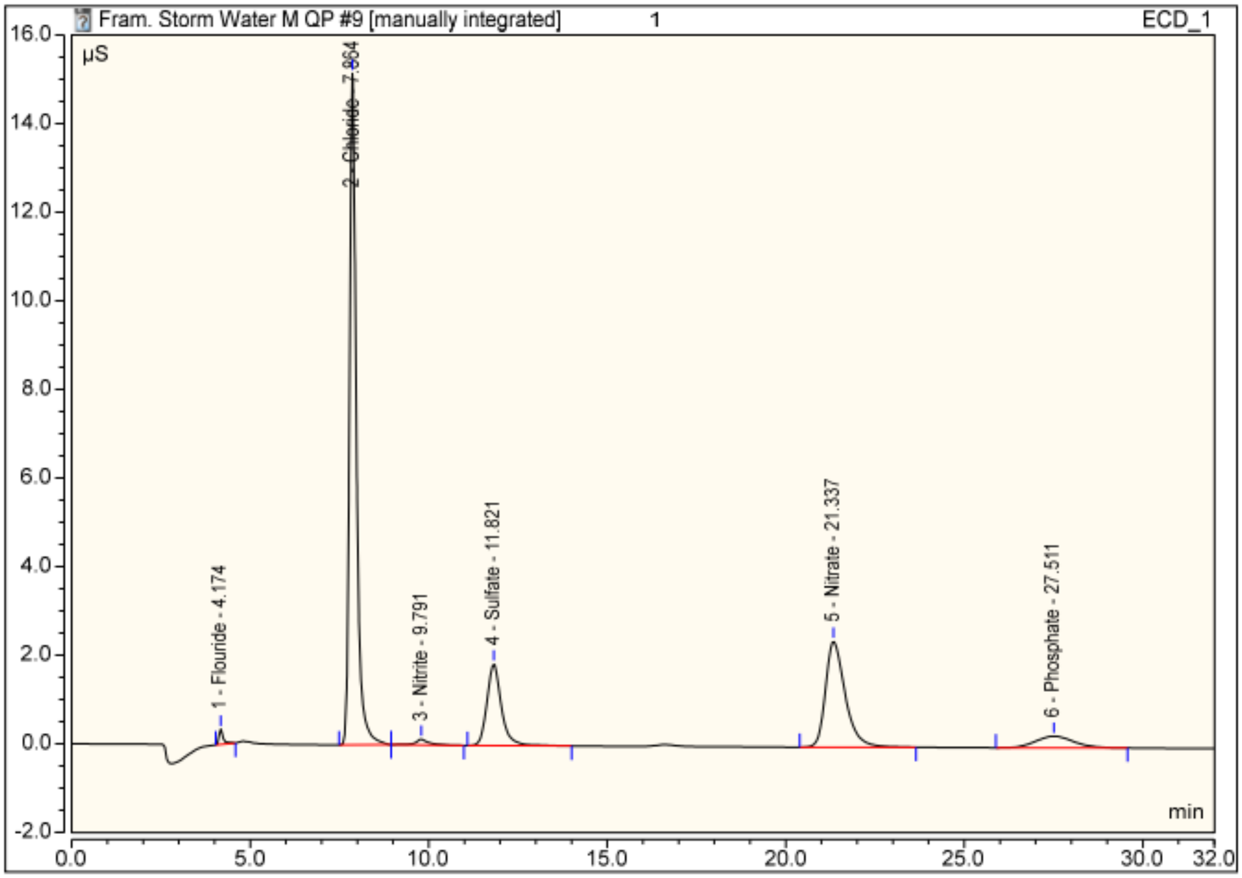
8	4000ppb	19.384	4.2998	9.98	7.55	6.17	2012.8785
9	1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
10	2	18.684	0.0026	0.04	0.00	0.02	1.2061
11	3	18.687	0.0013	0.02	0.00	0.01	0.6005
12	4	18.750	0.0018	0.02	0.00	0.01	0.8200
13	Blank	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
14	Blank	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
15	Blank	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	Sum:	173.031	9.165	56.563	16.290	35.160	4290.371
	Average:	19.226	1.018	6.285	1.810	3.907	476.708
	Rel.Std.Dev:	2.037 %	139.261 %	75.021 %	138.168 %	74.852 %	139.261 %

No.	Name	Time min ECD_1 Nitrate	Area µS*min ECD_1 Nitrate	Rel.Area % ECD_1 Nitrate	Height µS ECD_1 Nitrate	Rel.Height % ECD_1 Nitrate	Amount ECD_1 Nitrate
1	Blank	21.337	0.0171	14.03	0.02	5.48	5.8652
2	Blank	21.420	0.0218	8.65	0.03	3.71	7.5023
3	200ppb	22.547	0.4232	17.34	0.63	9.66	145.3760
4	400ppb	22.557	0.7271	15.47	1.09	8.14	249.7875
5	800ppb	22.537	1.2912	14.22	1.90	7.16	443.5777
6	1200ppb	22.511	1.8227	13.77	2.72	6.98	626.1775
7	2000ppb	22.441	2.8886	13.54	4.29	6.79	992.3559
8	4000ppb	22.281	5.7634	13.38	8.09	6.62	1980.0057
9	1	21.337	1.5257	24.63	2.39	11.88	524.1347
10	2	21.394	1.5636	25.40	2.43	12.17	537.1630
11	3	21.467	1.0514	12.92	1.64	5.43	361.2094
12	4	21.500	1.0589	13.01	1.65	5.43	363.7945
13	Blank	21.640	0.0836	11.99	0.12	3.61	28.7087
14	Blank	21.661	0.0812	13.68	0.11	4.06	27.8914
15	Blank	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	Sum:	306.630	18.319	212.025	27.120	97.105	6293.550
	Average:	21.902	1.309	15.145	1.937	6.936	449.539
	Rel.Std.Dev:	2.422 %	116.673 %	30.289 %	111.804 %	39.431 %	116.673 %

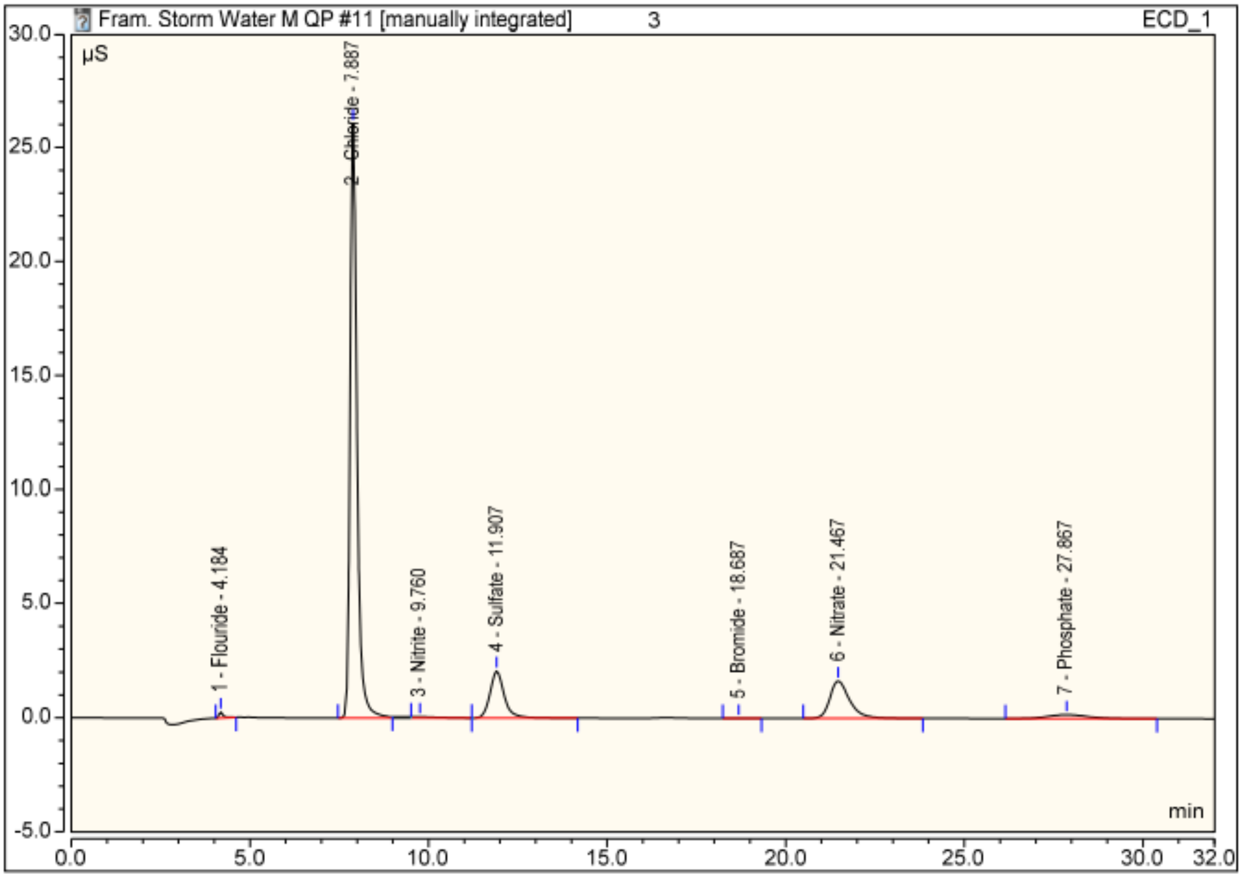
No.	Name	Time min ECD_1 Phosphate	Area µS*min ECD_1 Phosphate	Rel.Area % ECD_1 Phosphate	Height µS ECD_1 Phosphate	Rel.Height % ECD_1 Phosphate	Amount ECD_1 Phosphate
1	Blank	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
2	Blank	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
3	200ppb	29.244	0.3172	13.00	0.28	4.22	201.2640
4	400ppb	29.374	0.6554	13.95	0.57	4.27	415.8263
5	800ppb	29.431	1.2922	14.24	1.12	4.22	819.8425
6	1200ppb	29.451	1.8448	13.94	1.64	4.19	1170.3928
7	2000ppb	29.387	3.1032	14.54	2.70	4.29	1968.8122
8	4000ppb	29.074	6.3345	14.70	5.19	4.25	4018.8617
9	1	27.511	0.3257	5.26	0.26	1.30	206.6500
10	2	27.684	0.2831	4.60	0.23	1.13	179.6364
11	3	27.867	0.2202	2.71	0.17	0.57	139.7304
12	4	27.967	0.2217	2.72	0.17	0.56	140.6549
13	Blank	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

14	Blank	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
15	Blank	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	Sum:	286.988	14.598	99.653	12.327	28.990	9261.671
	Average:	28.699	1.460	9.965	1.233	2.899	926.167
	Rel.Std.Dev:	2.877 %	133.793 %	53.784 %	131.281 %	60.148 %	133.793 %

ICS generated graph for Sample 1.



ICS generated graph for sample 3.



Conc in PPB

					BLANK
	1	2	3	4	5
CL	683.05	683.75	1179.47	1187.09	4.7685
NO2	18.47	18.78	14.74	0	8.7905
SO4	236.01	225.98	261.668	263.5758	0.9793
NO3	524.1347	537.163	361.209	363.7945	28.7087
PO4	206.65	179.6364	139.73	140.6549	0

Conc in PPM

CL	0.68305	0.68375	1.17947	1.18709	0.004769
NO2	0.01847	0.01878	0.01474	0	0.008791
SO4	0.23601	0.22598	0.261668	0.263576	0.000979
NO3	0.524135	0.537163	0.361209	0.363795	0.028709
PO4	0.20665	0.179636	0.13973	0.140655	0

NO3-N	0.118353	0.121295	0.081563	0.082147	0.006483
PO3-P	0.067389	0.05858	0.045566	0.045868	0
TP		0.183		0.196	