Worcester Polytechnic Institute

Improving Stormwater Management for the Salisbury Pond Area

A Major Qualifying Project

Submitted to the Faculty of

Worcester Polytechnic Institute

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List of Acronyms

BMP - Best Management Practices

CWA - Clean Water Act

DO - Dissolved Oxygen

EPA- Environmental Protection Agency

GIS- Geographic Information System

ICPMS- Inductively Conducted Plasma Mass Spectrometer

ICS- Ion Chromatography Spectrometer

MassDEP- Massachusetts Department of Environmental Protection

NPDES - National Pollutant Discharge Elimination System

TP- Total Phosphorus

TSS - Total Suspended Solids

WPI - Worcester Polytechnic Institute

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Authorship

Fernand Gay - Fernand wrote four of the methodology sections (3.0, 3.3, 3.4, 3.5), as well as parts of the results, focusing on the GIS, HydroCAD, and BMP analysis (4.2, 4.3, 4.4). Additionally, Fernand wrote the design section for Salisbury Estates (section 5.3), and the first paragraph of the conclusion. Fernand also spearheaded the BMP designs and ensured that each BMP design was appropriate.

Jeffrey Desjardins - Jeffrey wrote the abstract, introduction, contributed to section 2.5.2 of the background, parts of the Total Phosphorus and Total Suspended Solids sections of the results (4.1.3 & 4.1.2), and the design section for Worcester Fallen Firefighters Memorial Area (5.5). Jeffrey was responsible for conducting many laboratory tests, including Total Phosphorus and Total Suspended Solids.

Meghan McCudden - Meghan wrote the Capstone Design Statement, the Professional Licensure, parts of the background (primarily writing about Salisbury Pond and past projects in section 2.5), parts of the methods (primarily the HydroCAD methodology in section 3.4.2), part of the results (primarily for ICS and ICP-MS results in 4.1.1, as well as parts of 4.1.2 and 4.1.3), and the last two paragraphs of the conclusion. Meghan was also responsible for the hydrologic modeling in HydroCAD.

Morgan Emery - Morgan wrote the BMP part of the Background (2.4), the Locations and Sampling sections (3.1, 3.2) and the GIS section (3.4.1) for the methodology, and she wrote part of the Grassy Hill Area design section (5.4). Morgan was also responsible for creating maps using ArcGIS.

Edie Hudson - Edie wrote the stormwater, stormwater contaminants and stormwater regulations portions of the background (2.1-2.3) and contributed to parts of the design section (primarily the Grassy Hill Area design section 5.4). Edie was also responsible for creating the poster for Project Presentation Day.

All other sections not specifically mentioned were written as a group, and everyone continuously edited each other's work. Everyone worked together on the BMP designs, first determining what the best BMP would be a certain location, and then performing calculations for the actual BMP design.

Abstract

Stormwater runoff transports various pollutants from the land surface to groundwater and larger bodies of water. This contamination can negatively impact certain bodies of water along with their aquatic life. This project addressed the impacts of stormwater runoff on Salisbury Pond, a pond in Worcester located adjacent to the WPI campus. By sampling, testing, and analyzing the quality and determining flows and loads of local runoff for the areas surrounding Salisbury Pond, this project developed and recommended applicable stormwater Best Management Practices (BMPs) to minimize the local contributions to surface water pollution in Salisbury Pond.

Acknowledgements

Throughout our project, we received help from numerous individuals. First, we would like to thank Worcester Polytechnic Institute's Civil and Environmental Engineering (CEE) Department. Without the professors and resources available for us in this department, we could not have easily accessed the knowledge or tools to complete this work. Subsequently, we would like to thank Professor Paul Mathisen, for advising our project, providing feedback, and guiding us through figuring out our project. We would also like to thank the previous CEE Lab Manager Wenwen Yao for all the work she did in teaching us the testing procedures and assisting us in analyzing our samples. Finally, we would like to thank Nitsch Engineering and their representatives: Coleman Horsley and Sandra Brock. Without Nitsch, this project would not have been possible. Coleman and Sandra's guidance allowed the project to unfold and expand to where it has ended up currently. They provided supportive and reasonable feedback, which allowed us to learn a lot from this experience.

Executive Summary

Contaminated stormwater runoff is a major source of water pollution for urban areas. When precipitation or storm events occur, the resulting stormwater flows across impervious surfaces collecting numerous harmful pollutants and solids, eventually carrying these pollutants into larger bodies of water, or discharging them into the ground. Contaminated stormwater runoff can cause very serious public health issues, which also hurts the environment and economic stability of the area. With seasonal flooding from heavy rainfall events, drainage systems are needed to redirect stormwater runoff, and manage or treat it. While these drainage systems are helpful in the process of managing stormwater, they can also frequently be a gateway for pollutants to enter water bodies as well. This is why Best Management Practices (BMPs) are useful for treating stormwater before it flows into larger bodies of water.

Salisbury Pond, an impounded water body adjacent to WPI in Worcester, MA, has been experiencing these problems due to stormwater runoff. A number of studies have shown that the pond receives large loads of sediments, nutrients, and other contaminants from upstream runoff. The contributions of local runoff from the adjacent areas have not been accurately determined. These contributions depend on the quality of runoff from different land surface types, which is also not well defined.

The goal of this project was to help mitigate the effects of stormwater runoff on Salisbury Pond, by analyzing runoff from different areas around the pond and campus and developing feasible recommendations for mitigating the impacts of this runoff. For our project, we partnered with the environmental consulting company Nitsch Engineering, Inc. Nitsch has specialized in providing civil engineering, land surveying, transportation engineering, structural engineering, green infrastructure, planning, and GIS services since 1989. For our project, Nitsch Engineering was interested in sampling and testing water quality, for the purposes of understanding the effects of land surfaces on the quality of stormwater runoff. The various surface types in Salisbury Pond provided a valuable case study for assessing these effects. To successfully make recommendations and designs for managing and treating stormwater, we had to first do research on BMPs and contamination.

After gathering information on these topics, we needed to sample from specific locations around the campus area, for the purpose of analyzing contamination and flow across different surface types, or land areas. Completing that analyzation process would then allow us to develop

our recommendations, based on the needs of chosen areas. Thus, after sampling we had to perform our lab testing to obtain contamination levels for analysis. The data analysis consisted of determining the levels of total suspended solids (TSS), total phosphorus, iron, copper, lead, sodium, potassium, aluminum, magnesium, calcium, phosphate, nitrate, sulfate, chloride, and fluoride. Using ArcGIS, the watershed catchments around Salisbury Pond were determined, as well as the areas, the slopes, and the land use of the catchments. This information was used for hydrologic modeling with HydroCAD, a stormwater modeling software. From HydroCAD, we were able to determine the drainage velocities, the impervious versus pervious area for the pond catchments, and the overall runoff quantification. Once the watershed was characterized and the runoff was quantified, recommendations and designs were developed for managing and treating the stormwater runoff.

Using the data we gathered, we then integrated our findings with future work being done for Institute Park and Salisbury Pond. We developed three recommendations for improving the management of stormwater going into Salisbury Pond, one of which being a design for the Salisbury Estate Area, an apartment complex located adjacent to the pond. This design would treat the stormwater runoff coming from Salisbury Estates right by the main parking lot. The second recommendation was treatment for the Firefighter Memorial Walkway located right next to the O’Connell Football Field. The BMP walkway already constructed there already provides treatment and pre-treatment. However, there is an area directly in front of the walkway and filtration garden located there, where an additional forebay, or bioretention system, could be constructed. This recommendation would provide a treatment system to handle the flow from the larger contributing area.

The final pre-treatment recommendation which we developed, would be for the grassy hill area near the rotunda on the main side of the pond. We determined that the slope and TSS loading there would be more properly managed if there were at least some basic pre-treatments for runoff coming from that area, to reduce flooding and turbidity in the water. Overall, these BMPs should mitigate the impacts of stormwater runoff to Salisbury Pond by reducing the amounts of Total Suspended Solids, Total Phosphorus, sodium, and chloride entering the pond.

In completing this project, we wanted to target new ways of tackling and managing stormwater. We also wanted to provide a good basis for future project groups, and research going forward as well. Thus, our finished deliverables included a poster for presentation, along with our report, and a presentation of our design and recommendations.

Capstone Design Statement

This Major Qualifying Project (MQP) satisfies the design capstone component required for graduation by WPI's Department of Civil and Environmental Engineering. This design component is required for the program's accreditation by ABET and the American Society of Civil Engineers (ASCE). According to ABET, a capstone design experience should include engineering standards and multiple constraints, as well as skills and knowledge learned in previous coursework (ABET, n.d.). This project included designing a Best Management Practice (BMP) for the WPI Townhouses of the WPI campus to mitigate stormwater pollution. While working on possible designs to improve stormwater quality, the MQP team considered social, environmental/sustainable, and economic constraints.

Social: Before designing any BMP, the team needed to consider who would be impacted by this project. This project is for the WPI campus, with a focus on the areas near the WPI Townhouses and Institute Park. Because these areas have residential students and faculty living or working there, the team needed to make sure to accommodate their needs and try not to disrupt their lives. Additionally, as the park is a public space, the team made sure not to disrupt or bother the public. In fact, through proper stormwater mitigation, the team hoped to improve public health and enjoyment of the open space. Also, the design and project needed to abide by the policies set by WPI to maintain safety and regulations.

Environmental/Sustainable: As the goal of this project was to mitigate effects of stormwater with a BMP, the design should hopefully improve the environment on campus. When designing the BMP, the team considered the materials and construction involved with the design so that there isn't any negative environmental impact. To ensure that the environmental impact of a new design isn't harmful, the team considered possible green infrastructures as a BMP.

Economic: Lastly, as this project would be built at WPI's behest, the team considered the economic aspects of their design. Our final design should be effective at removing pollutants in stormwater without being costly to build or for WPI to maintain.

Professional Licensure

The National Council of Examiners for Engineering and Surveyors (NCEES) recommends that engineers become professionally licensed to protect the “health, safety, and welfare of the public” (NCEES, n.d.). Essentially, professional licensure ensures public safety by restricting practice to engineers who have proven their competence in the profession. Professional Engineers (abbreviated as PEs) are able to prepare, sign, and seal engineering plans to be submitted for approval by a public authority (National Society of Professional Engineers, n.d.). Because their licensure allows them more responsibilities, PEs tend to be paid more than their non-licensed counterparts (National Society of Professional Engineers, n.d.). Engineers are licensed at the state level, and each state has its own requirements for an engineer to become professionally licensed. However, the minimum qualifications for most states are met through a combination of education, experience, and exams. The basic pathway to become a PE is as follows:

- Attend an EAC/ABET-accredited college and earn a bachelor’s degree.
- After graduation, take (and pass) the NCEES Fundamentals of Engineering (FE) exam to become an Engineer in Training (EIT).
- Gain four years of relevant engineering experience by working under a PE.
- Finally, take the NCEES Principles and Practice of Engineering exam to become a licensed PE (NCEES, n.d.).

1.0 Introduction

Water is often called “the universal solvent” due to its ability to dissolve such a significant number of elements and compounds. We all can realize how effective water is at washing away a large variety of particles since we utilize it every day to wash our clothes, dishes, hands, and more. In the same washing manner, when water from rain and snowstorms (i.e., stormwater runoff) flows across land surfaces, it absorbs and washes away many particles including dirt, trash, chemicals, and animal waste. Most stormwater runoff eventually flows into nearby rivers, ponds, and lakes, resulting in the contaminants that it washes away also ending up in bodies of surface water.

Protecting and regulating the quality of surface water has been a focus in our country since 1948 when the Federal Water Pollution Control Act was first passed. In 1972, the Act was developed and updated to the Clean Water Act (CWA). These acts established the structure for limiting pollution discharges into the nation's bodies of water and maintaining quality standards of the surface water. The National Pollutant Discharge Elimination System (NPDES), managed by the Environmental Protection Agency (EPA), actively regulates stormwater pollution at industries and construction sites, but much of the pollution washed into bodies of water by stormwater runoff is a result of events like animal excretion, littering, washing vehicles, and maintaining lawns (NPDES Stormwater Program | US EPA, 2022). Pesticides and fertilizers are widely utilized for improving growth of plants and grass; however, they often contain significant amounts of phosphorus, nitrogen and potassium that when in excess can be washed away by stormwater runoff. Animal excrement of pets and local wildlife which contains significant amounts of phosphorus and nitrogen also affects the quality of stormwater runoff. Phosphorus, nitrogen, and other elements are necessary nutrients to the environment since they are consumed by plants and soil microbes for growth. However, excessive levels of certain elements can be dangerous to the health of aquatic systems as it causes eutrophication which is accelerated growth of algae and large aquatic plants. This leads to decreased dissolved oxygen (DO) levels in the water, leaving other aquatic plants and fish oxygen depleted. In severe cases, the accelerated growth of algae can create algae blooms which also release algal toxins harmful to the quality of air.

These contamination issues also pertain to Salisbury Pond, the pond adjacent to Worcester Polytechnic Institute's campus. By understanding how these different contaminants impact aquatic environments, we can work to better manage and protect surface water bodies. The ultimate goal of this project is to reduce the negative impacts stormwater runoff has on Salisbury Pond by recommending well-designed practices to minimize the stormwater runoff flow and contaminant load. By examining the area around Salisbury Pond, mapping the contributing stormwater runoff, collecting samples of stormwater, and conducting lab tests on the samples, we were able to analyze the quality of local stormwater runoff regarding common contaminants based on location. From here, the recommendations of applicable stormwater Best Management Practices were developed to minimize the contaminant load of stormwater runoff relative to Salisbury Pond.

2.0 Background

This chapter provides relevant information on topics related to stormwater runoff, its effects on the environment, and how it is managed. First, information regarding stormwater runoff and common contaminants is presented, then this section looks at topics such as stormwater regulations and best management practices, which will be referenced later in the design process of the project. Finally, previous collaborations with Nitsch on stormwater projects are discussed, as well as other case studies examining the impact of land use on stormwater runoff.

2.1 Stormwater

Pollutants that are spread through stormwater runoff are a lesser known, yet impactful, danger to our environment. Stormwater runoff occurs when precipitation slides across hard, impervious surfaces, picking up contaminants along the way, until it eventually gets soaked up into the ground, goes down a catch basin or flows into a body of water. In Massachusetts, stormwater is the single largest source for water quality impairment in the state's open bodies of water (MassDEP, 2008a). Runoff contaminants include various different types of materials that get picked up on the journey, some more harmful than others.

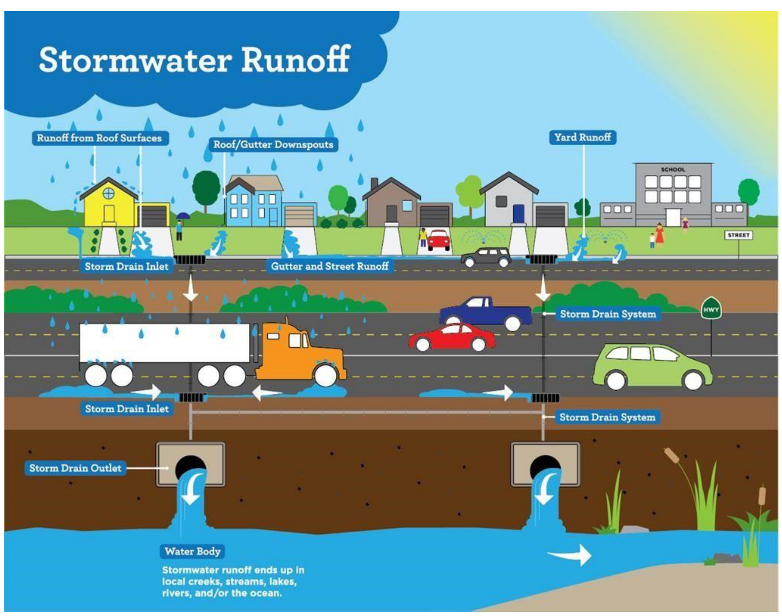

Figure 1*: Illustration of Stormwater Runoff (City of Bainbridge, n.d.)*

2.2 Common Contaminants

A majority of contaminants that get transported are results of human activity. A few of the substances that are commonly identified in stormwater runoff include pesticides, grease, antifreeze, and other everyday materials that can be dangerous to the environment. The main contaminants that these substances leave off are phosphorus, nitrogen, TSS (Total Suspended Solids), and heavy metals.

Phosphorus and nitrogen are naturally occurring nutrients essential to plants and animals. However, when there is an overabundance of them present, they can turn out to cause adverse health effects and detrimental ecological imbalances (USGS, n.d.). The primary sources of these nutrients in stormwater runoff include yard waste, pet waste, fertilizer, manure, and organic wastes (EPA, 2013c and USGS, n.d.). Both nitrogen and phosphorus have adverse effects on bodies of water when in high concentrations. This is because once the balance in which the rate of algae grows is thrown off, it can result in an overgrowth. Algae overgrowth in a lake, for example, can deplete the oxygen levels and essentially “suffocate” a lake and the living organisms that reside in them (EPA, 2013b and USGS, n.d.). This process is termed eutrophication, where an excess of nutrients in a body of water causes an accelerated growth of plant life and a death of animal life due to “dead zones” areas with little to no oxygen in the water (EPA, 2013a).

***Figure 2**: Algae Overgrowth Near a Residential Community (EPA)*

Total suspended solids are particles greater than two microns found in water. TSS includes both inorganic and organic materials. These solids come from vehicle emissions, construction, road salt, pedestrian debris, atmospheric deposition of particles, and many other sources (Minnesota Stormwater Manual, 2021). Like phosphorus and nitrogen, TSS can also cause oxygen-depriving algal blooms, but there are a few other problems this contaminant can bring to bodies of water. Suspended solids that end up on the floor of a body of water can result in clogging and can end up altering their topography. Another high risk of TSS is its impact on the turbidity of water. Turbidity is the cloudiness in water that can block out sunlight, reduce light absorption, and negatively affect the natural balances of aquatic life.

Additional stormwater contaminants include heavy metals such as copper, zinc, cadmium, nickel, chromium, mercury, and lead. Sources of these metals include vehicle emissions, construction, and other industrial activities; when mildly acidic precipitation comes in contact with these metals, these metals can be dissolved and carried into bodies of water. Heavy metal contaminants are most commonly found in highly developed urban stormwater runoff due to the great amount of parking lots, roads, construction, and industrial activities (Brooks Applied Labs, 2016).

2.3 Stormwater Regulations

Stormwater regulation occurs at both a national and state level. In 1972, the National Pollutant Discharge Elimination System (NPDES) was created as part of the Clean Water Act to address water pollution in the United States. Per the Clean Water Act, NPDES regulates point sources of pollution to water through its permit controls: technology-based limits and water quality-based limits (EPA, 2015a). Regarding stormwater, the NPDES program regulates stormwater runoff from three potential sources. These sources are municipal stormwater sewer systems (MS4s), construction activities, and industrial activities. Typically, people who operate these sources must obtain a NPDES permit before they can discharge any stormwater (EPA, 2015b).

Acceptable amounts of runoff contaminants differ from state to state. In Massachusetts, the Stormwater Policy was issued in 1996, and the Massachusetts Stormwater Handbook was released the following year. The Massachusetts Stormwater Handbook was most recently updated in 2008 to improve treatment of runoff and promote pollution prevention (MassDEP, 2008a). MassDEP has also identified certain standards that stormwater management systems must meet in order to be implemented. The Stormwater Management Standards “address water quality and water quantity by establishing standards that require the implementation of a wide variety of stormwater management strategies” (MassDEP, 2008a). These standards are applied based on the Massachusetts Wetlands Protection Act, as well as the Massachusetts Clean Waters Act (MassDEP, 2008a). The standards in the handbook are summarized below:

1. No new stormwater conveyances may discharge untreated stormwater directly to or cause erosion in wetlands or waters of the Commonwealth.

2. Stormwater management systems shall be designed so that post-development peak discharge rates do not exceed pre-development peak discharge rates.

3. Loss of annual recharge to groundwater shall be eliminated or minimized through the use of infiltration measures including environmentally sensitive site design, low impact development techniques, stormwater best management practices, and good operation and maintenance. At a minimum, the annual recharge from the post-development site shall approximate the annual recharge from pre-development conditions based on soil type. This Standard is met when the stormwater management system is designed to infiltrate the required recharge volume.

4. Stormwater management systems shall be designed to remove 80% of the average annual post-construction load of Total Suspended Solids (TSS).

5. For land uses with higher potential pollutant loads, source control and pollution prevention shall be implemented in accordance with the Massachusetts Stormwater Handbook to eliminate or reduce the discharge of stormwater runoff from such land uses to the maximum extent practicable.

6. Stormwater discharges within the Zone II or Interim Wellhead Protection Area of a public water supply, and stormwater discharges near or to any other critical area, require the use of the specific source control and pollution prevention measures and the specific structural stormwater best management practices determined by the Department to be suitable for managing discharges to such areas, as provided in the Massachusetts Stormwater Handbook.

7. A redevelopment project is required to meet the following Stormwater Management Standards only to the maximum extent practicable: Standard 2, Standard 3, and the pretreatment and structural best management practice requirements of Standards 4, 5, and 6. Existing stormwater discharges shall comply with Standard 1 only to the maximum extent practicable. A redevelopment project shall also comply with all other requirements of the Stormwater Management Standards and improve existing conditions.

8. A plan to control construction-related impacts including erosion, sedimentation and other pollutant sources during construction and land disturbance activities shall be developed and implemented.

9. A long-term operation and maintenance plan shall be developed and implemented to ensure that stormwater management systems function as designed.

10. All illicit discharges to the stormwater management system are prohibited (MassDEP, 2008a).

In Massachusetts, whether one or more BMPs are being utilized, the practice(s) must have a cumulative effect of at least 80% TSS removal. According to the Massachusetts Stormwater Handbook Volume 1 Chapter 2, TSS includes contaminants such as nitrogen and phosphorus. It is noted that if other particular contaminants need to be removed, there are other standard guidelines to be in compliance with. One method of ensuring 80% TSS total removal is to implement one BMP and calculate the amount of TSS removed. For example, if results come out to 60% TSS removed, then another BMP may be added to get rid of the other 20%. The following table describes different Best Management Practices for the removal of TSS and the effectiveness of each (MassDEP, 2008c).

Table TSS

TSS Removal Efficiencies for Best Management Practices	
Best Management Practice (BMP)	**TSS Removal Efficiency**
Non-Structural Pretreatment BMPs	
Street Sweeping	0-10%, See Volume 2, Chapter 1.
Structural Pretreatment BMPs	
Deep Sump Catch Basins	25% only if used for pretreatment and only if off-line
Oil Grit Separator	25% only if used for pretreatment and only if off-line
Proprietary Separators	Varies – see Volume 2, Chapter 4.
Sediment Forebays	25% if used for pretreatment
Vegetated filter strips	10% if at least 25 feet wide, 45% if at least 50 feet wide
Treatment BMPs	
Bioretention Areas including rain gardens	90% provided it is combined with adequate pretreatment
Constructed Stormwater Wetlands	80% provided it is combined with a sediment forebay
Extended Dry Detention Basins	50% provided it is combined with a sediment forebay
Gravel Wetlands	80% provided it is combined with a sediment forebay
Proprietary Media Filters	Varies – see Volume 2, Chapter 4
Sand/Organic Filters	80% provided it is combined with sediment forebay
Treebox filter	80% provided it is combined with adequate pretreatment
Wet Basins	80% provided it is combined with sediment forebay
Conveyance	
Drainage Channels	For conveyance only. No TSS Removal credit.
Grass Channels (formerly biofilter swales)	50% if combined with sediment forebay or equivalent
Water Quality Swale – wet & dry	70% provided it is combined with sediment forebay or equivalent
Infiltration BMPs	
Dry Wells	80% for runoff from non-metal roofs; may also be used for runoff from metal roofs but only if metal roof is not located within a Zone II, or IWPA or at an industrial site
Infiltration Basins & Infiltration Trenches	80% provided it is combined with adequate pretreatment (sediment forebay or vegetated filter strip, grass channel, water quality swale) prior to infiltration
Leaching Catch Basins	80% provided a deep sump catch basin is used for pretreatment
Subsurface Structure	80% provided they are combined with one or more pretreatment BMPs prior to infiltration.
Other BMPs	
Dry Detention Basins	For peak rate attenuation only. No TSS Removal credit.
Green Roofs	See Volume 2. Chapter 2. May reduce required water quality volume. No TSS Removal Credit.
Porous Pavement	80% if designed to prevent runon and with adequate storage capacity. Limited to uses identified in Volume 2, Chapter 2.
Rain Barrels and Cisterns	May reduce required water quality volume. No TSS Removal Credit.

Figure 3*: MassDEP Table Displaying BMPs and Respective Efficiencies (MassDEP, 2008c)*

2.4 Best Management Practices

In the realm of stormwater treatment, discoveries are being made every day. Scientists have begun to search for greener solutions to stormwater treatment in various different ways. BMPs, or Best Management Practices, are one of the primary ways in which stormwater is treated sustainably. Originally, BMPs were used strictly in the realm of hydrology, to help mitigate the effects of flooding and natural hydrologic issues that arose. However, with increased traffic and construction in the modern day, BMPs have been restructured to help mitigate the increased effects of pollution as well.

The EPA defines Best Management Practices (BMPs) as techniques, measures, or structural controls used to manage volume and quality of stormwater runoff (OC Public Works, n.d.). According to the EPA, BMPs should “filter out pollutants and/or prevent pollution by controlling it at its source” (EPA, 2015b).

According to the *Massachusetts Stormwater Handbook*, MassDEP categorizes BMPs into five classes: Structural Pretreatment, Treatment, Conveyance, Infiltration, and Other BMPs which do not fit into the previous four classes (MassDEP, 2008c).

Structural Pretreatment BMPs collect the first flow of stormwater during a rain event. This class removes large sediment particles to prevent the clogging of other BMPs. These are used primarily for areas with high-risk of pollution such as busy roads and gas stations. Pretreatment BMPs can be constructed as on-line or off-line structures. On-line structures are designed to treat the full water volume. Off-line structures are designed to collect a certain amount of flow (MassDEP, 2008c). Structural BMPs include deep sump catch Basins, oil/grit Separators, proprietary separators, sediment forebays, and vegetated filter strips (MassDEP, 2008b).

Treatment BMPs are classified as Stormwater Treatment Basins, Constructed Stormwater Wetlands, or Filtration BMPs. Stormwater Treatment Basins provide attenuation for the peak flow rate by collecting runoff and settling out sediment. Constructed Stormwater Wetlands aim to remove pollution by vegetation uptake, collection, and settling. Filtration BMPs use media to remove sediment and are used commonly if space is limited (MassDEP, 2008c). Specific kinds of Treatment BMPs are bioretention areas, rain gardens, constructed stormwater wetlands, extended dry detention basins, proprietary media filters, sand and organic filters, and wet basins (MassDEP, 2008b).

Conveyance BMPs are designed to collect and move runoff to other BMPs. Some also include measures to treat runoff using infiltration, filtration, or temporary storage (MassDEP, 2008c). Conveyance BMPs include drainage channels, grassed channels, and water quality swales (MassDEP, 2008b).

Infiltration BMPs decrease runoff volume by reducing surface flow and promoting groundwater recharge. However, these structures are not designed to give channel protection or flood water storage (MassDEP, 2008c). Examples of Infiltration BMPs are infiltration basins, infiltration trenches, leaching catch basins, subsurface structures, and dry wells (MassDEP, 2008b).

Other miscellaneous BMPs that do not fit into any of the above classes include dry retention basins, green roofs, porous pavements, and rain barrels and cisterns (MassDEP, 2008b).

A summary of types of BMPs and the specific BMPs that fall under each type is shown in Figure 3 below.

Table 2.1		
BMPs for Controlling Stormwater Quantity		
	Pretreatment BMP	BMP that requires pretreatment
Pretreatment		
Deep Sump Catch Basin	Yes	No
Oil Grit Separators	Yes	No
Proprietary Separators	Yes	No
Sediment Forebays	Yes	No
Vegetated Filter Strips	Yes	No
Treatment		
Bioretention areas/rain gardens	No	Yes
Constructed stormwater wetlands	No	Yes
Extended Dry Detention Basins	No	Yes
Gravel Wetlands	No	Yes
Proprietary Media Filters	No	Yes
Sand/Organic Filters	No	Yes
Tree Box filters	No	Yes
Wet basins	No	Yes
Conveyance		
Grass Channels	No	Yes
Water Quality Swales – Dry	No	Yes
Water Quality Swales – wet	No	Yes
Infiltration BMPs		
Dry Wells	No	No pretreatment required for runoff from non-metal roofs and metal roofs outside Zone II, IWPA and industrial site.
Infiltration Basins	No	Yes
Infiltration Trenches	No	Yes
Leaching Catch Basins	No	Yes
Subsurface Structures	No	Yes
Other BMPs		
Dry Detention Basins	No	No
Green Roofs	No	No
Porous Pavements	No	No
Rain Barrels & Cisterns	No	No

Figure 4*: MassDEP Table Displaying Types of BMPs (MassDEP, 2008c)*

2.5 Past Analysis of Salisbury Pond and Other Ponds

In recent years, WPI has increasingly examined the impacts of stormwater runoff in Salisbury Pond and other similar ponds. As Salisbury Pond is right next to WPI’s campus, there is a concern as to how WPI’s stormwater quality may negatively affect Salisbury Pond and the surrounding Institute Park. To examine the impact of stormwater runoff and how it is affected by varying surface types (i.e., a grassy hill versus a heavily used road), WPI has partnered with Nitsch Engineering for several MQPs around and beyond WPI’s campus.

2.5.1 Salisbury Pond

Salisbury Pond has been a staple of Institute Park since the 1800’s. The pond, pictured in Figure 5 below, is an artificial lake created by the dam on Grove Street. In 1834, the pond was originally utilized as a mill pond that supplied power to Stephen Salisbury II's wire mill (City of Worcester, n.d.). Eventually, Salisbury Pond (aptly named after the Salisbury family) would go on to power the Washburn and Moen Northworks complex. In 1887, Stephen Salisbury III donated eighteen acres of his family's farmland to serve as a green space for both the citizens of Worcester and the students of WPI, named "Institute Park" (Friends of Institute Park, n.d.). Many WPI students and Worcester residents attend concerts at the park, organize games and activities at the park, or even just go for a walk around Institute Park. Despite being the centerpiece of Institute Park, Salisbury Pond has suffered from environmental pollution since its creation.

Figure 5*: An Aerial Photo of Institute Park and Salisbury Pond (City of Worcester, n.d.)*

Salisbury Pond currently has years of sedimentation buildup polluting the body of water. A 2013 study conducted by Weston & Sampson Engineers found that Salisbury Pond's average depth is three feet, a significant decrease from its original twelve-foot depth; in some parts of the pond, the sedimentation build-up is at least five feet deep (Kotsopoulos, 2013). Sources of pollution include drainage from construction and industrial sites, parking lots, and weeds and algae in Salisbury Pond (Friends of Salisbury Pond, n.d.). The most concerning contaminants found were heavy metals, petroleum hydrocarbons, and semivolatile organic compounds (SVOCs). Weston & Sampson recommended dredging the pond and removing 50,000 cubic yards of sediment to improve the recreational value and ecological quality of the pond, but the city of Worcester is concerned about the cost of dredging, which would be upward of $7 million (Kotsopoulos, 2013).

Still, there have been other efforts to clean up Salisbury Pond and examine its water quality. In 1970, a Task Force (including WPI students) was created to clean up pollution in Salisbury Pond, and they were able to remove 5,000 cubic yards in sediment. In 2005, the Friend of Institute Park organization was founded to advocate for park improvements and "securing funds to cleanse Salisbury Pond via dredging and the installation of a forebay" (Friends of Institute Park, n.d.). Additionally, several MQPs from WPI have been based on improving the water quality and stormwater management of Salisbury Pond and similar ponds.

2.5.2 Previous Stormwater MQPs in Collaboration with Nitsch Engineering

Nitsch Engineering is a civil engineering firm founded in 1989 by WPI graduate Judy Nitsch (Nitsch Engineering, n.d.). They have been ranked in the top twenty-five engineering firms every year in Massachusetts since 2011, according to *Boston Business Journal* (Nitsch Engineering, 2021). Nitsch Engineering embodies their tagline of "building better communities with you" with a goal of positively impacting their clients, employees, and communities. Nitsch Engineering is also familiar and committed to helping the WPI community as they have been sponsoring WPI project work on stormwater management for several years. Nitsch has worked with several MQP teams to develop stormwater management systems for the WPI campus and other organizations in Worcester. To complete our project goal, we will be looking at these projects' results and conclusions and expanding upon the work they have accomplished.

In 2019, Nitsch sponsored an MQP team to examine the water quality of stormwater runoff on the WPI campus from several surface types. These surface types include a parking lot, a light road, a heavy road, a walkway, a green roof, a gray roof, a grassy hill, and Salisbury Pond. The overall goal of this project was to analyze the composition of the stormwater runoff on campus to determine the relationship between land type and contaminant loading in stormwater, and then develop a BMP design based on this relationship. The team tested for nitrogen, total phosphorus, TSS, and other pollutants. After collecting and analyzing stormwater samples from each of the land surface types, the MQP team concluded that surface types do impact contaminant loading in stormwater. In particular, they found that the walkway had the highest concentration of TSS, while the grassy hill had the highest concentration of total phosphorus. The team then designed a rain garden, a level spreader, a swale, and a sediment forebay to reduce the runoff entering Salisbury Pond and effectively remove pollutants. These BMP designs would be placed near areas of concern, such as the walkway or the grassy hill (Acaba et. al, 2019).

More recently, in 2020, Nitsch sponsored an MQP team to examine the contaminants in stormwater runoff going into two ponds at the EcoTarium Science Center in Worcester. The purpose of the project was to look at the contaminant concentrations in different stormwater flows around the EcoTarium, and then design an appropriate BMP. The MQP team collected samples from seven different locations: the upper pond, the lower pond, the upper parking lot, the lower parking lot, the stream, the stream outflow, and the roof. After collecting samples, the team tested for pH, total phosphorus, ammonia, anions and metals, bacteria, and TSS. Analysis of the data showed that all of the locations had higher concentrations of total phosphorus, coliform, and E. coli than the New Jersey Surface Water Standard, which the team used for comparison. Based on the data, the MQP team recommended that the EcoTarium build a vegetation filter strip and a rain garden in the upper lot area, and an oil/grit separator and an infiltration tank for the lower lot area (Vogel et. al, 2020).

3.0 Methodology

Our project is a collaboration with Nitsch Engineering involving land analyses, testing, and designing new stormwater management systems. The scope for this project can be broken down into four processes or tasks. The first task was sampling from a variety of surface types. The next task was to quantify pollutant loading from various stormwater runoff catchments, while also assessing how the contaminants and flow differ from location to location. Then, after determining the nature of contamination for each location, we could perform a detailed analysis on the land and direction of flow from that area. Then finally, the last process involved taking all data from our analysis of different contaminant levels and loadings and using this information to design and recommend different BMPs, or applicable green infrastructure changes for areas of the campus. To carry out these processes, we had to develop a plan. As a team, we aimed to accomplish four main objectives, in order to make project processes as effective and clean as possible.

1. Collect and sample water from our selected sites during precipitation events.
2. Conduct laboratory analyses for various contaminants in the pond water and stormwater.
3. Analyze contaminant data and runoff characteristics to gain a better understanding of the impacts of surface and land characteristics on water quality.
4. Develop possible stormwater solutions to reduce the concentration of contaminants in the stormwater.

Although it is not the only focus of our project, the overall goal of this project is to help mitigate the effects of stormwater runoff on Salisbury Pond. Thus, to achieve this goal, we had to collect samples from locations on and around the WPI campus during various rain events. Then, by analyzing the contaminants in these samples, we were able to characterize areas based on contaminants and get a better sense of what was going into the pond. This would allow us to develop our recommendations. The section of the report presents and explains the necessary aspects of the objectives that were required for our methodology.

3.1 Sampling Locations

The goal for location selection was to sample stormwater runoff from a variety of different surfaces, while expanding on the past work done. We wanted to filter sampling locations down to areas with different land uses and surface types. By doing so, we gained a better understanding of how stormwater management needs differ from one area to another. In total, we wanted to sample from seven different locations around campus. So, we utilized the sampling location summary chart generated by the 2019 team to determine which areas we wanted to repeat along with our new target areas for sampling around the pond. This process would allow us to achieve our goal of determining if surface types impacted contamination levels, and whether or not contamination levels increased or decreased over time in certain areas. This approach would be used to help us then decide what types of designs are best for certain areas, and subsequently develop our recommended improvements to the WPI stormwater management effort.

From the previously mentioned 2019 project, sampling was done for Salisbury Pond, the grassy hill by Skull Tomb, and the gray and green roofs of East Hall. For our project, we decided to resample these locations to provide the necessary comparison data. In addition, we decided to sample three new locations that had not been looked at in the past: Salisbury Street, the grassy hill near Salisbury Pond, and a catch basin on Rumford Ave at one of the entrances to the Salisbury Estate Townhouses. A rainwater sample was also collected to compare direct rainwater to runoff. These sampling locations and their surface types are described in Table 1, and a map showing our sampling locations is provided in Figure 6.

Table 1: Sampling Locations and Surface Types

Location	Surface Type	New or Redone
Skull Tomb	Grassy Hill	Redone
Gray Roof	Regular Roof	Redone
Green Roof	Vegetation Roof	Redone
Salisbury Pond	Pond	Redone
Salisbury Street	Heavy Traffic Road	New
Grassy Hill near Salisbury Pond	Grassy Hill	New
Salisbury Estates Catch Basin	Parking Lot / Light Traffic Road	New

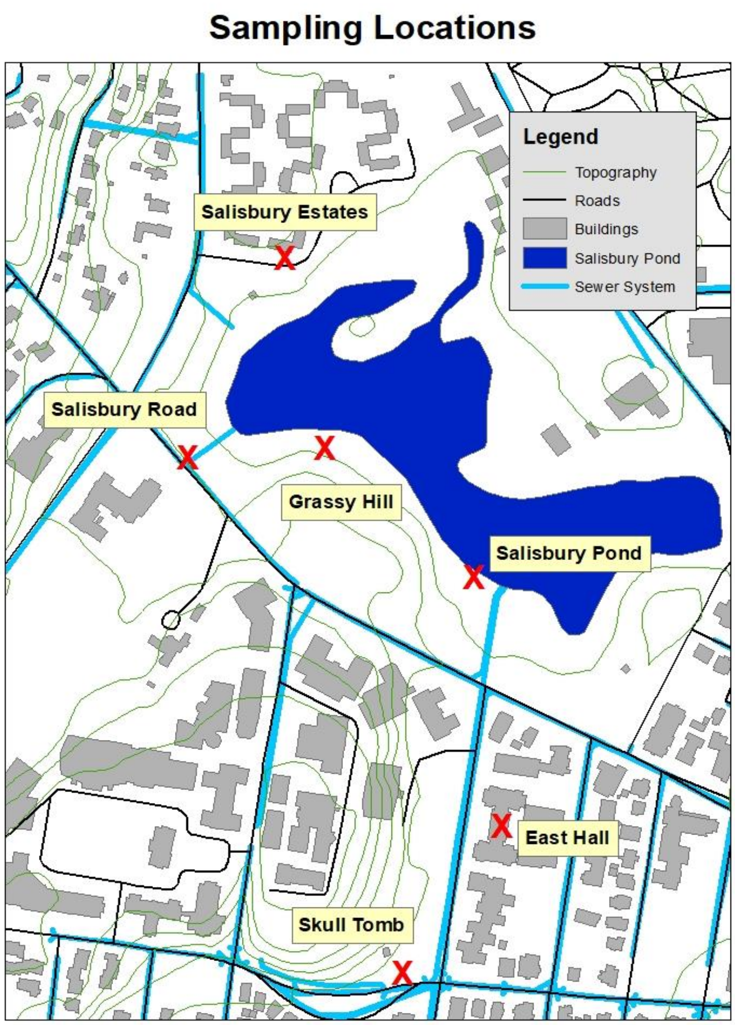

***Figure 6**: GIS Map of Sampling Locations (Made on ArcMap)*

Figures 7-13 are pictures of the sampling locations for reference. Figure 7 is the grassy hill near the Skull Tomb, Figures 8 and 9 are the gray and green roofs of East Hall, Figure 10 is Salisbury Pond, Figure 11 is Salisbury Street, Figure 12 is the grassy hill near Salisbury Pond and Salisbury Street, and Figure 13 is the catch basin near Salisbury Estates.

***Figure 7**: Skull Tomb Grassy Hill*

***Figure 8**: East Hall Gray Roof Stormwater Collector*

Figure 9*: East Hall Green Roof Stormwater Collector*

Figure 10*: Salisbury Pond*

Figure 11*: Salisbury Street*

Figure 12*: Salisbury Street Hill*

Figure 13*: Salisbury Estates*

3.1.1 Sampling Process

Samples were collected from the locations in the above section. One sample was collected from the Skull Tomb Hill and Salisbury Pond. Two samples from different storms were collected from Salisbury Street, the grassy hill leading to Salisbury Pond, and the Salisbury Estates Catch Basin. Three samples were collected from the Gray and Green Roofs; two of the samples were from the same storm and the other was from an additional storm. The dates and times of sampling collections are located in Table 2. The pH for each sample is also recorded in this table, as that was obtained the same day as the samples were taken.

Before sample collection at the location, bottles were rinsed three times with the distilled water in the lab to ensure proper quality assurance and control. The basis for our sampling protocol can be found in Appendix A. During each sampling trip, a clean 300 mL plastic bottle and 1 L DO glass bottle were filled, and the current weather temperature for the date of sampling was noted as well. Runoff was collected by using aluminum foil to funnel the water into the bottles at these locations: the Skull Tomb Hill, Salisbury Pond, Salisbury Street, Salisbury Street Hill, and Salisbury Estates catch basin. For the gray and green roofs, runoff was collected using the stormwater collectors in the lower floor of East Hall. Before the storm, these were fully drained to remove the old rainwater and allow new runoff to be collected for our samples. In addition to these samples, a rainwater sample was also collected before contact with any surface with the use of a large bowl. This water was then poured into a 300 mL plastic bottle for testing. After sample collection, the bottles were placed in the lab fridge.

Table 2: Sampling Dates and Times

Location	Date	Time	pH
Salisbury Pond	10/26/2021	12:00 PM	4.76
Grassy Hill near Skull Tomb	10/26/2021	12:20 PM	6.27
Salisbury Street	10/30/2021	8:20 AM	5.56
Grassy Hill near Salisbury Pond	10/30/2021	8:30 AM	4.88
Salisbury Estates Catch Basin	10/30/2021	8:45 AM	5.24
Green Roof	11/12/2021	11:30 AM	6.56
Gray Roof	11/12/2021	11:45 AM	5.76
Salisbury Street	11/12/2021	12:30 PM	5.37
Grassy Hill near Salisbury Pond	11/12/2021	12:45 PM	5.41
Salisbury Estates Catch Basin	11/12/2021	1:00 AM	5.27
Green Roof	11/12/2021	5:40 AM	6.24
Gray Roof	11/12/2021	5:50 AM	5.89
Rainwater	12/6/2021	8:00 AM	6.76
Gray Roof	12/7/2021	11:00 AM	6.15
Green Roof	12/7/2021	11:00 AM	6.49

For a baseline analysis after our pH testing, we assessed that the pond areas were very acidic compared to the others. All other pH levels were relatively normal for stormwater runoff.

3.2 Laboratory Testing

We completed a series of laboratory tests to obtain different measurements, and concentrations for our analysis. The lab testing equipment, and the contaminant level or concentration which they allowed us to test for, are listed below:

- pH probe for pH levels
- Spectrophotometer for total phosphorus concentrations
- Ion Chromatography Spectrometer (ICS) for fluoride, chloride, nitrite, sulfate, bromide, nitrate, and phosphate concentrations

- Inductively Conducted Plasma Mass Spectrometer (ICPMS) for manganese, copper, lead, sodium, magnesium, calcium, andiron
- A filtration device for TSS concentrations

These contaminants were selected because they were our main contaminants of concern that are often treated by many different types of BMPs, and they are also included in most water quality standards. The results of these laboratory tests can be found in Appendix H.

pH Testing

The pH of a water system has the tendency to change the type of aquatic life which can survive there. When the pH changes from what it naturally is by a lot, the aquatic life that the ecosystem supports there will begin to die out. The pH levels were obtained by using an [insert name of device] pH probe. Before testing the samples, the probe needed to be standardized using buffer solutions. We used 4, 7, and 10 pH buffers to standardize the probe. These pH buffers are essentially solutions typically made of a weak acid and its conjugate base. These solutions provide a fixed pH reference, which is then used to calibrate the probe. The probe was standardized before and after each sample was tested, to ensure QA/QC. After standardizing, the probe was placed into each of the sample bottles to obtain and record the pH levels. pH testing was conducted within the day after sample collection, to ensure more accurate pH readings.

Total Phosphorus

Total phosphorus concentrations need to be regulated often, because high concentrations of this contaminant can seriously harm an aquatic ecosystem. Phosphorus is a very important nutrient which supports life growth on our planet, but high concentrations in water can suffocate aquatic organisms, when it produces algae blooms. The total phosphorus concentrations were obtained by using spectrophotometry. Spectrophotometry is a testing method involving the measurement of how much light passes through a substance. Every substance absorbs light at a different wavelength. Thus, total phosphorus samples had to be prepared by digesting our unfiltered water samples, a sample of deionized (DI) water, and six standards with specific levels of phosphorus for calibration.

The digestion process was performed by adding nitric and sulfuric acid to a beaker of sample water and heating the samples on a hot plate until approximately 1 mL of the sample was left, or the sample started fuming, and then drops of hydrogen peroxide were added if the sample was too cloudy or colored. After a day of this digesting process, DI water was added to the samples until the volume reached 25 mL. Once this step was done, a drop of phenolphthalein indicator was added to the samples, and they were titrated with sodium hydroxide. The complete titration is indicated by the sample turning a slight purple hue. After the titration, molybdovanadate was also added to the samples, and then they were mixed thoroughly and measured in the spectrophotometer.

Anion and Metals

The anions which we tested for, are the specific compounds and electrolytes such as nitrate and chloride which, like many other anions, exist naturally and produce nutrients that can have adverse health effects on water quality. Metals are also necessary in low concentrations, but they become toxic to organisms when seen in higher concentrations. Anion and metal analyses used ten mL of our filtered water samples. For the ICS Anion test, standards of 100, 200, 400, 800, 1200, and 3000 ppb were made. For the ICP-MS Metal test, 100µL of concentrated nitric acid was added to each of these filtered samples. After this preparation was completed, the samples and standards were then handed off to the lab manager to perform the rest of the ICS Anion and ICP-MS Metal test procedure.

Total Suspended Solids

The amount of total suspended solids in bodies of water can have very serious effects on the environment as a whole. TSS is the measure of how many non-dissolved solids exist in a water system. When TSS concentrations are high, this can lead to an increase in the turbidity of water. Turbidity is simply the measure of relative clarity of a liquid. With increased turbidity, the amount of light which the water can absorb goes down, which leads to heat, in the form of light, being reflected out into the environment. This phenomenon contributes to global warming by raising the temperature of the atmosphere. In addition to this, toxins and nutrients will often attach to solids in water. TSS measurements were taken by first measuring out an amount of our sample water. Then a filter of a measured weight was used to filter that measured water sample, leaving the suspended solids on the filter. The filter was then dried and weighed. After the first round of weighing, the filters with solids on them were placed back into the oven for another hour to dry further before being weighed again. This process of re-drying the filters ensures that the measurement is of a consistent, completely dry weight. If the consecutive weight measurements of one dried filter were not within 4% of each other, the sample would continue to be dried and weighed each hour until a consistent weight was found. These consistent weights, and the total volume of sampling filtered, were then used to calculate the average TSS concentration for each sample.

Full Lab Procedures

The more detailed testing procedures are outlined in Appendices B-F. Each of the tests identified different contaminants in the collected samples. To ensure quality and control, only one person conducted an entire experiment rather than multiple people working on the same procedure. This was done in an attempt to minimize the variation of human error in collecting data. Multiple rain events were also sampled to ensure that the data was accurate for the general trends. The results from the lab testing influenced which BMPs were considered in the design process for the project.

3.3 Watershed Characterization Through GIS and HydroCAD Analysis

In order to hit our objective of analyzing and understanding the water quality on campus, we had to utilize the software systems: HydroCAD, Google Earth, ArcMap, and ArcGIS. We needed these systems so that we could outline and map the full watershed of the WPI campus. HydroCAD is a computer-aided design tool used by civil engineers to model stormwater runoff (HydroCAD Software Solutions, n.d.). ArcMap, ArcGIS, and Google Earth are some of many Geographical Information Systems (GIS) available for use by the public. GIS systems help provide and connect data layers for certain locations on a map, in order to help discover and analyze patterns or relationships geographically (ESRI, n.d.). By using a combination of the maps generated by past teams, along with the maps generated by us, we were able to define the location of structures, surface boundaries, soil classifications, and sub-watershed boundaries. The complete set of data collected utilizing these systems, allowed us to visually comprehend surface features, drainage flow directions, boundaries of watersheds draining into the pond, and any other stormwater drainage conditions. These systems were also very helpful for us to initially decide our sampling sites. Thus, by using the different GIS systems and HydroCAD, we were able to characterize the stormwater runoff based on the NRCS method guidelines and determine the flow going into Salisbury Pond.

3.3.1 GIS

Google Earth and ArcMap were utilized to create and analyze all map data. First, tributary areas for Salisbury Pond were identified by looking at topography, sewer lines, catch basins, and hydrography data on ArcMap. The data was layered on top of each other to be able to predict where water would be flowing into Salisbury Pond. Boundaries for the tributary area were marked on a map using Google Earth. The entire tributary area was broken up into three main catchment sections: the area section directly around Salisbury Pond, an area section to the Northwest, and an area section to the South. Next, each of these three areas were further divided into 4 or 5 sections depending on their soil type, found by using data tables from ArcMap. In Figure 14 below, the three tributary areas for the Pond are displayed.

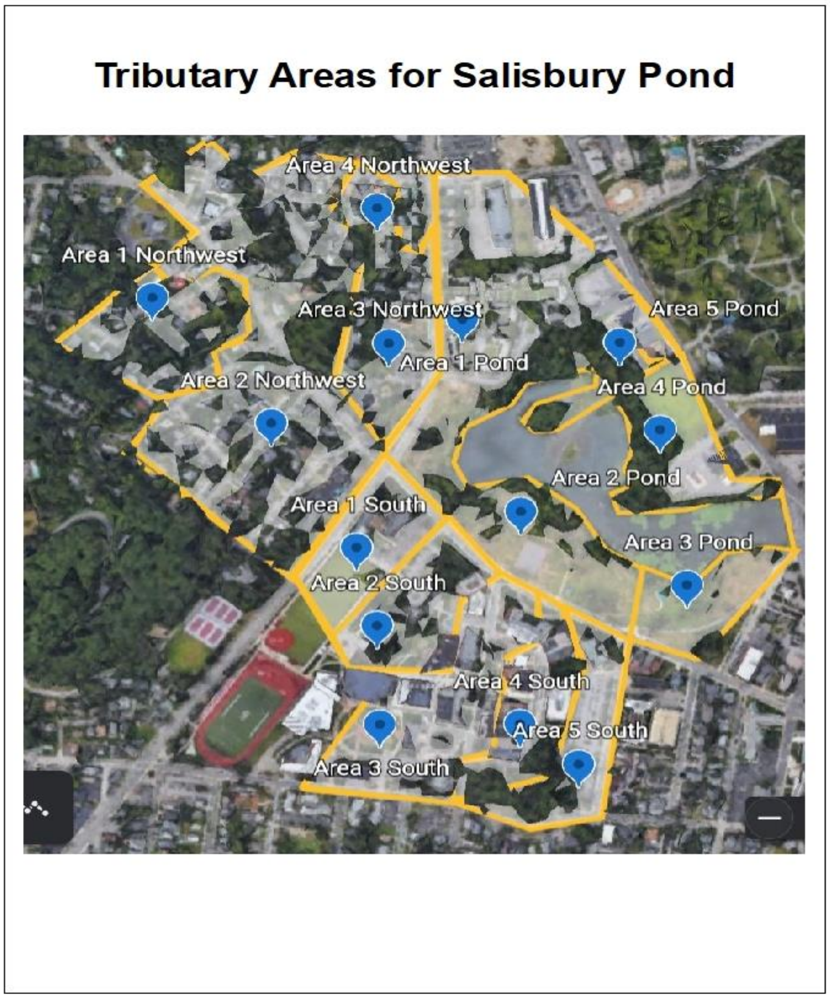

***Figure 14**: Tributary Areas to Salisbury Pond for HydroCAD Analysis (Made with Google Earth)*

After sectioning off the larger tributary areas for the pond, we obtained land characteristics such as area, soil type, and land use for each catchment, and recorded them for our HydroCAD analysis, described in the section below. However, while there may be three total catchment areas shown here, for the purposes of our project, we decided to focus on the main pond catchment area and its subcatchments, for further analysis in our project results section.

3.3.2 HydroCAD

After acquiring the soil characteristics, the areas, the land use, the slope, and the hydraulic length for each of the subcatchments, this information was used to create a HydroCAD model for Salisbury Pond and the previously stated three designated areas. The HydroCAD model created is depicted in Figure 15 below. Additionally, rainfall events based on one, two, five, ten, and twenty-year storms from NOAA were added to the HydroCAD analysis. These rainfall events were based on information from the Worcester Airport rain gauge.

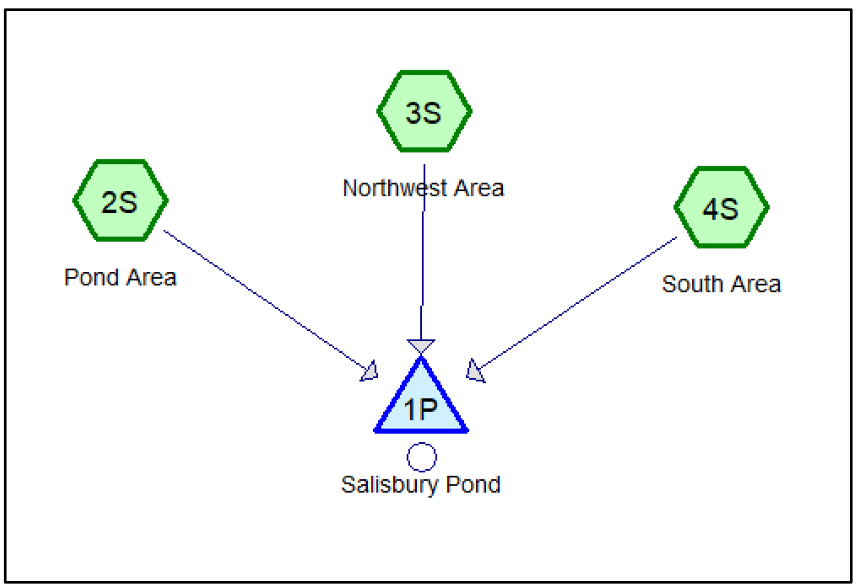

***Figure 15**: HydroCAD Model with Catchments and Pond*

The slope and hydraulic length for each catchment were used to calculate the respective time of concentration in HydroCAD; specifically, HydroCAD used the Lag/CN method to calculate each time of concentration value. These calculations yielded a hydrograph for each area, demonstrating the flow of the stormwater runoff over twenty-four hours. HydroCAD used the SCS TR-20 method to calculate runoff flow (in cfs), as well as providing the velocity (in ft/sec) for each subcatchment within the catchments. For our project, we were looking to mitigate the effects of high flow and TSS concentrated runoff from hilly or sloped areas. These areas tend to have the highest flow rates due to gravity.

3.4 BMP Design Ideas

We geared our design ideas and process towards recommending new BMPs for Salisbury Pond. In aiming to design and recommend BMPs, we were specifically focused on pollutant removal through flow mitigation and sediment filtration. Our team wanted to develop one detailed design recommendation and two theoretical design recommendations. To narrow down our viable options, we created a chart displaying the different uses and descriptions of a couple of different BMP designs. We chose to circle in on the most relevant or applicable BMP designs and how they could be useful for certain surface types or land areas, specifically around Salisbury Pond. Table 3 displays the four selected BMPs and their respective descriptions and area requirements below. A more complete description of the BMPs is available in Section 4.4.

Table 3: BMP Design Feasibility Comparison

BMP Type	Description	Locations & Areas	Typical Management Needs	Min. Area Requirements
Grass Swale	Shallow, vegetated channel, also called bioswale or vegetated swale	Near edges of roads/At least 10 feet from buildings or urbanized areas	Vegetation mowing, erosion checkups, trash removal, replanting, sediment buildup removal, and mulch replacement (for roadways, or parking lots	Width must be 2-8 ft. Must be designed to treat either 2-year, or 10-year storm flow. Minimum soil bed depth of 18 in. Must be designed to hold at least a foot of ponding. Seasonal water table must not be within 2-4 ft. away from the swale bottom
Infiltration Trench	Rock and soil-filled trench	Urbanized areas Sites with limited space/between buildings or properties, or along road rights-of-way	Pea gravel and topsoil needs to be replaced monthly, inlet needs to be cleaned monthly, grass needs to be mowed monthly, and system needs to be checked semi-annually, and pretreatment basin needs to be aired out yearly and cleared every 5 years	Contributing drainage area to any individual infiltration trench should be restricted to 5 acres or less. The minimum depth to the seasonal high-water table, bedrock, and/or impermeable layer should be 2 ft. from the bottom of the trench. Many additional spacing requirements as well.
Vegetated Filter Strip	Vegetated areas designed to accept laterally distributed sheet flow, also called buffer strips or vegetated buffers.	Urban areas/Adjacent to impervious surfaces or buildings	Minimal management needed after first 2 years; 2-4 seasonal checkups in each of first 2 years	For TSS removal credit, the strip must be at least 25 feet long and generally as wide as the drainage area for the strip. Minimum width of the filter strip must be 20% of the length of the flow path or greater than or equal to 8ft.
Bioretention (Rain Garden, Trickling Filters)	Shallow, vegetated basins with a variety of planting/filtration media, often including underdrains.	Urban or Suburban areas/Near parking lots, parks, or heavy traffic roads	Regular watering if no precipitation occurs for 2 weeks, clearing of unwanted plant debris every so often, sediment cleaning and vegetation mowing 6x a year, yearly inspections, replace plants and reinforce every 5-7 years	The depth of the soil media must be between 2 and 4 feet, to allow for pollutant removal in soil, and excavations deeper than 4 ft. are expensive

All of the designs which we decided to focus on, were meant to be applicable for the pond area. However, not all of these designs are necessarily feasible for maintenance and construction requirements, due to the amount of recreational area for the pond. While we were trying to improve the quality of the pond, we also had to take aesthetics and community use into account as well. Thus, by creating Table 3 above, we were able to establish a baseline sense of the possible design recommendations for certain areas around the pond. We realized that the limited or small unused areas around the Salisbury Estate area of the pond would require more feasible BMP ideas, which also take into account the aesthetics aspect for our design recommendations. Thus, after completing our land and flow analysis for these areas as previously mentioned in Section 3.3, we would limit our recommended BMPs to ones which could run along the entire, or just a portion of the edge of the pond.

3.5 Deliverable

For the purposes of our project, we tried to find unique solutions to stormwater quality issues, which may not be fully addressed or properly managed by the existing management systems that we have in place today in general.

In deciding potential deliverables, we were aiming to address the issue of stormwater quality in an innovative, efficient, and simplistic process. We wanted to build upon the previous work done, and hopefully provide new insights for discoveries in improving stormwater quality going forward. As a team, we decided that by characterizing main areas of interest by their flow and specific pollutant concentration loads, we would then be able to develop our recommendations for each area, in ways which allow others to think about and envision solutions for their own communities. In doing so, we not only aimed to simplify the testing and design process for treating stormwater at WPI, but for other communities as well. The general public knows very little about treating stormwater quality as it is.

The proposed BMP designs and suggestions utilize both conventional BMP designs, and new technology or ideas, for the purpose of future work and environmental impact. Our design locations and recommendations were displayed on our project poster along with the potential benefits which they present for each area. The final deliverables for our project consist of the final MQP report, the proposed BMP design recommendations, and our project poster for our presentation day.

4.0 Results

This project included water quality monitoring, analysis modeling, and design of a set of Best Management Practices (BMPs) to improve the quality of Salisbury Pond in Worcester, MA. In order to effectively accomplish our project goal of improving the quality of the water in Salisbury Pond, we needed to complete a variety of necessary tests to understand the overall quality of the water. If certain contaminants were seen in high concentrations, this would affect the design and recommendation process for our BMPs. The results we obtained from our laboratory testing were used to characterize our sampling locations against the contaminant loadings present at each location. We characterized the watershed using ArcGIS, and then we completed hydrologic modeling using HydroCAD software. These analyses were used to evaluate the runoff and land characteristics for our sampling locations, in order to assess the structural applicability of different BMPs for each area. This section discusses and presents the results which we obtained from our laboratory testing, along with GIS & HydroCAD analysis.

4.1 Laboratory Results

Lab results were grouped together based on the locations that the samples came from. There were seven sample locations, with four of them being utilized specifically for comparative data. All of the TSS and TP test results were grouped below the rest of the contaminant results and pH measurements, to allow for better graphical display of concentrations, and clarity. For all of the tables and graphs below, the averages for each of the contaminant concentrations and measurements at each location were used. Appendices H-J shows the laboratory sheets with the raw data from the sampling results.

4.1.1 ICS Anions and ICP-MS Metals Lab Results

Anion and metal ion concentration results were obtained through mass spectrometry utilizing an Ion Chromatography Spectrometer (ICS) and Inductively Conducted Plasma Mass Spectrometer (ICP-MS). For results, we primarily focused on all of the contaminants which had high or substantial enough concentration levels for analysis, comparison, and visibility in our charts. However, in Figures 16 and 17, we display charts for concentration level results in all of our comparative sampling locations, and the results for the more substantial area concentrations, respectively. These charts were separated for clarity in display. For the pond tributary runoff locations, the grassy hill had noticeable concentrations of iron (approximately 2.0 ppm), sodium (approximately 3.0 ppm), and chloride (approximately 1.5 ppm). Salisbury Street had high concentrations of sodium (approximately 7.0 ppm), sulfate (approximately 3.0 ppm), and chloride (approximately 10.0 ppm). Finally, the catch basin near Salisbury Estates yielded approximately 5.0 ppm of sodium, 2.0 ppm of sulfate, and 8.0 ppm of chloride. The most likely reason for higher concentrations of sulfate, sodium, and chloride is the usage of salts for road treatment during the winter. Additionally, the amounts of phosphate and nitrate were low for all of the tributary runoff locations, as the concentrations for both contaminants were less than 1 mg/L.

The rest of the locations all had notable concentrations of sodium, and most (with the exception of Salisbury Pond) had higher concentrations of sulfate and chloride. Compared to the previous team's results, the grassy hill near the Skull Tomb saw a decrease in concentrations of sodium and chloride. In 2019, the sodium concentration was approximately 5.5 ppm, while the chloride concentration was almost 9.0 ppm (Acaba et. al, 2019). Our samples, obtained in 2021, all had concentrations less than 4.5 ppm, thus showing a decrease in the presence of sodium and chloride over the years, which is good. The amount of sulfate relatively remained the same at around 2.0 ppm. The green roof saw increased concentrations of sodium, sulfate, and chloride, as the concentrations in 2019 were all less than 3.0 ppm. Additionally, the gray roof had a zinc concentration of approximately 1.1 ppm, and the 2019 results did not include any zinc measurements. Salisbury Pond also saw an increase in phosphate to 1 mg/L, as phosphate was not detectable in the 2019 results (Acaba et. al, 2019).

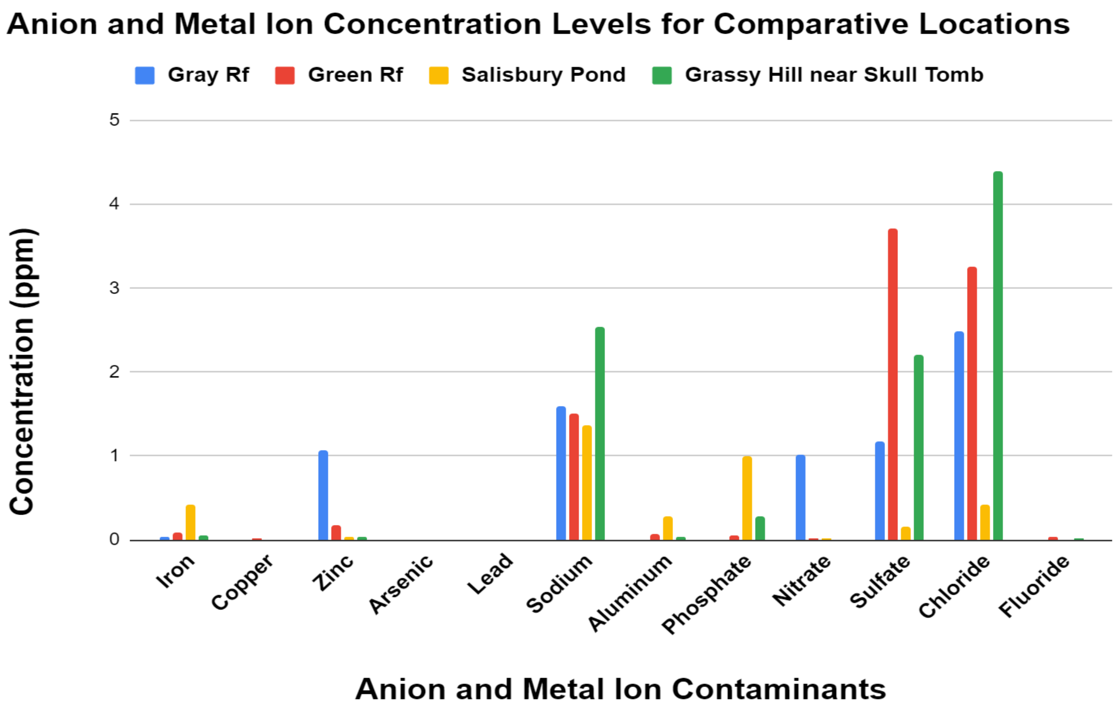

Figure 16*: Anion and Metal Ion Concentrations for Comparative Sampling Locations*

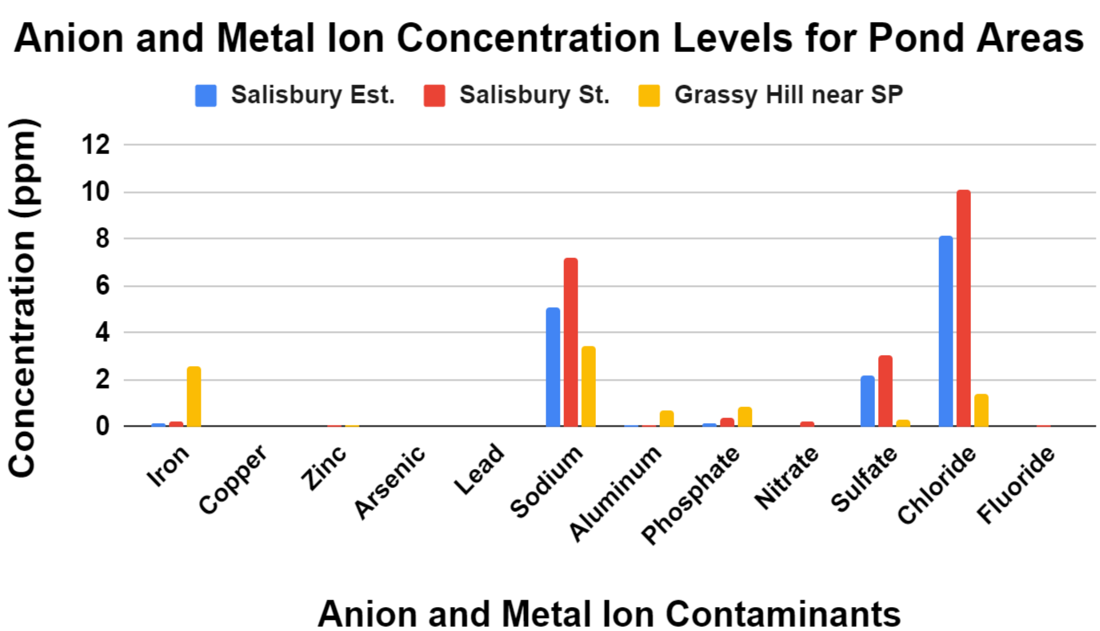

Figure 17*: Anion and Metal Ion Concentrations for Sampling Around Pond Area*

4.1.2 Total Suspended Solids (TSS) Lab Results

The TSS concentration for each sample was found by following the TSS procedure found in Appendix E. The TSS concentrations were determined for six of our seven sampling locations by averaging the concentrations of multiple samples from each location; these averages are displayed in Figures 18 and 19 below.

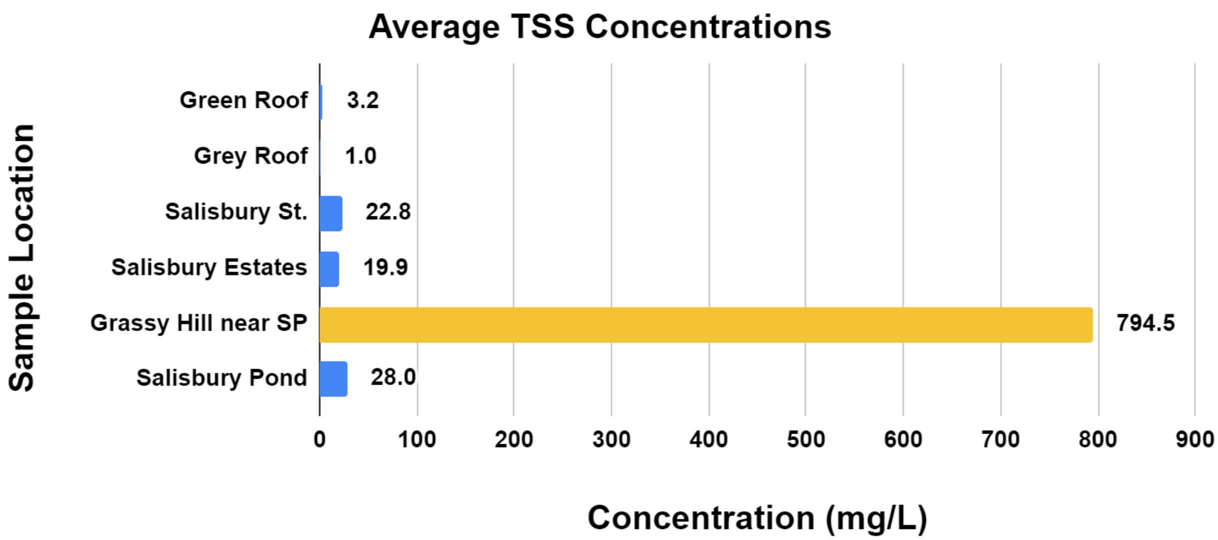

Figure 18*: Total Suspended Solids Averages for Sampling Locations*

As can be seen in Figure 18, the location with the greatest average concentration of total suspended solids by far, was the grassy hill near Salisbury Pond. The grassy hill's water samples had an average concentration of 794.5 mg/L of TSS. Figure 19 doesn't include the Grassy Hill location's extremely high concentration, so it's easier to see the range of the other five locations' average TSS concentrations.

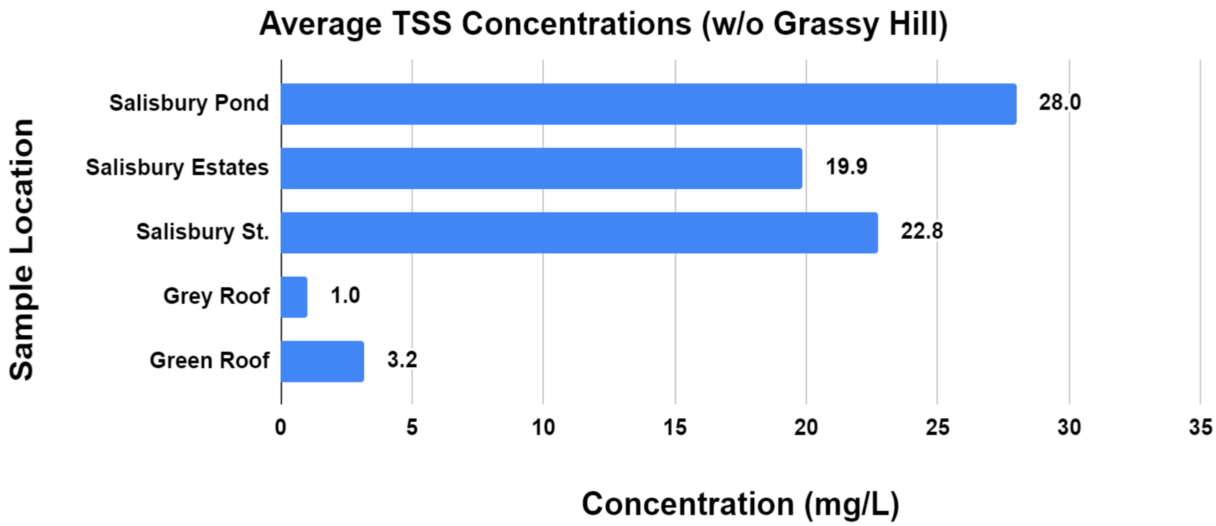

Figure 19: *Total Suspended Solids Averages for Sampling Locations (w/o Grassy Hill)*

Without including the grassy hill, the location with the greatest concentration of TSS would be Salisbury Pond with a concentration of 28.0 mg/L. The samples from Salisbury Estates and Salisbury Road also had a considerable amount of TSS, with concentrations of 19.9 mg/L and 22.8 mg/L respectively.

Compared to the previous results on WPI's stormwater quality and various surface types, the TSS concentrations we found for all of the surface types - green roof, gray roof, light road, heavy road, and grassy hill - were greater than the previous year's. For example, the grassy hill that the previous MQP team sampled, the grassy hill near the Skull Tomb, only had a TSS concentration of approximately 0.3 mg/L. Our grassy hill sample, at 794.5 mg/L of TSS, is over 200 times greater than the concentration at the Skull Tomb grassy hill. Even the gray roof and green roof, the same locations previously sampled, saw an increase of TSS concentrations from under 0.1 mg/L to 1.0 mg/L and 3.2 mg/L, respectively (Acaba et. al, 2019). TSS concentrations could be greater because we chose areas closer to Salisbury Street and other busy construction and industrial areas that would produce more sediments and other solids.

4.1.3 Total Phosphorus (TP) Lab Results

The total phosphorus concentrations were found for each sampling location by following the procedure in Appendix C. Similar to the TSS concentrations, the average total phosphorus concentration was used for eight locations: rainwater, the gray roof, the green roof, Salisbury

Pond, the grassy hill near the Skull Tomb, Salisbury Street, the grassy hill near Salisbury Pond, and Salisbury Estates. Figure 20 depicts the total phosphorus concentration in mg/L for the eight locations, while Figure 21 shows the percentages of total phosphorus that is suspended.

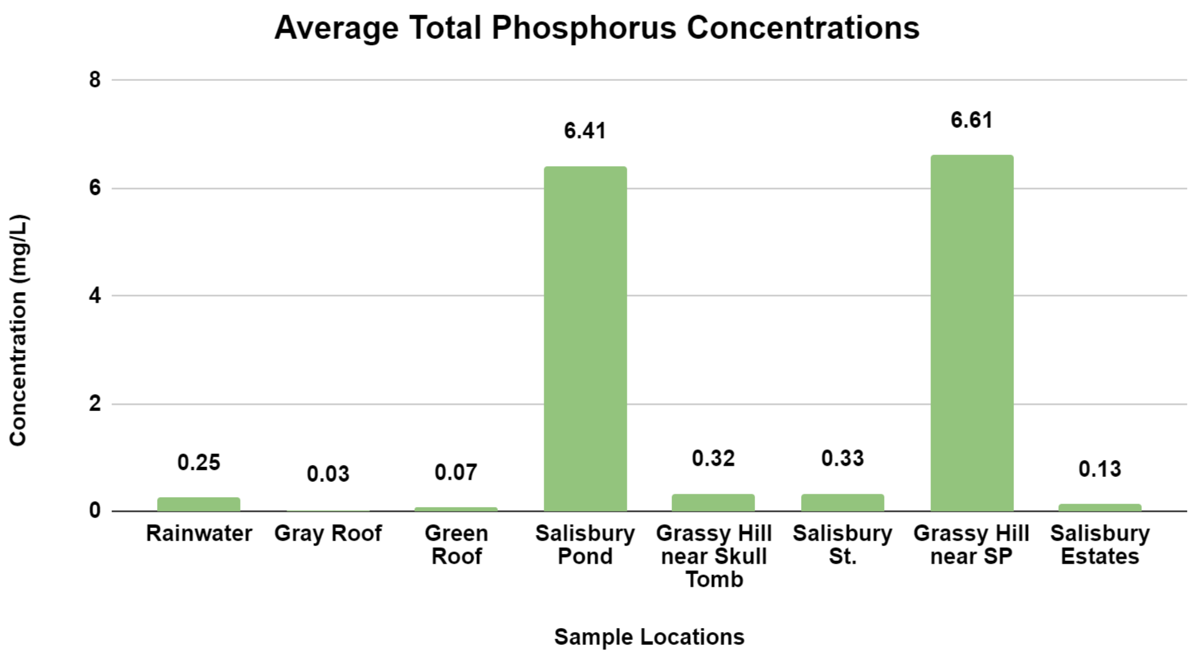

Figure 20*: Total Phosphorus Averages for Sampling Locations*

Displayed in Figure 20 above, the samples collected from the edge of Salisbury Pond and the grassy hill near Salisbury Pond had the two highest total phosphorus concentrations. This is very similar to the previous year's sampling results, as their grassy hill sample also had the highest concentration of total phosphorus across all sampling locations. Additionally, compared to the previous year, the concentration of total phosphorus for the Skull Tomb grassy hill has decreased from 2.0 mg/L to only 0.32 mg/L. Still, the sample we collected for a grassy hill location was approximately three times greater than the other team's chosen grassy hill sample (Acaba et. al, 2019).

Possible reasons for greater concentrations of total phosphorus near Salisbury Pond could be an increased usage of fertilizer in the green space or the presence of geese. Flocks of geese and their goslings are commonly seen around many of Worcester's parks and lakes including right over in Institute Park and Salisbury Pond. The presence of geese can significantly increase the amount of phosphorus in stormwater runoff because geese typically live and build their nests close to bodies of freshwater. On average goose droppings are only 1% phosphorus, however each goose excretes feces every 12 minutes and up to 1.5 pounds per day meaning a flock of simply ten geese can scatter up to 15 pounds of feces each day (Steele, 2020). Thus, the presence of geese near Salisbury Pond could be the reason why the phosphorus levels are so high in the area.

Additionally, the sample from the edge of Salisbury Pond contained 6.41 mg/L of phosphorus, while the grassy hill sample had 6.61 mg/L. Salisbury Street only had a concentration of 0.33 mg/L, while the sample from the Salisbury Estates catch basin had 0.13 mg/L. These sampling locations' total phosphorus concentrations all exceed the New Jersey Standard at 0.1 mg/L of total phosphorus. Samples from East Hall's green roof and gray roof showed total phosphorus concentrations of 0.07 mg/L and 0.03 mg/L, respectively. All of this year's surface types and the previous surface types (with the exception of the grassy hill) all had relatively similar and low concentrations of total phosphorus. Nitsch was very interested in seeing the impact of various land surface types on total phosphorus concentrations. Based on our sampling results, we believe that the grassy hill areas tend to have greater total phosphorus concentrations than other surface types due to more natural animal exposure possibly. Impervious surfaces, such as lightly traveled or heavily traveled roads, seem to have very low concentrations of total phosphorus (under 1.0 mg/L).

The percent of phosphorus within suspended solids, for samples with substantial TSS concentrations, was determined by utilizing the dissolved phosphorus concentrations obtained from the ICP-MS procedure. Subtracting the concentration of dissolved phosphorus from that of total phosphorus gave us the concentration of phosphorus in suspended solid form for an area. By then dividing this concentration by that of the suspended solid concentration for that area, and multiplying by 100, we were able to obtain the percentages of phosphorus from suspended solids for each area. These values, displayed below in Figure 21, helped us determine how much phosphorus we could potentially remove by TSS filtration alone.

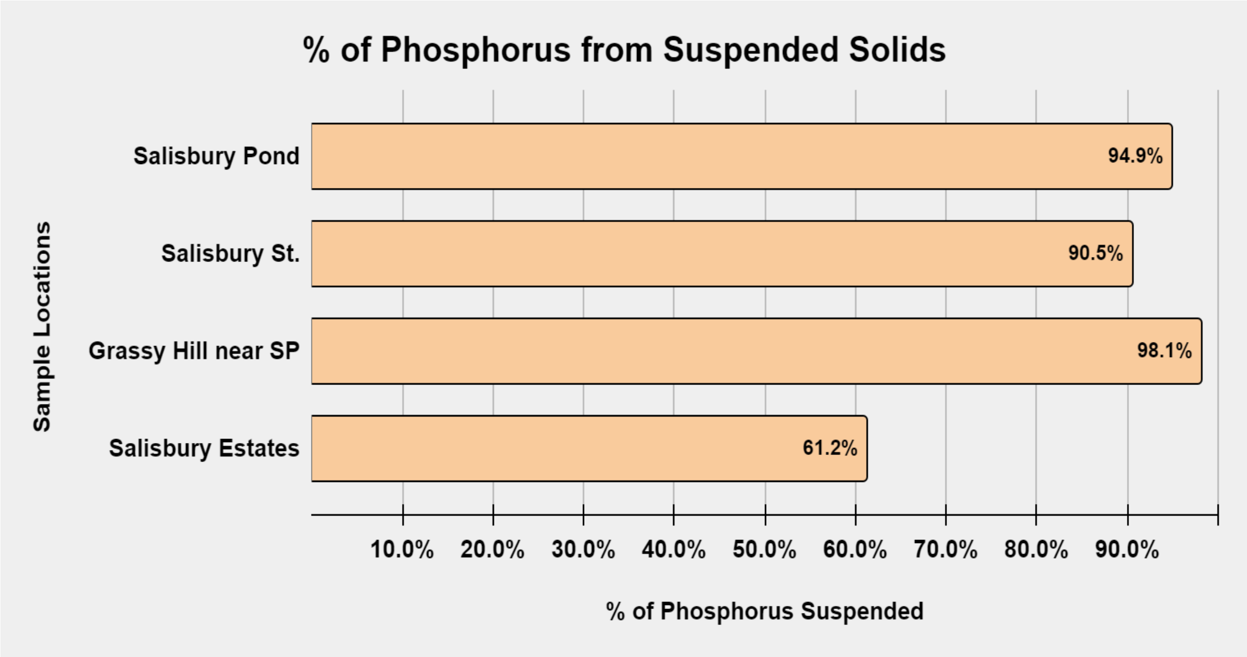

Figure 21*: Percentages of Phosphorus from Suspended Solids for Select Locations*

Overall, based on the laboratory results, the water quality for the main Salisbury Pond area was and still is currently lacking in TSS and TP treatment. The four main areas with the highest contaminant concentrations all surround the pond and drain into it. These four areas also had the most substantial data overall for other contaminants as well.

4.2 GIS Land Characterization

Because contaminants are absorbed by stormwater runoff as the water flows through a subcatchment, BMPs are typically placed in locations where they can effectively treat most of the contaminants present in the runoff. So, when runoff is flowing downstream, the main limiting factor in designing a BMP system is the stormwater flow rate and volume. Since most stormwater runoff in the area flows into the public drainage systems, the rest of the remaining stormwater is usually concentrated into singular flow paths before it enters the pond. For this reason, we needed to conduct a basic land characterization for the pond area and its subcatchments. A map of the subcatchments can be found in Figure 22, and the subcatchments' characteristics (surface type, soil type, land use, and area) can be found in Table 4. These characteristics were used in the hydrologic modeling for HydroCAD.

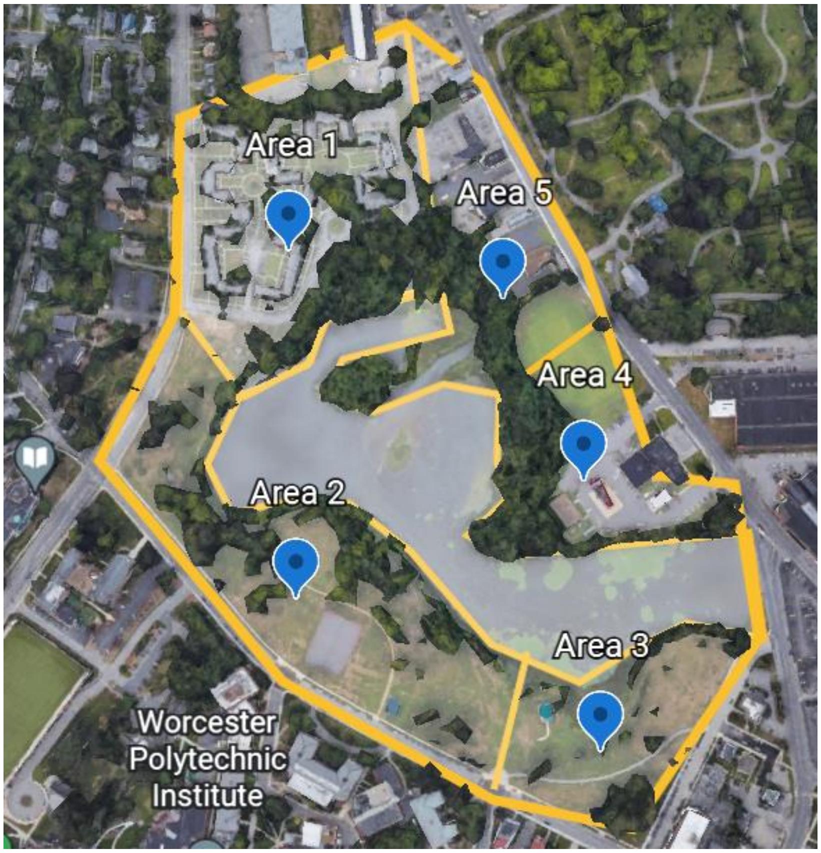

Figure 22*: Subcatchment Areas Surrounding Salisbury Pond*

Table 4: Characteristic Summary for Catchment Areas Surrounding Salisbury Pond

Catchment	**Characteristic Summary**				
	Subcatchment	**Land Type**	**Soil Type**	**Land Use**	**Area (m^2)**
Pond Area	**1**	Pavement, Grass	C	Multiple Family Residential, Forest, Recreation	46,741
	2	Grass	C	Recreation	36,585
	3	Grass	A	Recreation	21,802
	4	Pavement, Grass	A	Urban Public, Institutional, Recreation, Forest	31,075
	5	Pavement, Grass	Unknown	Non-forest Wetland	12,453

While Soil Type may be informational and important in designing for construction, they are not a major contributor to the HydroCAD analysis. However, this information, along with the land use info, allowed us to assess the daily traffic and feasibility for BMP designs in the catchment areas.

4.3 HydroCAD Analysis

After the subcatchments were modeled and determined using GIS, we utilized the HydroCAD software, as previously mentioned, to evaluate the runoff flow for these areas. Figure 23 shows the Hydrograph, which was created for the entire pond catchment, and then evaluated by each of its subcatchments in the following tables below it. The HydroCAD software used the SCS Rainfall Method to simulate the peak flows using the rainfall data collected from the Worcester Regional Airport's rain gauge. In Table 5, the existing drainage flow summaries for each catchment are displayed as well.

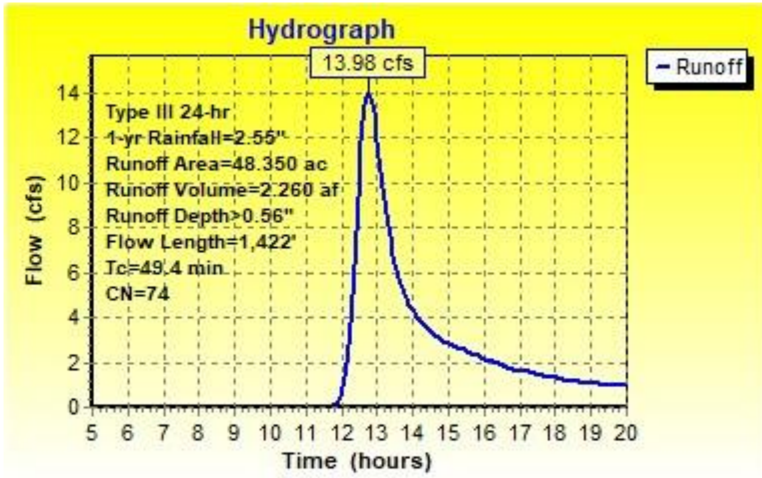

***Figure 23**: Hydrograph of the Pond Area Catchment for a 1-Year Storm Event*

Table 5: Flow Data Summary for Pond Catchment Areas

Catchment	**Existing Drainage Summary**					
	Subcatchment	**Length (ft)**	**Slope (ft/ft)**	**Tc (min)**	**Velocity (ft/s)**	**Capacity (cfs)**
Pond Area	**1**	598	0.01	14.8	0.67	-
	2	293	0.0426	6.9	0.71	-
	3	347	0.0224	10.9	0.53	-
	4	209	0.0226	7.2	0.48	-
	5	76	0.0313	2.7	0.46	-

Upon obtaining our testing data and visiting the pond area, we decided to narrow our HydroCAD analysis to our BMP design locations. This was done for two reasons. First, the BMP catchments which we focused on had the three highest drainage velocities for the available areas around the pond. Catchment 3 is not a major contributing area to the pond in terms of drainage, especially with the drain on Lancaster Street on that side of the pond. The second reason for focusing on those three main catchments was the fact that they possessed the sampling locations with the three highest TSS and TP concentration levels. Thus, in Tables 6 and 7 we show the rainfall data and associated calculated peak flows for each of these catchments. The rainfall data in Table 6 was collected from the Worcester Regional Airport's rain gauge. The data shown in Table 7 was collected from the National Oceanic Atmospheric Administration (NOAA) Atlas.

Table 6: Rainfall Data for Storm Events Showing Peak Flows for the Day from Worcester Regional Airport's Rain Gauge

	Storm Event	Amount of Precipitation (in)	Duration of Storm Event (hr)	Peak Flow (cfs)
Subcatchment 1 (Salisbury Estate Area)	10/26	0.95	22	0.5029
	10/30	2.1	21	1.1646
	11/12	0.89	9	1.1517
Subcatchment 2 (Grassy Hill Area)	10/26	0.95	22	0.3936
	10/30	2.1	21	0.9115
	11/12	0.89	9	0.9014
Subcatchment 4 (Firefighter Memorial Area)	10/26	0.95	22	0.3344
	10/30	2.1	21	0.7744
	11/12	0.89	9	0.7658

Table 7: Runoff Flows for Catchment Areas Based Off Different Storm Intensities from NOAA ATLAS Storm Data

Runoff Volumetric Flow Rates (cfs)					
Storm Intensities	**1 Year (2.55 in)**	**2 Year (3.12 in)**	**10 Year (4.84 in)**	**25 Year (5.92 in)**	**100 Year (7.57 in)**
Runoff of Pond Subcatchment 1 (Salisbury Estate Area)	16.13	21.32	37.07	46.9	61.81
Runoff of Pond Subcatchment 2 (Grassy Hill Area)	8.45	12.72	27.02	36.5	51.24
Runoff of Pond Subcatchment 4 (Firefighter Memorial Area)	8.64	13	27.58	37.24	52.24

The information above would allow us to properly assess the flow for our three main areas of interest. We provided the peak flow for those storm events for comparison with the NOAA ATLAS Storm data. This would help us get a better understanding of how the average flow rates and total rainfall, for the specific storm events we sampled on, compare with the estimated flow rates and total rainfall provided by the NOAA ATLAS based off of our total drainage areas for the BMP locations. In addition to this, we also needed the total impervious and pervious areas for the three locations to ensure that we met all the design standards and criteria provided in the MassDEP Stormwater Handbook Vol. 2. The area estimates are displayed in Table 8 below.

Table 8: Impervious vs. Pervious Area Percentages for BMP Design Areas

BMP Design Locations	Total Area (acres)	Impervious Area (acres)	Pervious Area (acres)
Salisbury Estates Area	11.55	7.51	4.04
Grassy Hill Area	9.04	2.26	6.78
Firefighter Memorial Walkway Area	7.68	2.46	5.22

The area estimates displayed above gave us a better understanding of the main catchment areas for the pond. While the impervious areas for two of the main three locations are low, we have one area with a relatively higher estimated total impervious area, which serves as a good comparison for our data. The grassy hill catchment has the lowest estimated impervious area, but this area still saw the highest concentrations of TSS and TP.

4.4 BMP Analysis

The information in the above sections would allow us to properly assess the flow and contaminant loading for our three main catchment areas of interest. After completing this step in our full analysis, we needed to compare the three main BMPs which we decided to focus on, in order to assess what systems should be in place for the main catchments of concern. We decided to leave water quality swales out of our analysis, due to the area and flow treatment requirements required, referenced in Section 3.4 of our methods section. Table 9 below lists the advantages and disadvantages of the BMPs, along with their removal efficiencies as well, down below. Additional information on the design feasibility for the BMP options can be found in Table 3 in Chapter 3.

Table 9: BMP Design Effectiveness Comparison

BMP Type	Advantages / Disadvantages	Removal Efficiencies
Infiltration Trench	**A:** Allows for groundwater recharge - Reduces downstream flooding - Preserves natural water balance - Effective pollutant removal - Low-cost maintenance and construction - Suitable for smaller areas **DA:** Needs to be maintained frequently and properly planned out to work - Mostly works for smaller drainage areas - Potential risk of groundwater contamination over time - Gets clogged	Total Suspended Solids: 80 - 90%. Total Phosphorus: 40-60%; Total Nitrogen: 50 - 60% ; Metals : 80 - 90%
Vegetated Filter Strip	**A:** Reduces peak runoff velocity, volume, and peak flows - Effective in sediment removal - Minimal maintenance - Mimics natural hydrology - Applicable to urban areas - can be used as part of runoff conveyance system with other BMPs - Minimal wildlife disruption or harm **DA:** Design can greatly affect removal efficiency - Used for gentle slopes - Not effective when flooded	Total Suspended Solids: 10 - 45%
Bioretention (Rain Garden, Trickling Filters)	**A:** Can provide groundwater recharge and preserve the natural water balance - Supplies shade, noise absorption, and windbreak - Effective in pollutant removal - Can be used in small spaces or areas - Mosquito killers **DA:** Requires careful landscaping and maintenance - Not too effective for larger areas	Total Suspended Solids: -44 - 90%; Total Phosphorus: 30 - 90% ; Total Nitrogen: 30 - 50% Metals: 35 - 90%

With the three main catchment areas for the pond possessing higher concentrations of TSS, TP, Sodium, and Chloride, we decided that these would be the best BMP recommendations. While other BMPs can be useful for treating these contaminants, the area requirements and pretreatments necessary for them can cost a lot of money and become quite cumbersome for maintenance and construction. The natural aesthetics for the pond is also a necessary factor too, as we do not want to take away from the public recreational and natural space. These BMPs can all qualify as pretreatment, and they allow for the greatest degrees of flexibility in terms of design spacing and requirements compared to the other BMPs. In section 5.1 of the following chapter, we further explain the walkway plan for the pond which was taken into account for BMP design recommendations. Thus, we needed to prioritize spacing while meeting standards and providing substantial treatment.

5.0 Designs & Recommendations

For our project, we decided to develop recommendations for three areas surrounding Salisbury Pond. The locations chosen for BMP designs are the Salisbury Estates area, the grassy hill near Salisbury Pond, and the Worcester Fallen Firefighter Memorial. We developed a detailed design for the Salisbury Estates area, and recommendations for traditional BMPs for the two other areas. The recommendation we developed for the Salisbury Estates Area is a walkway and biofiltration trench leading down to the available area in front. Then, the recommendation, which we developed for the grassy hill is a vegetated filtration strip, and the recommendation for the Worcester Fallen Firefighter Memorial is an additional smaller version of a similar filtration strip design, placed in front of the current BMP system located there. Figure 24 is a map showing where the proposed BMP designs would be located.

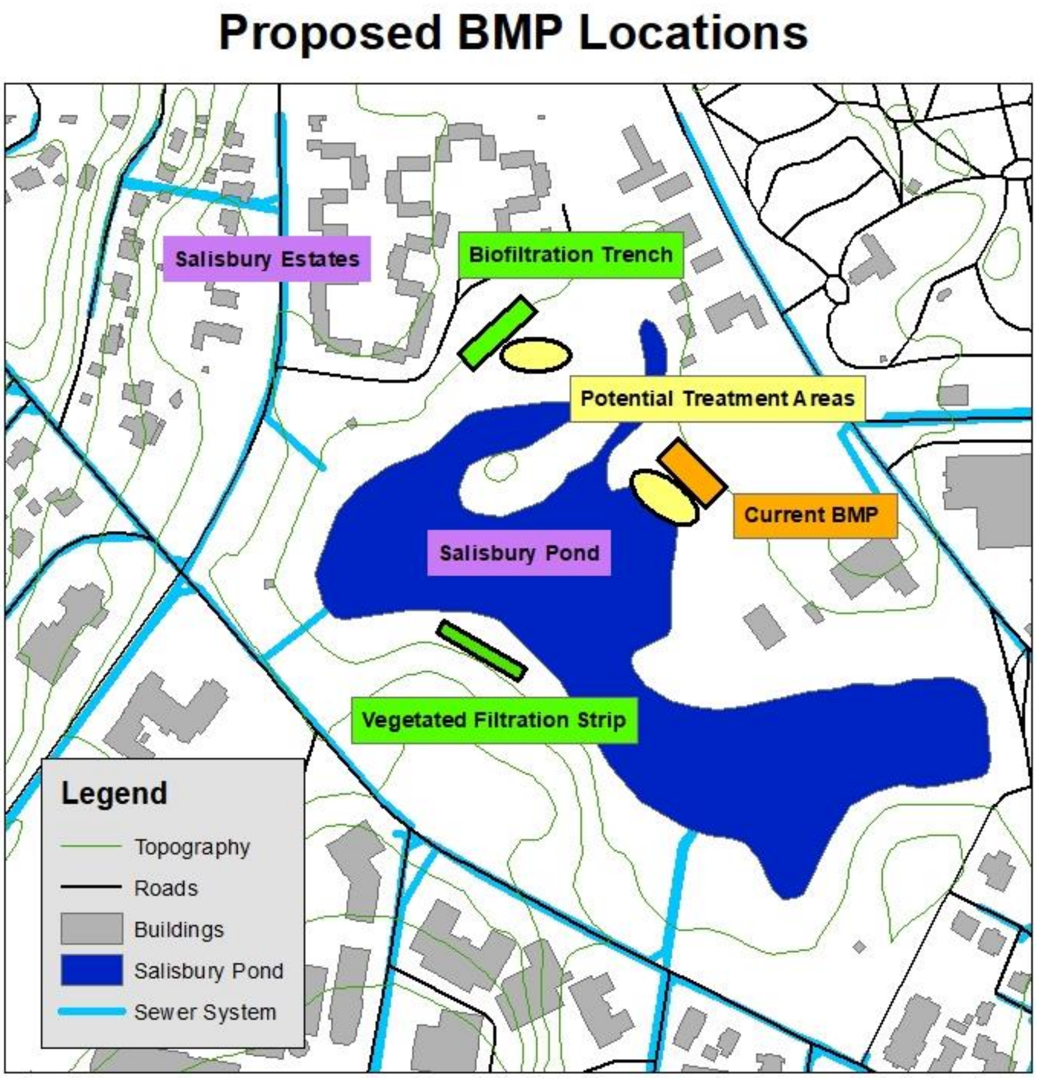

***Figure 24**: Map of Locations for Proposed Best Management Practices*

5.1 Institute Park Pathway Plan

Since June of 2017, the City of Worcester had developed a park pathways master plan for a walkway surrounding the edge of Salisbury Pond. There is a historical connection between WPI and the pond, and this walkway was meant to be the next chapter of that story. However, since the time of its publication, the master plan for the pond has only been partially executed. When our team was looking for ideas on how to improve the pond, we came across this master plan article and document, and we had decided that this could potentially be a great reference for our design recommendations for the Grassy Hill and Salisbury Estate areas. At first, we were initially only focused on the opposite side of the pond near the Salisbury Estate Townhouses. However, upon taking a second look at the walkway plan and actual location for the bridge portion already constructed, we saw that the bridge was built differently from the plan view. The bridge connecting Rumford Ave to Grove Street, is closer to the edge of the pond than originally shown in the master plan. In addition to this, there is a forebay for the area near the upper portion of that bridge which has not yet been constructed, but this system would drain into the area between Salisbury Estates and the football field. Figures 25 and 26 are two aerial images of the entire original walkway plan and the existing bridge area.

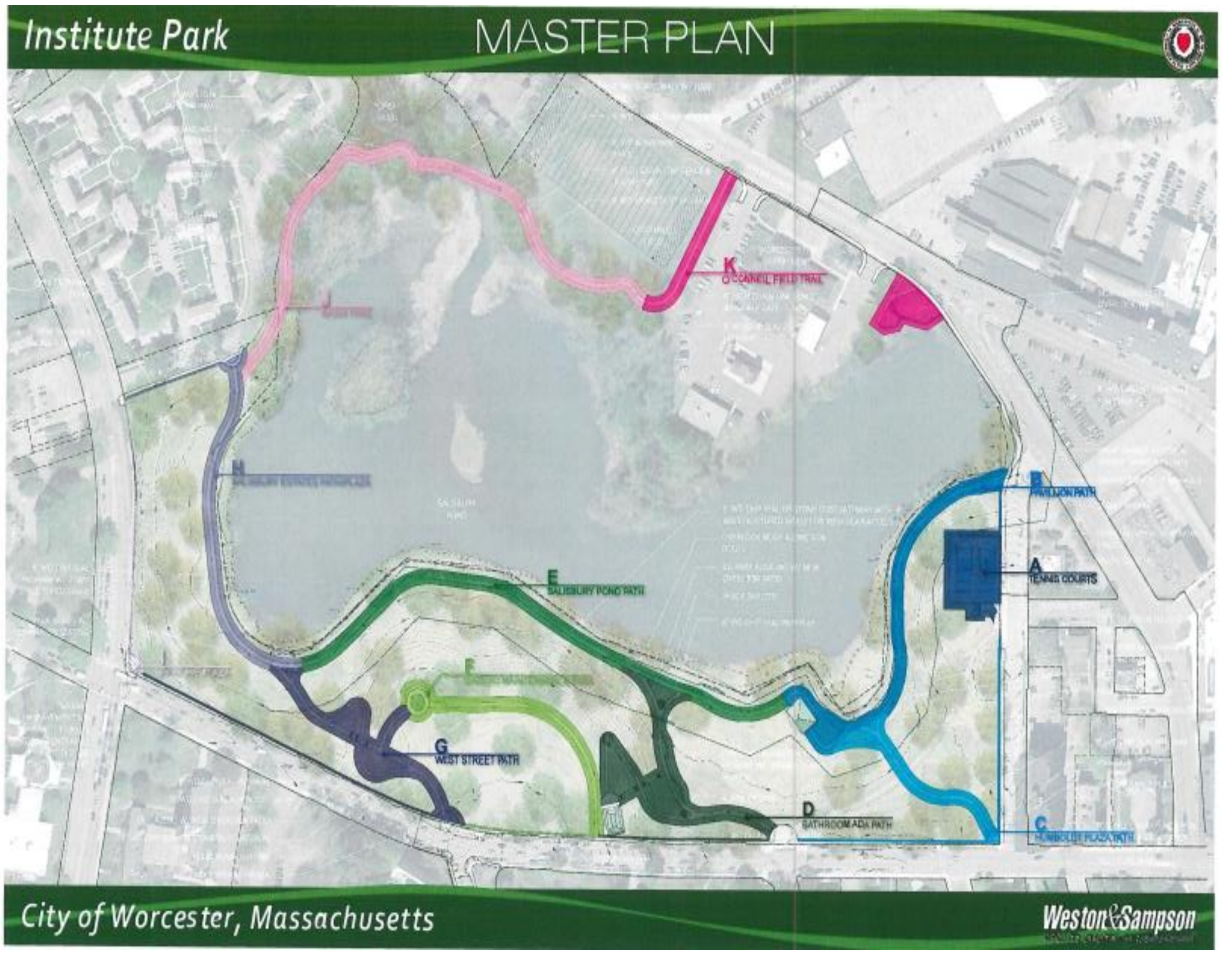

Figure 25*: Walkway Plan for Salisbury Pond (Institute Park Pathways Master Plan, 2017)*

Figure 26*: Aerial Live Image View of Constructed Bridge Area (Made on ArcGIS Online)*

As you can see in the two images above, the bridge was constructed much closer to the pond edge, as previously mentioned above, and there is a much greater area of free space between the bridge and parking lot. We decided that a small staircase incorporated into the design system for this area, leading down to an additional treatment area for both of the systems, would serve as a great addition and opportunity for both educational, environmental, and maintenance purposes. For the Grassy Hill area, the walkway plan was taken into consideration for the purpose of design recommendation specifics, and design general dimensions. We would gear our design for that area towards its applicability and purpose in relation to the walkway plan.

5.2 BMP Design Parameters

In order to put together a substantial design, we needed to first evaluate the potential design areas for their slope, one inch one-hour storm volume, and peak treatment flow rates. This allowed us to effectively evaluate the necessary area requirements for recommendations and meet design standards. In order to tailor the basic layout of conventional BMPs to our different design recommendations, we needed to make a couple of educated assumptions and set some basic parameters for soil media:

List of Requirements and Parameters:

- Minimum length required for a filter strip is 25 ft.
- The minimum width of the filter strip must be 20% of the length of the flow path, or at least 8ft. wide
- Maximum length of an infiltration trench is 25 ft.
- Minimum depth required for a filter strip is 12 in.
- Depth of an infiltration trench must be between 3-12 ft.
- Minimum depth to the seasonal high-water table, bedrock, and/or impermeable layer should be 2 ft. from the bottom of the trench.
- Minimum overall depth required for a bioretention/biofiltration system is 2.75 ft.
- Bioretention systems must be designed to treat 5% - 7% of total impervious surface drainage area for pretreatment
- Slopes for both areas must be less than 6%
- Design for Bioretention must account for at least 6 in. of ponding on top
- *Soil Media Requirements (Bottom - Top)*:
    - Pea Gravel or Bridging Stone bottom layer must be 6-12 in.
    - Planting, Bioretention, and/or FocalPoint High Flow Biofiltration soil media layer, for both retention and infiltration must be 2-4 ft.
    - Topsoil or fine-shredded hardwood mulch layer must be 2-3 inches
- OSHA maximum height and step length of a standard staircase step is 9.5 in.

5.3 Salisbury Estates Area

Along the edge of the pond, near Salisbury Estates, there is a fair amount of available land to put a rain garden or vegetated filter strip in place. Right in front of the roundabout of Salisbury Estates, adjacent to that entrance, there is a steep enough slope to build a staircase or walkway down to the edge of the pond with two terraced biofiltration square-area trench strips along the sides, leading down to the bottom of the embankment. This structure would essentially be a biofiltration and retention trench, or a combination of the three BMPs which were primarily focused on. The BMP was produced based off the minimum requirements and guidelines for treatment, provided in the Massachusetts Stormwater Handbook Vol.2 & Clean Water Toolkit, along with the guidelines set forth in the and the installation guide for a FocalPoint Biofiltration System, developed by the company ACF Environmental. The installation guide (Appendix G) provides some necessary information and possible supplies which could be implemented with their FocalPoint filtration products in a basic system. This guide was simply used as an additional reference in modeling, for our detailed BMP design recommendation. The filtration media is an ultra-efficient high flow soil media, that treats and drains large volumes of stormwater runoff in a small footprint (usually up to 90% smaller than traditional bioretention systems) in order to meet post-construction stormwater treatment requirements (FocalPoint Biofiltration Systems, 2014). The underdrain and topsoil design parameters which they have set forth in their installation guide are efficient and scalable, allowing them to be applied to our design recommendation. They are also in accordance with the standards presented by MassDEP in the Stormwater Handbook Vol. 2.

Essentially, the cross-section requirements presented in the FocalPoint Installation Guide (Appendix G) incorporate a lot of the same parameters for media filters required for proper treatment by MassDEP. However, the structure and composition for the media layers in our design recommendation would be slightly different to meet the state standards. The bottom layer of bridging stone or pea gravel would be one foot deep. The layer of planting/bioretention, or FocalPoint soil media on top of this layer would be two feet deep. Then, the top and final layer of fine-shredded hardwood mulch would be two inches deep.

The structure would have two levels of these same soil measurements, with the rectangular aerial area for the first upper level being smaller than that of the second lower one. The depth for the first and smaller rectangular area would also be deeper than the depth of the second with an additional 1 ft. of bridging stone and pea gravel for that area. A more simple diagram of the media layer outline provided by FocalPoint is shown below to help illustrate the layout.

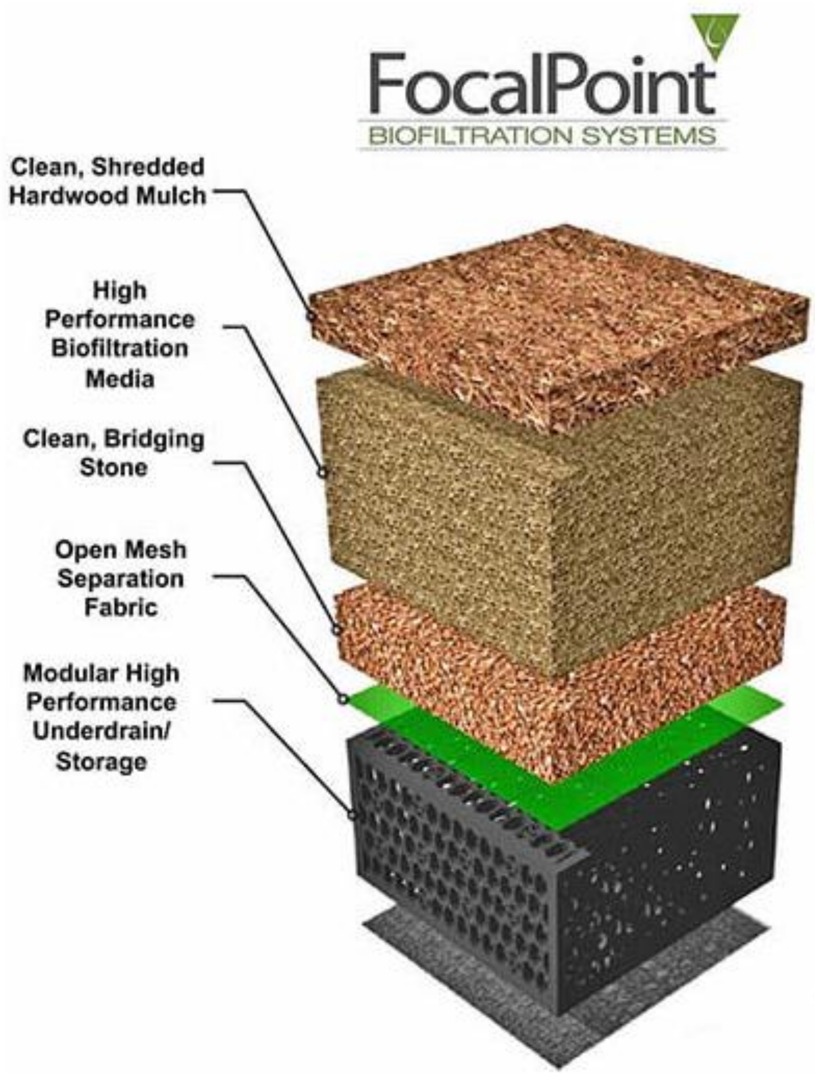

Figure 27: *FocalPoint High-Flow Biofiltration System Diagram (FocalPoint Biofiltration Systems, 2014)*

The steps of the staircase or walkway in the middle of the system, would be made of permeable interlocking concrete pavement, or PICP, to allow for infiltration. Combining the stair pavement with outflow pipes placed inside the modular underdrain strip at the bottom, would allow the entire structure to then serve as an innovative and educational BMP, by allowing access for sampling and analysis to be done from this structure and area in the future. The structure for our design also would have a 6" diameter outflow PVC pipe on the bottom layer of the garden on both sides of the staircase. The outflow pipe on the bottom layer of the design would be in the front of the structure, allowing the overflowing water to flow down into the potential forebay area in front of it. The design dimensions and specifics for this structure are outlined below:

Area Required for the Rain Garden:

- Total Impervious Drainage Area = 7.51 acres
    - Min. Area for Bioretention Treatment = (5% of Drainage Area) = (0.05) * (7.51 acres) = 0.376 acres ≈ 16,378.56 ft^2.
- 1-inch / 1-hour Storm Volume (for 0.376 acres) = 1,365 ft^3 (USGS Calculated)
- Required Min. Depth of Structure = (2 levels) * (1 ft. Pea Gravel/Bridging Stone Layer + 2 ft. Bioretention/FocalPoint High Flow Biofiltration Soil Media Layer + 2 in. Fine-shredded Hardwood Mulch Layer) + (6 in. Ponding Depth) = (2* 3.17 ft.) + 6 in = 6.83 ft.
- Min. Area Required for Structure = (1-inch / 1-hour Storm Volume) / (Required Min. Depth of Structure) = (1,365 ft^3) / (6.83 ft.) = 199.85 $ft.^2$

Length and Width Dimensions

- Required Length of BMP Treatment = 25 ft.
- Width of BMP Treatment = (Min. Area Required for Structure) / (Required Length of BMP Treatment) = 199.85 $ft.^2$ / 25 ft. = 7.99 ft. ≈ 8 ft.
    - Minimum Treatment Dimensions: 25ft. x 8ft. x 6.83ft (depth of media).
    - 9 stairs down the middle, (9.5 in. x 5 ft. x 9.5 in (step depth)

The purpose of the two levels being terraced would allow for the reconstruction of the natural slope which exists there, while providing more area and opportunity for infiltration and pre-treatment. A drawing of the basic plan and profile view layouts for this design are displayed in Figures 28 and 29.

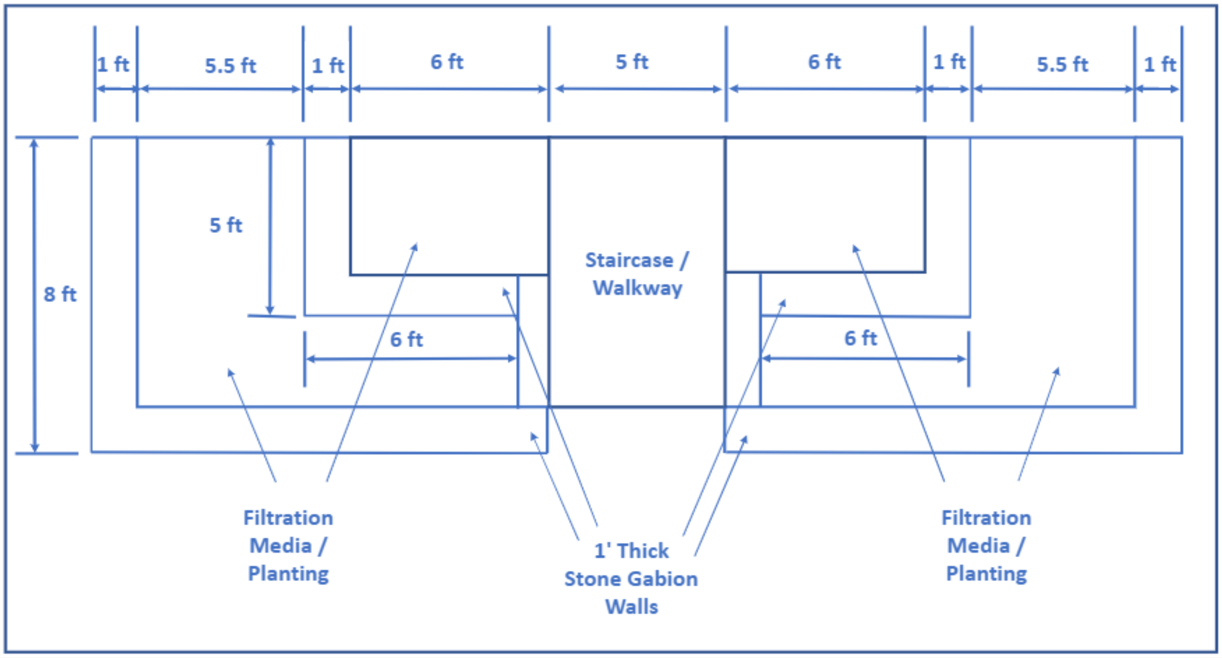

Figure 28: *Plan View Layout for Design*

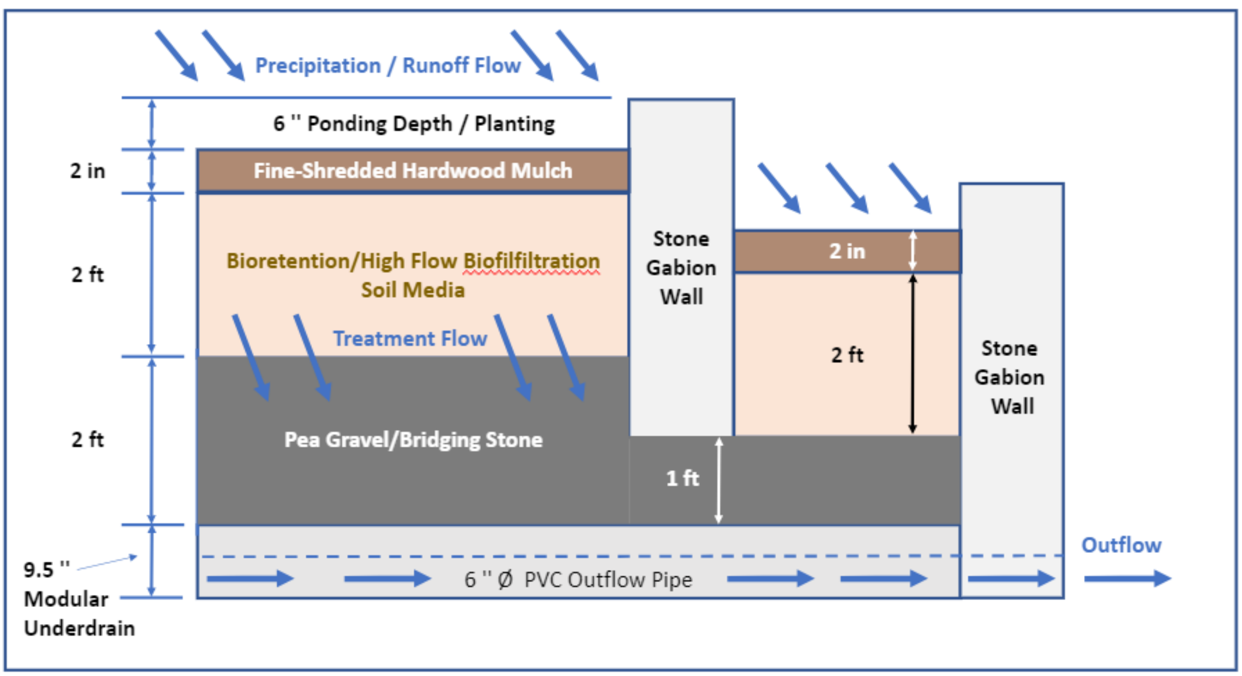

Figure 29: *Profile View Layout for Design*

This design idea would serve as an opportunity to both allow people to get closer to the actual pond, while providing an appealing display of different plant and filter combinations. This terraced strip and staircase would occupy a rectangular area extending from the edge of the parking lot/roundabout on Rumford Ave. over the depression in the slope right in front, down to the lower-elevation area. See Figure 30 displaying the proposed rectangular area for our BMP design on the front view of that area.

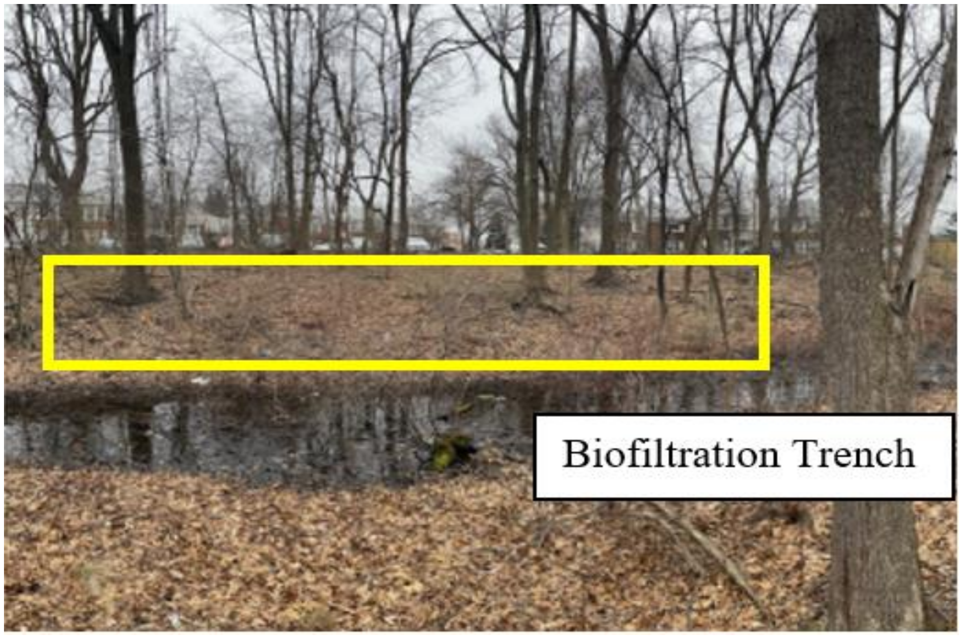

Figure 30: *Front View of Proposed BMP Area*

The purpose of the rain gardens or strips in this sense, would be to prevent contaminants in runoff from Salisbury Estates from reaching the pond untreated. The structure would allow for contaminants to be flushed out and reduced by the filtering of the structure. Rain gardens work as an excellent method for a first flush, where pollutants are usually found in their highest quantities. By slowing down the flow of stormwater runoff with vegetation and filtration media, we would be able to effectively gather enough water in the underlying drainage containment of the BMP from infiltration, for the purpose of future sampling from the outflow pipe during storm events. The system would also require monthly maintenance, which would provide the opportunity for cleaning projects for youth groups in the future as well possibly. When constructed properly, rain gardens are especially beneficial for reducing runoff volumes, and possess the baseline potential to remove high percentages of pollutants. This would be extremely beneficial for that section of the pond, as the results from that area were high in both TSS and total phosphorus.

5.4 Grassy Hill Area

The grassy hill area of Salisbury Pond is a new sampling location that was analyzed for the implementation of a BMP. There is a need for a BMP in this area because Salisbury Street is a high traffic road that can cause a lot of contamination to runoff into the pond below. After observation during sampling, it was noted that stormwater runoff flows down the hill from above, near the road, and pools at the bottom right before draining into the pond. Where the runoff collects would be an effective place for a BMP. Since this is quite an open area, a variety of BMPs were looked into for the best method when it comes to mitigating these effects.

Since the grassy hill area off of Salisbury Road has a slope, the most practical BMP for this area would be the vegetated filter strip, also known as a buffer strip. A vegetated filter strip, as described in section 3.5, is ideal for shallow slopes and areas that do not get overly flooded. An example of a vegetated filter strip can be seen in Figure 30.

It is an effective way of counteracting contaminants that flow down the hill adjacently from the roadways and pavement. In this case, adjacent to the impervious surfaces surrounding Salisbury Estates, the vegetated filter strip would be placed along the bottom of the steeper side of that hill between the slope and Salisbury Pond. These filter strips are designed to remove pollutants such as pesticides, sediments and organic matter (NRCS, 2022) from runoff. Not only is it highly effective in preventing pollutants from entering the pond, but it is also aesthetically pleasing as it blends in and mimics natural processes. As a result of this, there is little to no disruption regarding the surrounding wildlife and can serve as a potential habitat as well (NRCS, 2022). The main issue when it comes to this BMP is that it is not effective in flooding scenarios. However, this can be counteracted by using it in conjunction with another BMP which is very possible with filter strips. Another benefit to note is the fact that this BMP is very low maintenance. It only requires two to four months of maintenance within the first couple of years and then minimal management from then on. In addition, vegetated filtration strips are aesthetically pleasing and to the overall beauty to the Salisbury Pond area. It is important for the filtration strip to blend in with the natural environment and accent the pond to help with the acceptance of the filtration strip by the community and quicken its construction.

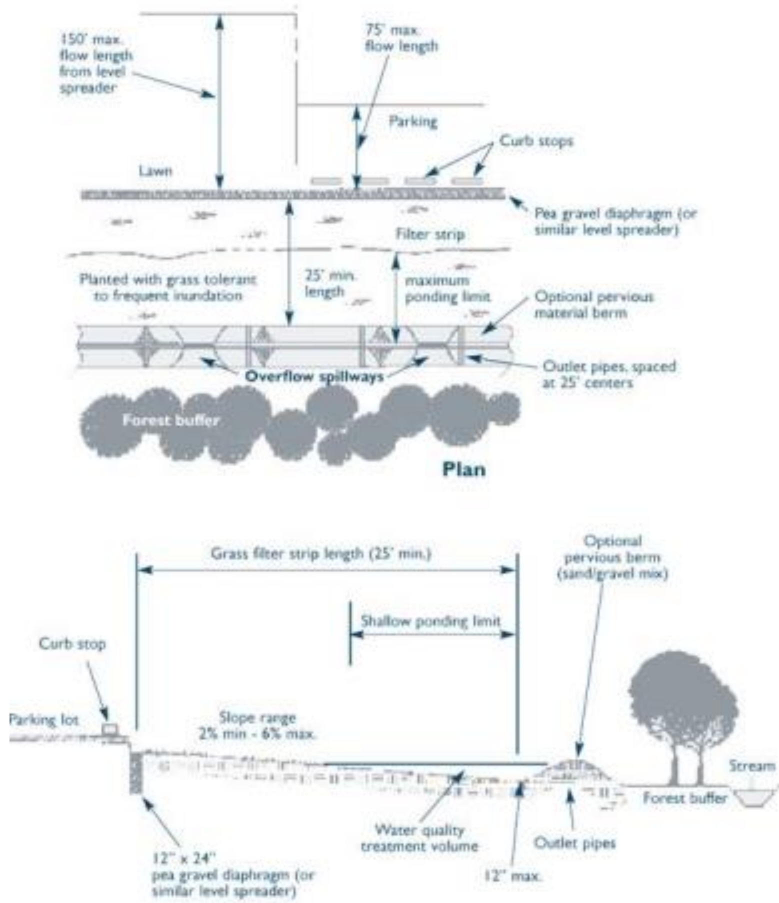

Figure 31*: Plan and Profile View of a Typical Vegetated Filter Strip Located Next to a Parking Lot with A Stone Diaphragm (MassDEP, 2008b)*

As previously discussed, there are plans to build a walkway along the edge of Salisbury Pond, very close to where our proposed vegetation filter strip would lie. The filtration strip could be considered in the design of the walkway which would add to the aesthetics of the pond. Since the walkway has not been constructed yet, the proposed design for the filtration strip is limited to a general area where there is the most need for a BMP. This area is where the stormwater runoff pools at the bottom of the hill. By placing the filtration strip at this location, the runoff would have a place to collect and be filtered for contaminants before flowing into the pond. Figures 32 and 33 show different views of where the filtration strip would be placed based on where the most amount of runoff pooled during a rain event.

The minimum length required for a filtration strip is 25 feet, and the minimum width is 20% of the length of the flow path, which is 150 ft. The height of the grass planted above should also not exceed one foot in height. The baseline design requirement details are shown below:

Dimension Requirements for Vegetated Filtration Strip:

- Impervious Area = 2.26 acres
- Maximum Pervious Flow Path of 150 ft.
    - Minimum Width Required = (20% of Impervious Flow Path) = (0.2) * (150 ft) = 30 ft.
    - Required Length of Treatment = 25 ft.

Area of Vegetated Filtration Strip

- <u>Min. Area Required for Structure</u> = (25 ft.) * (30 ft) = 750 ft^2

As calculated above, the minimum area required for the strip is 750 sq ft. The designers of the walkway can use the minimum required area as a baseline to fit the filtration strip in with their plans, and the length and width dimensions can vary depending on the desired layout with the walkway. Potential dimensions could be 25 feet long by 85 feet wide, with plantings one foot in height. Since the sheet flow of water for this area pools at the bottom of the hill, near the edge of the pond, we determined that the filtration strip should follow this layout.

***Figure 32**: Aerial Image View of General Area for Filtration Strip for Grassy Hill Area*

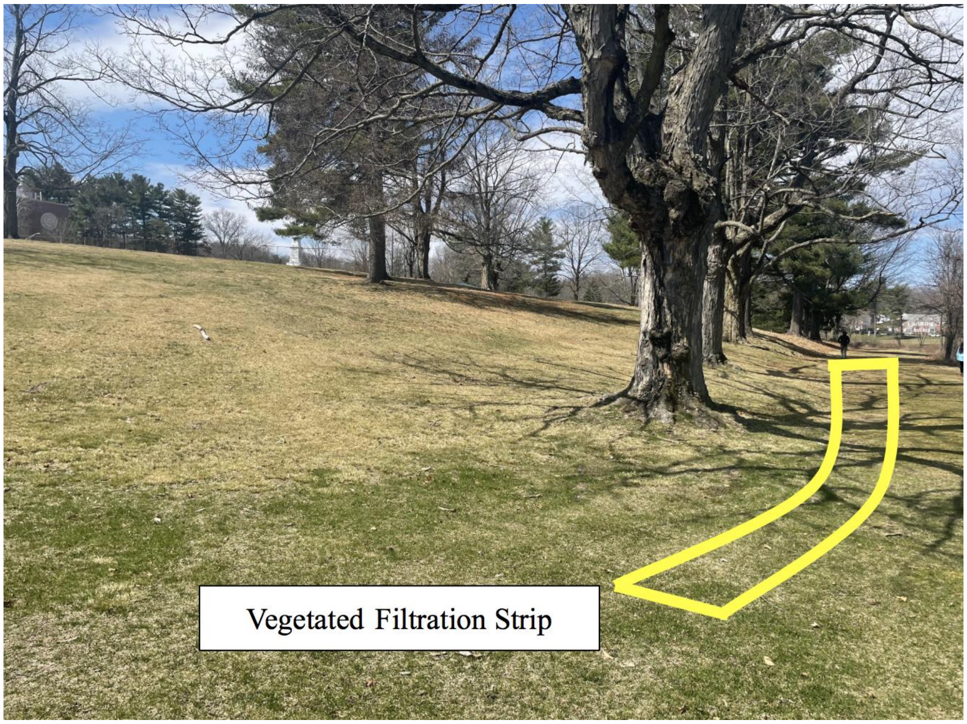

Figure 33: *Front View of the Proposed Area for Filtration Strip for Grassy Hill Area*

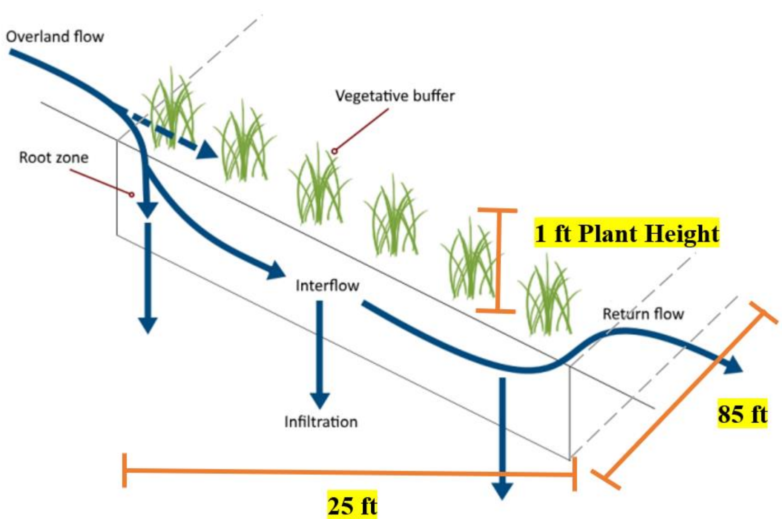

Figure 34: *Profile View of the Proposed Vegetated Filtration Strip for Grassy Hill Area*

5.5 Worcester Fallen Firefighters Memorial Area

When we first started our project, we had not initially looked at this area. However, upon coming across the walkway plans for the park, we noticed the firefighter memorial showing up on ArcGIS, but not on the plans. We decided to go over to the north-east side of Salisbury Pond, near the recently renovated O'Connell Field, where we saw the newly constructed Worcester Fallen Firefighters Memorial, along with a raised walkway along the edge of the field. As part of the Institute Park Pathway previously discussed in section 3.4.1, this walkway provides a scenic path connecting WPI's campus to the Firefighter Memorial and football field. Once we visited, we had also discovered that this memorial area doubled as a BMP system in the form of a rain garden and permeable walkway incorporated into the design. An image of the memorial area is shown in Figure 35.

Figure 35: *Rain Garden and Infiltration Walkway BMP at Worcester Fallen Firefighters Memorial*

This walkway was incorporated into our project for two main reasons. We wanted to assess the other side of the pond when it was time to start considering BMP designs, and we had been intrigued by the stormwater management model already in place there. This rain garden and walkway is a very cost-efficient and beneficial way to manage the volume and quality of runoff, while also increasing the aesthetic appeal of the memorial. Thus, upon visiting and discussing alternatives for this area, we decided to do an analysis on the treatment already accomplished by this system and offer any additional recommendations we thought could be useful.

An advantage of this rain garden is that it doesn't require an excessive amount of maintenance in the area where it's located. Plants may just need seasonal pruning and occasional watering during months when rain isn't prevalent, along with replacing and reinforcing plants and soil every so often. The existing rain garden had a measured soil depth of around 2.5 feet and a limited amount of plantings in the mulch covered basins. In theory, this rain garden should ideally treat stormwater runoff from the entire catchment surrounding the memorial and field. So, in the calculations below, we evaluated the baseline required area for the rain garden based on the measured depth and standard requirements, in order to determine if the memorial is adequate for the flow in the area.

Area Required for the Rain Garden:

- Total Impervious Drainage Area = 2.46 acres (From Table 8)
    - <u>Min. Area for Bioretention Treatment</u> = (5% of Drainage Area) = (0.05) * (2.46) = 0.123 acres ≈ 5357.88 $ft.^3$
- 1-inch / 1-hour Storm Volume (for 0.123 acres) = 447 $ft.^3$ (USGS Calculated)
- <u>Estimated Depth of Rain Garden (Measured)</u> = 30 inches = 2.5 ft.
- <u>Min. Area Required for Structure</u> = (1-inch / 1-hour Storm Volume) / (Required Min. Depth of Structure) = (447 $ft.^3$) / (2.5 ft.) = 178.8 $ft.^3$

Based on the above calculations, the minimum area for this memorial system should be about 180 sq. ft. This is the area required to treat at least 5% of the area's total impervious surface drainage area. As a permeable surface, the gravel walkways all around the football field and memorial are sufficient pre-treatment for the stormwater runoff in the area, and the overall estimated area for this walkway, obtained on ArcGIS, was around 25,000 $ft.^2$ Thus, installing an additional treatment system in this area would simply just provide an unnecessary additional buffer between the BMP system and the pond. However, as the climate gets better and the walkway finishes construction, more people will be in this area, and it will probably require slightly more maintenance in the future. Every five to seven years, the plants and soil may need replacement or reinforcement. This rain garden and walkway is a very cost-efficient and beneficial way to manage the volume and quality of runoff, while also increasing the aesthetic appeal of the memorial. As a permeable surface, the gravel walkways all around the football field and memorial are sufficient pre-treatment for the stormwater runoff in the area, and the overall estimated area for this walkway, obtained on ArcGIS, was around 25,000 ft^2. Installing an additional treatment system in this area would simply just provide an additional buffer between impervious surfaces and the pond.

In visiting the memorial, we also noticed that there was a substantial amount of area right in front of the BMP, with a small stone channel to reduce erosion, and guide runoff flow out from the system's main outflow pipe. Figure 36 display the stone channel and available area in front.

Figure 36: *Area for Potential Treatment near Firefighter Memorial Showing Stone Channel*

We were unable to obtain contaminant data for stormwater at this area, because the memorial was not very accessible at the time of sampling, and we had not been focused on this area initially. However, our first recommendation is that future project teams sample and analyze stormwater at this memorial, in order to evaluate the productivity of the rain garden in removing common contaminants. Our second recommendation is that an additional smaller biofiltration trench be constructed for this area in order to provide an additional buffer and add to the aesthetics of the available area.

Because there is already sufficient pretreatment and treatment for this area, the design would be much smaller in width and length with dimensions of 8 feet wide by 5 feet long as displayed in Figure 37 down below.

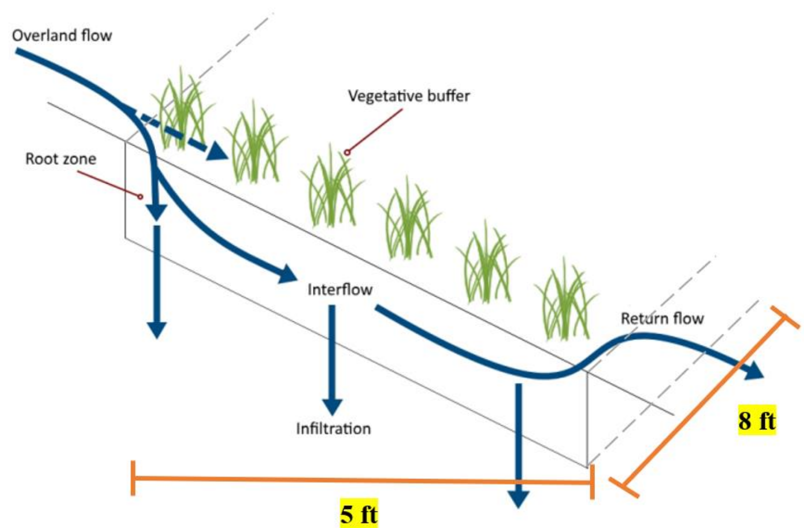

Figure 37*: Profile View of the Proposed Biofiltration Trench for Firefighter Memorial Area*

6.0 Conclusion

This project included water quality analysis of Salisbury Pond, particularly for stormwater, and then provided recommendations on how to improve stormwater management for the area. Based on laboratory results showing high amounts of TSS, TP, sodium, and chloride near Salisbury Pond, as well as the watershed characterization and hydrologic modeling from our GIS and HydroCAD analysis, we designed three BMPs for three locations: a biofiltration trench for the Salisbury Estates area, a vegetated filter strip for the grassy hill near Salisbury Pond, and the current BMP design for the Worcester Fallen Firefighters Memorial, with the addition of a forebay.

When discussing stormwater management, there are many other areas or aspects that are in need of improvement. With growing concerns and increased urban renewal, stormwater management efforts around campus could use a lot of help. However, taking into account the timeline of this project, the current global pandemic, and unfortunate scheduling circumstances and mishaps, we geared our project towards well-designed theoretical recommendations for new and innovative BMPs for the pond. Ideally, this project sought to target a new, or innovative, and more effective BMP design. In particular, we emphasized natural and filtration approaches to manage non-point source pollution. We planned to hit this target by researching the benefits and effectiveness of different filter-medium combinations and unconventional filtration systems, while still analyzing the different land characteristics of the campus watershed, to try and identify specific improvements to contaminant removal or flow mitigation efforts. In doing so, we developed our designs for each BMP based on surface type and runoff flow.

For future MQPs or similar projects regarding stormwater, we recommend further study on the WPI campus and surrounding areas. Because of time constraints, our group was not able to sample stormwater at Gateway Park, another part of WPI's campus. Thus, future project groups should examine the stormwater quality at Gateway and compare its sampling results to that of already sampled locations on and around campus. Additionally, future project groups should sample at the Firefighter Memorial's BMP design to analyze how effective the BMP is at removing contaminants and suggest any needed improvements. From our own project experience, we also recommend that future groups take careful consideration and time into their BMP design process, as well as focusing on sampling in the earlier stages of the project.

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Appendix A: Sampling Protocol

Sampling Protocol

Adapted from "WPI Nitsch Engineering MQP Field Sampling Protocol"

Equipment:

- Sampling bottles (size TBD)
  - Need to be cleaned ahead of sampling time
- Cooler
  - Ice
- Labels
- Field notebook/sample spreadsheet
- Permanent writing material (preferably Sharpie or pen)
- Disposable safety gloves
- Clear packing tape
- Thermometer
- YSI Model 85 probe

Prior to Sampling:

1. Check that all necessary materials for sampling are present, and make sure that these materials are clean and functionable.
   a. Rinse out the sampling bottles three times with distilled water.
2. Ensure that sampling bottles are correctly labeled.
   a. Write out labels beforehand.
3. Ensure that sampling crews know where they will be sampling and the purpose of sampling (a two-person crew is recommended).
4. Ensure that equipment is fully charged.
5. Record the weather conditions.
   a. Take a picture of the area upon arrival.
6. Record the amount of rain in the rain gauge.

Sampling:

1. Before collecting the samples, put on a pair of new gloves. Gloves should be changed for a new location.
2. Fill sampling bottles as much as possible, ensuring that the inside of the bottle is not touched.
3. Record the time, date, location, and label ID on the collected sample's label.
4. Place the sample into the cooler until further testing.
5. Repeat steps 3-5 for additional sampling at the same location.

Sample Sheet:

Sample ID	Location	Date	Time	Weather	Tests	Temperature	Notes

Appendix B: pH Procedure

pH Testing Procedure

1. Standardize the probe using 4, 7, and 10 pH buffers.
    a. Remove the probe from the storing solution and open the filling hole seal.
    b. Rinse the pH electrode with DI water and dry it with a Kimwipe.
    c. Place the probe into the 4-pH buffer solution.
    d. Press the STD button and wait for the screen to Stable.
    e. Accept the new standardized value by pressing STD again.
    f. Remove the probe from the buffer solution.
    g. Clean and place the probe into the next buffer solution.
    h. Repeat the above steps with each buffer solution.
2. Clean probe and place it into a 300 mL sample.
3. Wait 5 to 10 minutes for the probe to read as Stable.
    a. Note the final pH.
4. Repeat steps 1-3 for other samples.

Appendix C: Total Phosphorus Procedure

Total Phosphorus Testing Procedure

1. Clean glassware (100 mL beakers, 100 mL volumetric flasks, 25 mL volumetric flasks).
    a. Soak the glassware in an acid bath overnight, rinse 3 times with tap water, and then rinse 3 times with DI water.
2. Label 100 mL beakers with blank, standards, and sample IDs.
3. Make the standards.
    a. Take out the labeled bottle of standard from the refrigerator.
    b. Get the 100 mL volumetric flasks.
    c. Label flasks for standards.
    d. Pipette standard amounts according to the sheet.
    e. Fill flasks with DI water from an e-pure tap, then use a spray bottle to fill the flask to the line.
    f. Add parafilm to the flasks.
    g. Invert each flask 5 times.
4. Pour the blank, standards, and samples into 25 mL volumetric flasks.
    a. Rinse the flasks before filling.
        i. Add a little, swirl, dump out (do this twice).
    b. Use disposable, plastic pipette if over the line.
    c. Pour into the corresponding beaker, rinse the flask with a spray bottle twice.
5. Digest samples (about 1 mL of standards and samples will be left over in the beakers).
    a. Add 5 mL of nitric acid and 1 mL of sulfuric acid to each beaker.
    b. Heat on a hot plate until approx. 1 mL left or it starts fuming.
    c. Add drops of H_2O_2 if there are too many organics in the sample (sample would be cloudy and colored).
6. Turn on the spectrophotometer.
7. Make sure the spectrophotometer is on single wavelength and that the wavelength is set to 400 nm.
    a. Change the wavelength by pressing Manual Program.
8. Filter samples (may not be necessary for all samples, depends on sediment amount).
    a. #4 filter paper, Whatman
    b. Funnels
9. Get 3 solutions.
    a. Phenolphthalein: 1000 mL, white/clear bottle, clear solution
    b. Molybdovanadate: 1000 mL, white/clear bottle, yellow solution
    c. NaOH: 6.25 N, white bottle, clear solution
10. Get supplies for each solution
    a. (2) Disposable dropper, 100 mL beaker
    b. 1 mL pipette and tip (1-5 mL)
11. Get DI water (in a squirt bottle), paper towels, gloves, “my” cell from the water lab, and a large waste beaker.

12. Transfer the blank solution from the beaker into the cell; rinse with DI water to get all of the sample.
13. Add 1 drop of Phenolphthalein.
14. Add NaOH with dropper until the sample turns pink.
15. Add e-pure water to the line on the cell with the squirt bottle.
16. Add/pipette 1 mL of Molybdovanadate.
17. Set the spectrophotometer timer to 3 minutes.
18. Place the cell into the spectrophotometer (kimwipe first) with the white line mark facing outwards when the timer reaches 0.
19. Press Zero.
20. Rinse the cell into the large waste beaker.
21. Repeat steps 12-20 for the rest of the samples and standards, except press Read for step 19.
22. Dispose the waste into the hazardous waste bottle for total phosphorus.

Appendix D: ICS Anions Procedure

ICS Anions Procedure

1. Sample preparation:
    a. Filter samples through 0.45 μm syringe filter (sample should be at least 10 mL), store sample in refrigerator until analysis.
2. On the test day:
    a. Get vials, caps, a marker, the tool (black cylinder), and a plastic tray.
    b. Label vials.
    c. Use the tray when filling (fill to the top of the tray, roughly 8 mL).
    d. Use the tool to put on caps (use the "hole" end first and the other end further down).
    e. Carousel release/align, then set up the autosampler in this order:
        i. 2 blanks.
        ii. Standards = 100, 200,400, 800, 1200, 3000 ppb.
        iii. Samples.
        iv. 3 blanks (2 blanks and 1 one for auto shutdown).

Appendix E: TSS Procedure

Total Suspended Solids (TSS) Procedure

1. Set up the filtration apparatus, insert a filter, and apply a vacuum.
2. Wet the filter with a small amount of deionized water to seat it.
3. Shake the sample vigorously, and then measure out the predetermined sample volume using a graduated cylinder.
    a. Record the volume filtered in liters on the bench sheet.
4. Rinse the graduated cylinder and filter with three 20 mL volumes of DI water, allowing complete drainage between washings.
5. Continue suction for three minutes after filtration is complete.
6. Carefully transfer the filter to an aluminum weighing dish, and place the filter on a cookie sheet.
7. Place filters on the sheet into an oven set to 104 ± 1 °C, and dry for a minimum of one hour.
8. Remove the filters from the oven and transfer them to a desiccator to cool at room temperature.
9. Weigh one sample filter to the nearest 0.1 mg.
    a. On the bench sheet, record the sample ID and the mass (Mass 1) in the "Weight check" section.
10. Repeat steps 7 - 9 for all samples.
11. Repeat steps 7 -10 and record the mass as "Mass 2" in the "Weight Check" section of the bench sheet.
    a. If the mass of the filter increases less than 0.5 mg or the change in the mass of the solids is less than 4% of the previously measured mass, then continue with TSS calculations.
    b. If the mass of the filter increases by more than 0.5 mg or the change in the mass of the solids is less than 4% of the previously measured mass. Record each additional mass on the bench sheet as "Mass 3", "Mass 4", etc. Use the back of the bench sheet if necessary.
12. Record the Oven Dry Mass (in mg) on the bench sheet.

13. Calculate TSS.
14. Dump the remaining sample down the drain, remove the label, and rinse with tap water to remove any solids from the bottle.
    a. Wash bottles according to the bottle prep non-metals SOP 0150R01.

Appendix F: ICP-MS Metal Test Procedure

ICP-MS Procedure

1. Label the 15 mL test tubes.
2. Filter samples through a 0.45 μm syringe filter into 15 mL test tubes to reach the 10 mL line.
3. Add 100 μL of concentrated nitric acid (HNO3) to each test tube.
4. Mix well.
5. Store samples in the refrigerator until analysis.

Appendix G: Focal Point High Performance Modular Biofiltration System (HPMBS) - Underdrain and High Flow Media Installation Guide (pgs. 1-14)

Pre-Construction Checklist

TOOLS YOU WILL NEED:

- Laser or Transit
- Measuring Tape (Long enough to mark FocalPoint HPMBS footprint)
- Razor Knife
- Screw Driver / Nut Driver Set
- String Line
- Marking Paint
- Reciprocating Saw (To cut Inspection & Maintenance Port and Receiving Holes)
- Dead Blow Mallet
- Worktable (3/4" plywood placed on saw horses works well)
- Hog Ring Gun and Rings for Gabion (if specified)
- Level
- Torch (etc) to "weld" geotextile for 'cap & seal' step

MATERIALS YOU WILL NEED:

- Modular Underdrain Panels
- 8oz Non-Woven Geotextile to line excavation
- Microgrid Mesh
- Washed Bridging Stone (Typically 3/8" - 1/2" pea gravel)
- High Flow Biofiltration Media
- Base Material (95% compactable angular stone (½" – 1½") or coarse sand
- Pipe Boot Kits (If not using kits, you will need duct tape and a stainless steel band clamp for each inlet and outlet pipe, and for each inspection or maintenance port.)
- Pipe for Inspection and Maintenance Ports (Typically 6" or 12" SCH 40 PVC)
- Pipe Cap & Serialized FocalPoint Identification Cover
- Gabion basket(s) or other energy dissipation device (If Specified)
- Rock (For Gabions or Flow Dissipation, if Specified)
- Aged, Double Shredded Hardwood Bark Mulch, which has been screened to remove fines
- 10-33mm EPDM, or other impermeable material sized to cover the surface of the media bed, if the system will not be immediately activated.

EQUIPMENT YOU WILL NEED:

- Forklift and other equipment/tools needed to unload box truck
- Walk behind trench roller (plate compactor may also work)

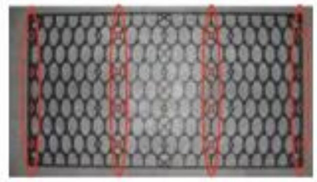
Note: This list does not include equipment or tools needed to excavate or level the floor of the excavation

FocalPoint
BIOFILTRATION SYSTEMS

1 ASSEMBLE MODULAR UNDERDRAIN

If Modular Underdrain units arrive on your project in flat panels they will need to be assembled on-site. Assembling the units should take 2-3 minutes per module. This is a conservative estimate used to approximate the total man hours needed for assembly. The estimate includes the workers doing the assembly as well as material handling people to keep the assembly workers moving.

Figure 1: Attach small plates at locations marked in red. The holes to be used for the middle panels are centered on an "X"



Unit	Mini	Single	Double	Triple	Quadruple	Penta
Time	2-3 minutes	2-3 minutes	4-6 minutes	6-9 minutes	8-12 minutes	10-15 minutes

Assembly Instructions – following the drawings in Fig. 2: Connect four small panels (B) into one large panel (A) using the short pegs (not the long pegs). Attach small panels onto the large panel at the locations marked in red on Fig. 1. Do NOT use the row of pin holes directly in the center or the two interior rows nearest the edges, as marked in red on Fig. 1.

Next, working from one end to the other, attach a second large plate (A) on the opposite side of the first.

Once the top and bottom large plates are attached, two more side plates (A) are attached to complete the sides of the Modular Underdrain unit. The picture in figure 2 shows is a SINGLE MINI Modular Underdrain. A single modular underdrain unit will be assembled in the same manner.

To build a DOUBLE unit (or larger), follow the directions above, starting at "Assembly Instructions:" using the top of the existing unit as the large plate. Bottom of the next module.

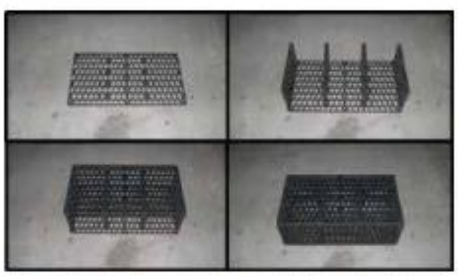


Figure 2: Follow these steps to assemble the underdrain units

Figure 3: Assembling on site during excavation will increase speed once the excavation is completed

TIP: To increase the speed of the installation, many contractors choose to assemble the Modular Underdrain units prior to or during excavation (Step 2) and base preparation (Step 3) (Fig. 3). Other contractors wait until these steps are completed and then perform the assembly IN THE EXCAVATION allowing completed units to be placed into their final location as they are assembled. Consider which option will work best for your project.

2 EXCAVATE

Excavate the designated area according to plans. Typical excavations should include:

- One foot perimeter around underdrain modules to allow for proper compaction of backfill
- Enough depth to accommodate a minimum 3" base (if required) below the underdrain modules

Figure 4: Excavation according to plans, following all governmental regulations

Level the bottom of the excavation (Fig. 4) as shown on plans. Most excavations have a flat bottom while some will slightly slope toward the outlet pipe.

Prepare the subgrade according to plans. This could require compaction for stability or prohibit compaction to promote infiltration.

If the subgrade is pumping or appears excessively soft, the design engineer should be consulted for advice. In many cases a stabilization geotextile and 6" of compactable material that drains well will be sufficient to amend the bearing capacity of the soil.

3 PREPARE BASE

Standing water in the excavation will prevent proper base preparation and must be removed, if present. In regions with sandy soils meeting the requirements noted and where the subgrade elevation is above the groundwater table, imported base materials may not be needed.

Base materials must be:

Compaction	95% Compaction (If infiltration is not a primary goal)
Shape	Angular
Size	Not larger than 1.5" in diameter
Consistency	Free of lumps, debris, and sharp objects that could cut geotextile
Applicability	Stone or coarse sand is acceptable if it meets requirements; In no case shall clays be used

Grade and level base as shown on plans.

TIP: Creating a smooth, level platform will allow for faster installation of Modular Underdrain, as units will fit together evenly, eliminating detail work that can delay your progress (Figure 5)

Figure 5: Base must be smooth to ensure units fit together without gaps

4 PLACE GEOTEXTILE ENVELOPE

Geotextile will be required on all FocalPoint HPMBS installations to separate the surrounding in-situ soils from the FocalPoint System. Check your plans to ensure that geotextile is to line your entire excavation, or will only be placed on the sides (if infiltration is a primary goal).

Cut full-width strips of Geotextile to the proper length and place them over the base and up the sides of the excavation, covering the floor and beyond walls of the excavation. This will be important in fulfilling step 11.

IMPORTANT: Allow enough geotextile to wrap the top of the system. This will aid in protecting the system until the site is completely stabilized and ready for activation.

Geotextiles are flammable. No smoking should be permitted on the geotextile.

Adjacent panels of material should be overlapped by 12" or more, as shown on the plans (Fig. 6).

Use pins, staples, sandbags or other ballast to hold the geotextile in place, preventing it from blowing or sliding out of position.

TIP: A prefabricated geotextile envelopes are available for smaller systems. This helps cut down waste and speeds up the installation process (Fig.7)

Figure 6: Roll out geotextile cut to fit the excavation in order to keep in-situ soils from migrating into the FocalPoint System. Geotextile strips must be cut generously in order to cover entire excavation on completion of the installation.

5 INSTALL MODULAR UNDERDRAIN

Determine the starting location. It is often helpful to use an inlet or outlet pipe to guide you. Using a string line, establish two adjacent edges of the Modular Underdrain footprint. Ensure that your corner is square. Mark these two edges with marking paint and remove the string line (Fig. 8).

5 INSTALL MODULAR UNDERDRAIN continued

Begin placing Modular Underdrain in the corner of the marked area. Do NOT place units on their sides, as this will void the warranty. Check your plans to ensure correct orientation of the Modular Underdrain (Fig. 9).

Check the plans to ensure the Modular Underdrain is running in the correct direction (North/South vs. East/West) to match the footprint shown.

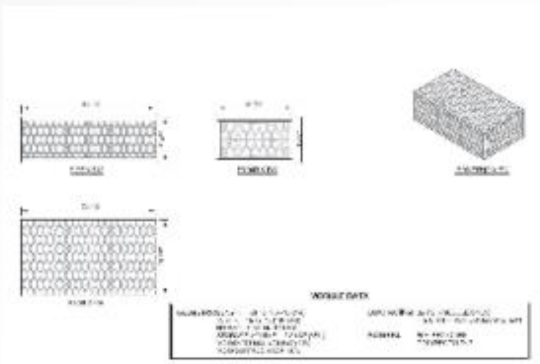


Figure 9: Make sure the tanks are oriented properly in the excavation.

Figure 8: Place modular underdrain in specified configuration within geotextile envelope.

Figure 9A: Minor Variations (less than width of top plate) in tank height are acceptable

Modular Underdrain units should fit together evenly. Minor gaps between units (< ½") or variations in the height of the units (< ½") are acceptable (Fig. 9A), but reasonable efforts should be made to minimize these variations. Minor gaps will be eliminated during compaction of side backfill material.

No lateral connections between adjacent underdrains modules are required.

6 INSTALL INSPECTION/MAINTENANCE PORTS

All ports should be made from pipe long enough to extend from the bottom of the Modular Underdrain to a point slightly above finished grade of the FocalPoint HPMBS. Taller is better, as the pipes can be trimmed on completion of the system installation. They are typically Schedule 40 PVC pipe, but can be formed from other types of pipe, as well.

Figure 11: 8" slots cut in to bottom of inspection port caps

Identify the location of all ports as specified on the approved drawings and remove the Underdrain Module(s) which will receive the port from each location.

Cut the pipe to length, leaving enough excess to trim the top when final grade is reached.

Cut several horizontal slots in the pipe starting at the bottom (Fig. 11). Slots should extend as high as the height of the lowest underdrain module being used. No perforations or slots should be visible above the top of the Modular Underdrain once the port is in place.

Using a reciprocating saw, cut the horizontal underdrain module plates in the center, between the two internal vertical plates, to receive the port (Fig. 12). Cut the openings for a tight fit around the port pipe. If the pipe specified will not fit between the two interior plates, one or both plates may be moved to the outer connection locations on the large plate . All horizontally oriented plates will need to be cut EXCEPT FOR THE BOTTOM PLATE. In total you will need to cut:

Unit	Cut
Mini & Single	1 plate
Double	2 plates
Triple	3 plates
Quadruple	4 plates
Penta	5 plates

TIP: If the location of the inspection ports is not shown on your plans, use a single inspection port located in the middle of the underdrain field. Install a port for every X sf of the underdrain system

IMPORTANT: Do not over-cut the Modular Underdrain plates. Minimize the gaps between the pipe and the Modular Underdrain plates. This is particularly important with the top plate.

For all units larger than a Single or Mini Underdrain Module, you will need to disassemble the Underdrain module in order to cut the interior horizontal plates. Reassemble the Underdrain Module when cutting is completed, and replace the Underdrain Module into the proper location.

TIP: If using Prefabricated Pipe Boot Kits, install them onto the pipe now, leaving the band clamps loose so that final adjustments may be made in Step 7.

Install the pipe into the Underdrain Modules.

Place the port pipe with pre-cut slots into hole. (Fig. 13). Be sure to cut the top of the pipe so that once the FocalPoint HPMBS Inspection Port Cap is placed onto the top of the pipe, the top of the Inspection Port Cap will be flush with or just above the finished grade. Once the pipe is in place, put the FocalPoint inspection port Cap or a temporary cap on the port to prevent debris from entering the system during backfill procedures (Fig. 14).

Figure 12: Cut 6" Hole into top panel of underdrain module to accommodate 6" pipe

Figure 13: Place inspection port into underdrain module

Figure 14: Cut inspection port to appropriate height stated on plans. Seal the opening on top of the pipe with the FocalPoint Inspection Port Cap or temporary lid

7 INSTALL MICROGRID MESH

Clean off any debris that may be lying on top of the exposed geotextile around the perimeter of the Modular Underdrain.

Cut strips of Microgrid Mesh to fit over the top and down both sides of the modular underdrain system. Adjacent strips of Mesh should overlap at least 12" or as shown on plans. Use rock bags or other ballast to temporarily secure overlaps (Fig. 15).

Where Modular underdrain intersects an Inspection or Maintenance Port, cut an "X" into the geotextile and pull it over the pipe. The flaps of the "X" should point AWAY from the Modular Underdrain (Fig. 16). Use stainless steel band clamp to seal the flaps to the pipe, being careful not to leave gaps that will allow bridging stone to enter the underdrain.

Figure 15 (Above): 12" overlap of Biaxial Mesh on top of underdrain module

IMPORTANT: Take special care with Inside Corners on the footprint of the system. Cut Microgrid Mesh as needed to ensure that it lays flat against the Modular Underdrain. Use additional pieces to seal the corner and any cuts that are made (12" overlap).

Figure 16 (Below): Cut an "X" into Biaxial Mesh to accommodate pipe penetration

Figure 17: fold corners flat against the tank

Fold Mesh for outside corners similar to sheets on a bed, and lay excess material flat against Modular Underdrain. Leave corners loose to avoid creating weak spots in the material. Temporarily secure excess fabric with duct tape (Fig. 17 left).

TIP: If using Prefabricated Pipe Boot Kits, install them onto the Inlet and Outlet Pipes, leaving the band clamps loose so that final adjustments may be made.

Connect Inlet & Outlet Pipes

Where the inlet and outlet pipes connect to an underdrain module or exits the excavation, cut an "X" into the Microgrid Mesh or geotextile so that the pipe runs through the Microgrid and makes DIRECT contact with the underdrain module (Fig: 18). Pull the flaps of the "X" cut over the pipe so that the flaps of the "X" point AWAY from underdrain module. Use a stainless steel band clamp to seal the flaps to the pipe, being careful not to leave gaps that will allow bridging stone to enter the underdrain.

Figure 18: Cut "X" in Biaxial Mesh and Geotextile to accommodate outlet pipes and seal with stainless steel band clamps

8 BACKFILL SIDES & TOP WITH PEAGRAVEL

Backfill bridging stone material around perimeter of the underdrain modules, distributing the material evenly to prevent shoving of the underdrain modules.

Use a trench roller, plate compactor, or hand tamper to compact backfill. When using taller underdrain modules, this placement and compaction should be done in 12" lifts.

Continue placing and compacting backfill around underdrain modules until the bridging stone reaches the top of the underdrain modules. Once bridging stone is level with the top of the underdrain, place 6" of bridging stone (or as specified) on top of underdrain modules (Fig 20).

Figure 19: Compaction of side is critical in order to keep soils from settling around the tank.

Figure 20 (Above): Place 6" of bridging stone on top of Microgrid Mesh

Figure 21 (Right): Use Inspection Port as marker for bridging stone depth

9 PLACE HIGH PERFORMANCE BIOFILTRATION SOILS

Level bridging stone and, place 6" of high flow media on top. Use marked stakes to ensure elevations. Once 6" of media has been placed, set Gabions (if applicable). Once Gabions have been installed, continue placing media until it is at the specified depth, (typically 18"). The top of the media should be 6" below the top of the gabion wall (if specified).

TIP: Before you place bridging stone use your inspection port to mark the different levels of fill as specified (Figure 20)

WARNING High Flow Media is a highly engineered soil - do not mix media with any other site, fill or excavated soils.

Figure 22: Place biofiltration soils, being careful not to mix with any other site soils, to specified depth

Figure 23: Level Soils once they are filled to specified depth

10 PLACE & FILL GABION (IF SPECIFIED)

(If gabion surround or leading edge is not specified continue to step 11)

Gabions are an optional feature that may not be included on your installation. If they are not included, skip this step and proceed to Step 11.

The gabion baskets are 12" tall. The interior dimensions of the gabion baskets needs to be equal to the exterior diameter of the underdrain unless specified otherwise. The top of the gabion should rise 6" above the top of the high flow media and 3" above the bark mulch.

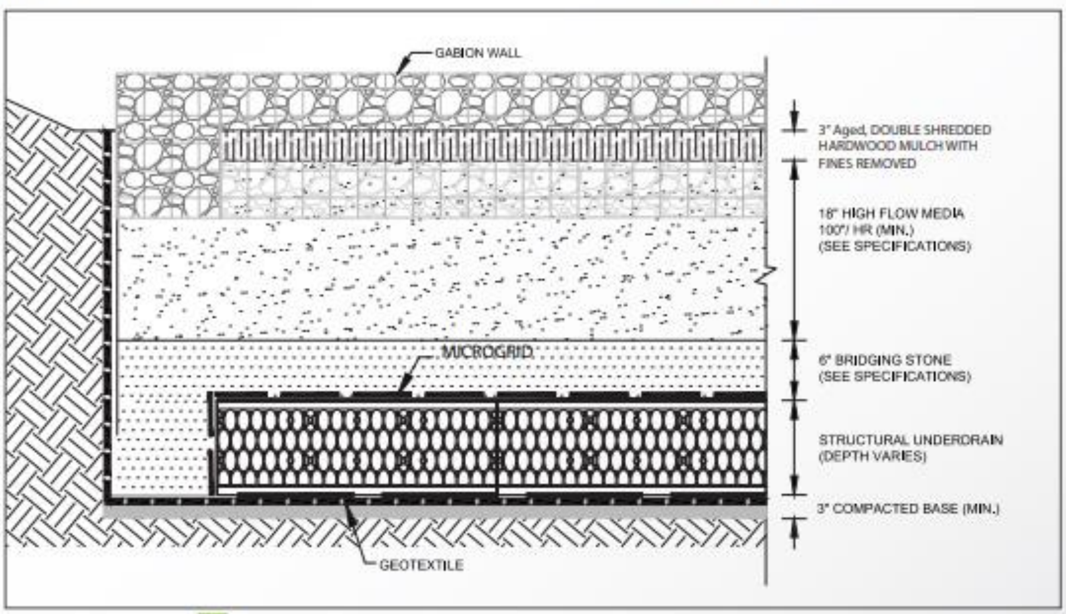
Place a geotextile separation barrier between the gabion and existing site soils as well as the gabion and media so that soil will not migrate into the rock creating a void. (Figure 24).

Once the gabion baskets are placed, overfill the gabions with 3" x 5" washed bull rock, or other specified material Once filled, seal the baskets with hog rings placed every three inches so that rock cannot be removed.

Figure 24: Place gabion wall so that it is square and level

Figure 25: Overfill rock into gabion and seal tight to prevent sagging. Rock will settle over time.

Figure 26



11 CAP & SEAL

This step protects the system if it is not to be immediately activated. The system should not be activated (plantings and mulch placed, and stormwater allowed to flow into system) until the surrounding drainage area reaches at least 90% stabilization. Premature activation and/or failure to carry out this 'cap & seal' step may invalidate the warranty on this system.

Protecting the FocalPoint HPMBS during construction is of the utmost importance. The sediment contained in the runoff from an un-stabilized drainage area may contaminate the biofiltration media, reduce the effectiveness of the FocalPoint HPMBS or cause failure.

Cut an appropriately sized piece of impermeable material (10-33mm) to fit the surface of the media bed. If multiple pieces are required, weld/glue them together to create an impermeable seal over the media bed.

Place the impermeable cover over the media bed.

Pull excess Geotextile Excavation Liner (see step 4) over the top of the FocalPoint System, fully cover the impermeable seal, overlapping the geotextile to fully prevent silt and sediment from reaching the seal and underlying media. Using a portable blow torch to 'heat weld' the geotextile and prevent the geotextile from moving or opening. You should practice this procedure on scrap material away from the system prior to attempting to do it over the system. Non-woven geotextiles are flammable and you must take extreme caution in doing this so that you do not leave the torch on the geotextile for too long. This procedure will create a perfect seam that will prevent sediment from bypassing the geotextile (Figure 29). If you cut your fabric too short, just make a patch for the uncovered area with another piece of geotextile, welding it all the way around.

WARNING
FAILURE TO INSTALL AND MAINTAIN ADEQUATE ESC PROTECTION FOR THE FOCALPOINT MAY VOID THE WARRANTY AND PERFORMANCE GUARANTEES.

Figure 30: A hose extension added to a blow torch.

TIP: If you add a hose extension onto the torch, it makes the procedure much easier.

Figure 29: Geotextile being melted together with a torch.

Once the system is capped and sealed, use a sign or any other warning mechanism to warn other contractors not to remove the cover until activation is authorized (Figure 31). This will protect the system until final stabilization. Other erosion control mechanisms may be required upstream of the FocalPoint HPMBS such as check dams, erosion control blankets, wattles or other best management practices. Please contact your local Convergent Value Added Reseller for suggestions.

Figure 31: FocalPoint Warning Sign

FocalPoint BIOFILTRATION SYSTEMS

12 ACTIVATE THE SYSTEM

Once 90% stabilization has been achieved; contact your local Convergent Water Technologies Value Added Reseller (www.convergentwater.com) for activation. Activation includes removing the protective 'cap and seal' cover on the biofiltration media bed and in situ testing of the media to insure that it meets performance specifications by means of an hydraulic conductivity test. This activation is provided by Convergent's VAR at no additional charge. At this time you may add specified plants to the media bed and the 3" non-floatable mulch layer if indicated (typical).

IMPORTANT:
The FocalPoint HPMBS should always remain capped until 90% stabilization is achieved and be the last thing planted to ensure that construction sediment does not enter the system.

Figure 33: Planted FocalPoint HPMBS

Figure 32: Protected FocalPoint HPMBS

WARNING

FAILURE TO CONFORM TO THIS STEP MAY VOID THE WARRANTY AND PERFORMANCE GUARANTEE. FOR THE FOCALPOINT HPMBS ACTIVATION CHECKLIST, CONTACT YOUR VALUE ADDED RESELLER.

13 PLANTINGS & MULCH

Placing the Plants:

1. Dig planting holes the depth of the root ball and two to three times as wide as the root ball. Wide holes encourage horizontal root growth that plants naturally produce.

2. With trees, you must ensure you are not planting too deep!! Don't dig holes deeper than root balls. The media should be placed at the root collar, not above the root collar; otherwise the stem will be vulnerable to disease.

Planting:

1. Remove plastic containers from container-grown plants. For plants in fiber pots, break away the top or remove the pot entirely.

2. If roots are circling around the root ball exterior, cut through the roots in a few places and remove the first inch of roots and planting material around the root ball. Cutting helps prevent circling roots from eventually girdling the trunk. If roots are not circling, the root ball should still be rubbed to loosen roots and promote growth into the media.

3. Remove tags and labels from plants.

4. Prune broken branches or suckers.

5. Only stake trees with large crowns, or those situated on windy sites or where people may push them over. Stake for a maximum of one year. Allow trees a slight amount of flex rather than holding them rigidly in place. Use guying or attach material that won't damage the bark. To prevent trunk girdling, remove all guying material after one year. Insure that stakes do not penetrate the bridging stone or underlying modular drainage system.

6. Plants should be watered at planting, especially during drought periods.

SPACING		
Type of Planting	**Rootball Size**	**Spacing on Center**
Shrubs	< 1 gallon	24 inches
Shrubs	5 gallons	42 inches
Shrubs	15 gallon	60 inches
Clump Grasses		24 inches
Small Trees		12 feet

DO NOT:

- Mulch in excess of 3 inches
- Compact media around the root ball
- Do not use annuals
- Keep in mind that some perennials (i.e. daylilies, hostas, etc…) die back in fall and re-emerge in spring. If you want greenery year round, be mindful of the perennials used.

Mulching:

Cover the exposed root ball top with mulch. No mulch volcanoes! Mulch should not touch the plant base because it can hold too much moisture and invite disease and insects. Evenly place 3 inches of double shredded, aged hardwood mulch which has been screened to remove fines, on the surface of the media (if specified).

Erosion Control:

Where water is entering a focal point in one location, be sure to place erosion control stones or other scour prevention BMP to prevent scouring

14 PERFORMANCE VERIFICATION

The Rub-I Infiltrometer is the most effective way to field verify engineered soil performance, construction and long term verification of performance. The Rub-I was designed to test the effectiveness of high flow soils and to ensure post control. Current ASTM standards for infiltration testing are not valid for flow rates exceeding 16 in/hr. To ensure the highest level of effectiveness, Convergent specifies that the FocalPoint HPMBS be tested within 60 days of installation and we recommend the system be tested annually thereafter to provide ongoing quality assurance.

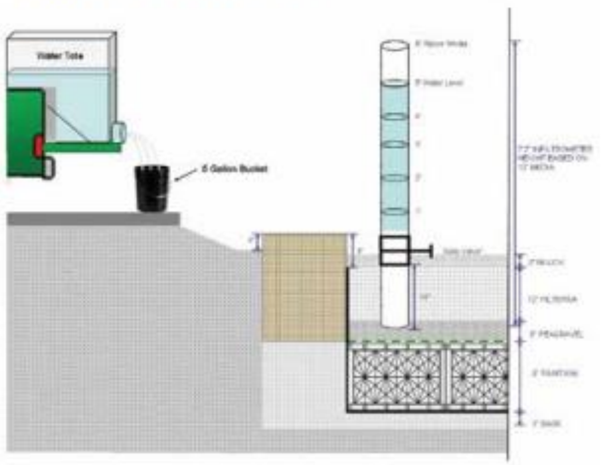
Objective:

To provide as-built confirmation of proper installation and hydraulic performance, to meet minimum high flow rate Infiltration rate requirements, of bioretention media on newly-placed bioretention systems. This procedure measures the entire media profile under saturated conditions to insure a reliable and accurate result.

Example Site Test Layout and Design Schematic:

(FSA = filter surface area, DA = drainage area)

For bioretention systems with a surface area less than 538 sf, in situ hydraulic testing should be conducted at one to three points that are spatially distributed. For systems with a surface area greater than 50 sf, an extra monitoring point should be added for every additional 1076 sf. (Values are based on recommendations from the Facility for Advancing Water Biofiltration.) Testing should be performed near the perimeter since this is the area most likely to be impacted by sediment in the runoff.



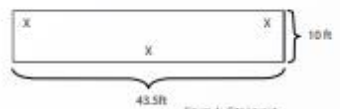


Figure 1: Site Layout

Media Depth (inches)	Max Drawdown Time (min:sec)
12	18:18
14	21:24
16	24:18
18	27:00
20	29:30
22	31:54
24	34:06
26	36:12
28	38:12
30	40:00
32	41:42
34	43:24
36	44:54
38	46:18
40	47:42
42	49:00
44	50:12
46	51:24
48	52:30

Test Methodology:

In an area near the location you plan to test, gently scrape away any material covering (e.g. mulch, gravel, leaves) filter media surface and confirm media profile depth by using a shovel to dig to under drain stone and place measuring tape in hole to determine depth from top of under drain stone to top of media bed. A flash light may be needed to ensure the under drain stone has been reached before a depth measurement is taken. Make every effort to minimize disturbance of surrounding media and underlying bridging stone.

FocalPoint
BIOFILTRATION SYSTEMS

14 PERFORMANCE & VERIFICATION *continued*

Figure 3: Hammering Pipe Into Media

Figure 4: Pipe Installed Into Media

Figure 5: Oil Application

Figure 6: Dissipater Stones

1. At the test location carefully clear away mulch without disturbing the underlying media and place base component of the Rub-I infiltrometer, a 6" PVC pipe (beveled end down), on the surface of the media. Ensure testing is not too close to vegetation. Place the wooden board over the pipe and then gently pound with the sledge hammer on top of the board (Figure 3). Hammer the PVC pipe into the entire media profile based on the depth previously determined, until it just breaches into the bridging stone. Drive the pipe straight down, avoiding tilt in any direction (Figure 4). Check with level. Note: It is important that the pipe is driven in slowly and carefully to minimize disturbance of the filter media profile. The media may slightly move downward in the pipe during hammering, but not more than 1 inch, and will not significantly affect hydraulic performance.

2. If pipe is less than 3 inches from media surface, remove media around outside of pipe so that the pipe has 3 inches of freedom from the media bed so that the infiltrometer gate valve coupling will properly slide onto the pipe.

3. Remove board and rub mineral oil on outside of PVC pipe above media (Figure 5).

4. Place 2 inch dissipater stones into pipe (Figure 6).

5. Slide gate valve with clear PVC cylinder down onto the PVC pipe in the media (Figure 7). Note: Disregard black coupling on clear pipe as well as pipe plug in this image.

6. Measure from the original surface of the media within the column to 1 ft, 2 ft, 3 ft, 4 ft and 5 ft gradations, and mark them on the clear PVC cylinder (Figure 8). The 1 ft and 5 ft marks are the critical marks, since the time to fall between these two intervals will provide the pass/fail time for the test. (The time at other intervals between 1 ft and 5 ft can be recorded for additional information, but will not be used in the pass/fail criteria).

7. Fill a 5 gallon bucket with 3 gallons of water.

8. Ensure the gate valve to the infiltrometer is closed. Fill with the 3 gallons of water (Figure 9). To create a worst case flow rate scenario (i.e. saturated condition), an initial wetting of the media using the infiltrometer is conducted by opening up the gate valve completely. The gate valve should be slowly opened by tapping on the handle with a hammer or wrench to prevent disturbance of the media surface by a sudden high flow of water. Pulling open by hand tends to force the valve open too quickly.

9. After the water level disappears from the clear column, a drain down time of 25 minutes is allowed to ensure free water has drained through the media.

10. After 25 minutes, ensure the gate valve is closed. Fill the 5 gallon bucket with water and continue to fill the column until water level reaches the very top of the clear pipe. Water is then re-introduced by opening the gate valve slowly by tapping the handle. A stopwatch should be started as the water level reaches 5 ft gradation and recorded at every 1 ft gradation. The stopwatch is stopped when the water level reaches the 1 ft mark.

11. Pass/fail criteria is based on maximum drawdown times (Table 1). For example, a media profile depth of 12 inches should not exceed a drawdown time of 18 minutes and 18 seconds between the 5 ft and 1 ft gradations.

For bioretention systems with a surface area less than 538 sf, in situ hydraulic testing should be conducted at one to three points that are spatially distributed. For systems with a surface area greater than 50 sf, an extra monitoring point should be added for every additional 1076 sf. These values are based on recommendations from the Facility.

Figure 7: Infiltrometer Placement

Figure 8: Gradation of Clear Pipe

Figure 9: Filling Infiltrometer with Water

For information on components & assembly of Rub - I Infiltrometer see the SOP (Standard Operating Procedure) document available from your Convergent VAR

Appendix H - Raw ICS Data Table

Sample Locations	Iron (ppm)	Copper (ppm)	Zinc (ppm)	Arsenic (ppm)	Lead (ppm)	Sodium (ppm)	Potassium (ppm)	Aluminum (ppm)	Vanadium (ppm)	Chromium (ppm)	Phosphate (ppm)	Nitrate (ppm)	Sulfate (ppm)	Chloride (ppm)	Flouride (ppm)
Gray Rf	0.0393	0.005	1.069	0	0	1.594	0.6196	0.004	0	0	0	1.01894	1.175104	2.480844	0.0100431
Green Rf	0.0856	0.0143	0.171	0	0.001	1.507	0.408	0.0696	0	0	0.055245	0.0193	3.708049	3.257041	0.0321145
Salisbury Est.	0.1195	0.004	0.0145	0.0015	0.0005	5.109	5.334	0.043	0	0.002	0.177536	0	2.14988	8.181174	0.0237856
Salisbury Rd.	0.2525	0.0115	0.039	0.001	0.002	7.1705	3.833	0.0465	0	0.0015	0.360871	0.22553	3.038844	10.07856	0.062023
SP	0.43	0.008	0.036	0.006	0.003	1.366	31.539	0.291	0.002	0.001	0.995162	0.01736	0.166876	0.415036	0
Grassy Hill near SP	2.5565	0.0075	0.033	0.0165	0.017	3.422	25.855	0.6685	0.003	0.001	0.857577	0.00404	0.318256	1.440621	0.0004823
Grassy Hill near ST	0.055	0.003	0.032	0.001	0.001	2.531	3.778	0.036	0	0	0.281732	0	2.208152	4.393436	0.0117959
Rainwater	0.009	0.002	0.01	0	0	1.282	0.517	0.008	0	0	0	3.37473	1.195807	1.843776	0.0059104

Appendix I - Raw TSS Data

Location name	# of TSS Samples	Total volume sampled	Average TSS (mg/L)
Green Roof	5	1350 ml	3.2
Gray Roof	5	2000 ml	1.0
Salisbury St.	2	450 ml	22.8
Salisbury Estates	2	650 ml	19.9
Grassy Hill near SP	2	122 ml	794.5
Salisbury Pond	1	100 ml	28.0

Appendix J - Raw TP Data

Location	Sample ID	Absorbance	Calculated conc. of P (ppm or mg/L)
Rainwater	RW1	0.021	0.25
Gray Roof	GRA3	-0.033	0.03
Green Roof	GRE3	-0.022	0.07
Salisbury Pond edge	SP1	1.509	6.41
Skull Tomb grassy hill	SK1	0.037	0.32
Salisbury St	SS1	0.040	0.33
Grassy hill Salisbury Pond	GH1	1.556	6.61
Salisbury Estates	SE1	-0.008	0.13

Appendix K - Proposal

Worcester Polytechnic Institute

Improving Stormwater Management for the Salisbury Pond Area

A Major Qualifying Project
Submitted to the Faculty of
Worcester Polytechnic Institute

Authors:

Jeffrey Desjardins, Morgan Emery, Fernand Gay, Edie Hudson, and Meghan McCudden

Advisor:

Paul Mathisen

Sponsor:

Nitsch Engineering

4/28/2022

Table of Contents

List of Acronyms

BMP - Best Management Practices

CWA - Clean Water Act

DO - Dissolved Oxygen

EPA- Environmental Protection Agency

GIS- Geographic Information System

ICPMS- Inductively Conducted Plasma Mass Spectrometer

ICS- Ion Chromatography Spectrometer

MassDEP- Massachusetts Department of Environmental Protection

NPDES - National Pollutant Discharge Elimination System

TP- Total Phosphorus

TSS - Total Suspended Solids

WPI - Worcester Polytechnic Institute

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Authorship

Fernand Gay - Fernand wrote four of the methodology sections (3.0, 3.3,3.4, 3.5).

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All other sections not specifically mentioned were written as a group, and everyone continuously edited each other’s work.

Abstract

Stormwater runoff absorbs various pollutants carrying them into larger bodies of water and groundwater. This contamination can negatively impact certain bodies of water along with their aquatic life since many pollutants alter the physical and chemical properties of stormwater runoff. Through sampling, testing, and analyzing the quality of local runoff for the areas surrounding Salisbury Pond, this project developed and recommended applicable stormwater Best Management Practices (BMPs) to minimize the local contributions to surface water pollution in Salisbury Pond.

Executive Summary

Contaminated stormwater runoff is a major source of water pollution for urban areas. When precipitation or storm events occur, the resulting stormwater flows across impervious surfaces collecting numerous harmful pollutants and solids, eventually carrying these pollutants into larger bodies of water, or discharging them into the ground. Contaminated stormwater runoff can cause very serious public health issues, which also hurts the environment and economic stability of the area. With seasonal flooding from heavy rainfall events, drainage systems are needed to redirect stormwater runoff, and manage or treat it. While these drainage systems are helpful in the process of managing stormwater, they can also frequently be a gateway for pollutants to enter water bodies as well. This is why Best Management Practices (BMPs) are useful for treating stormwater before it flows into larger bodies of water.

Salisbury Pond, an impounded water body adjacent to WPI in Worcester, MA, has been experiencing these problems due to stormwater runoff. A number of studies have shown that the pond receives large loads of sediments, nutrients, and other contaminants from upstream runoff. The contributions of local runoff from the adjacent areas have not been accurately determined. These contributions depend on the quality of runoff from different land surface types, which is also not well defined.

The goal of this project was to help mitigate the effects of stormwater runoff on Salisbury Pond, by analyzing runoff from different areas around the pond and campus and developing feasible recommendations for mitigating the impacts of this runoff. For our project, we partnered with the environmental consulting company Nitsch Engineering, Inc. Nitsch has specialized in providing civil engineering, land surveying, transportation engineering, structural engineering, green infrastructure, planning, and GIS services since 1989. For our project, Nitsch Engineering was interested in sampling and testing water quality, for the purposes of understanding the effects of land surfaces on the quality of stormwater runoff. The various surface types in Salisbury Pond provided a valuable case study for assessing these effects. To successfully make recommendations and designs for managing and treating stormwater, we had to first do research on BMPs and contamination.

After gathering information on these topics, we needed to sample from specific locations around the campus area, for the purpose of analyzing contamination and flow across different surface types, or land areas. Completing that analyzation process would then allow us to develop

our recommendations, based on the needs of chosen areas. Thus, after sampling we had to perform our lab testing to obtain contamination levels for analysis. The data analysis consisted of determining the levels of total suspended solids (TSS), total phosphorus, iron, copper, lead, sodium, potassium, aluminum, magnesium, calcium, phosphate, nitrate, sulfate, chloride, and fluoride. Using ArcGIS, the watershed catchments around Salisbury Pond were determined, as well as the areas, the slopes, and the land use of the catchments. This information was used for hydrologic modeling with HydroCAD, a stormwater modeling software. From HydroCAD, we were able to determine the drainage velocities, the impervious versus pervious area for the pond catchments, and the overall runoff quantification. Once the watershed was characterized and the runoff was quantified, recommendations and designs were developed for managing and treating the stormwater runoff.

Using the data we gathered, we then integrated our findings with future work being done for Institute Park and Salisbury Pond. We developed three recommendations for improving the management of stormwater going into Salisbury Pond, one of which being a design for the Salisbury Estate Area, an apartment complex located adjacent to the pond. This design would treat the stormwater runoff coming from Salisbury Estates right by the main parking lot. The other two recommendations would be one for treatment, and another for pre-treatment.
We developed another treatment recommendation for the Firefighter Memorial Walkway located right next to the O'Connell Football Field. The BMP walkway already constructed there already provides treatment and pre-treatment. However, there is an area directly in front of the walkway and filtration garden located there, where an additional forebay, or bioretention system, could be constructed. This would provide a treatment system to handle all of the flow there.

The final pre-treatment recommendation which we developed, would be for the grassy hill area near the rotunda on the main side of the pond. We determined that the slope and TSS loading there would be more properly managed if there were at least some basic pre-treatment for runoff coming from that area, to reduce flooding and turbidity in the water. Overall, these BMPs should mitigate the impacts of stormwater runoff to Salisbury Pond by reducing the amounts of Total Suspended Solids, Total Phosphorus, sodium, and chloride entering the pond.

In completing this project, we wanted to target new ways of tackling and managing stormwater. We also wanted to provide a good basis for future project groups, and research going forward as well. Thus, our finished deliverables included a poster for presentation, along with our report, and a presentation of our design and recommendations.

Capstone Design Statement

This Major Qualifying Project (MQP) satisfies the design capstone component required for graduation by WPI's Department of Civil and Environmental Engineering. This design component is required for the program's accreditation by ABET and the American Society of Civil Engineers (ASCE). According to ABET, a capstone design experience should include engineering standards and multiple constraints, as well as skills and knowledge learned in previous coursework (ABET, n.d.). This project included designing a Best Management Practice (BMP) for the WPI Townhouses of the WPI campus to mitigate stormwater pollution. While working on possible designs to improve stormwater quality, the MQP team considered social, environmental/sustainable, and economic constraints.

Social: Before designing any BMP, the team needed to consider who would be impacted by this project. This project is for the WPI campus, with a focus on the areas near the WPI Townhouses and Institute Park. Because these areas have residential students and faculty living or working there, the team needed to make sure to accommodate their needs and try not to disrupt their lives. Additionally, as the park is a public space, the team made sure not to disrupt or bother the public. In fact, through proper stormwater mitigation, the team hoped to improve public health and enjoyment of the open space. Also, the design and project needed to abide by the policies set by WPI to maintain safety and regulations.

Environmental/Sustainable: As the goal of this project was to mitigate effects of stormwater with a BMP, the design should hopefully improve the environment on campus. When designing the BMP, the team considered the materials and construction involved with the design so that there isn't any negative environmental impact. To ensure that the environmental impact of a new design isn't harmful, the team considered possible green infrastructures as a BMP.

Economic: Lastly, as this project would be built at WPI's behest, the team considered the economic aspects of their design. Our final design should be effective at removing pollutants in stormwater without being costly to build or for WPI to maintain.

Professional Licensure

The National Council of Examiners for Engineering and Surveyors (NCEES) recommends that engineers become professionally licensed to protect the “health, safety, and welfare of the public” (NCEES, n.d.). Essentially, professional licensure ensures public safety by restricting practice to engineers who have proven their competence in the profession. Professional Engineers (abbreviated as PEs) are able to prepare, sign, and seal engineering plans to be submitted for approval by a public authority (National Society of Professional Engineers, n.d.). Because their licensure allows them more responsibilities, PEs tend to be paid more than their non-licensed counterparts (National Society of Professional Engineers, n.d.). Engineers are licensed at the state level, and each state has its own requirements for an engineer to become professionally licensed. However, the minimum qualifications for most states are met through a combination of education, experience, and exams. The basic pathway to become a PE is as follows:

- Attend an EAC/ABET-accredited college and earn a bachelor’s degree.
- After graduation, take (and pass) the NCEES Fundamentals of Engineering (FE) exam to become an Engineer in Training (EIT).
- Gain four years of relevant engineering experience by working under a PE.
- Finally, take the NCEES Principles and Practice of Engineering exam to become a licensed PE (NCEES, n.d.).

1.0 Introduction

Water is often called “the universal solvent” due to its ability to dissolve such a significant number of elements and compounds. We all can realize how effective water is at washing away a large variety of particles since we utilize it every day to wash our clothes, dishes, hands, and more. In the same washing manner, when water from rain and snowstorms (i.e., stormwater runoff) flows across land surfaces, it absorbs and washes away many particles including dirt, trash, chemicals, and animal waste. Most stormwater runoff eventually flows into nearby rivers, ponds, and lakes, resulting in the contaminants that it washes away also ending up in bodies of surface water.

Protecting and regulating the quality of surface water has been a focus in our country since 1948 when the Federal Water Pollution Control Act was first passed. In 1972, the Act was developed and updated to the Clean Water Act (CWA). These acts established the structure for limiting pollution discharges into the nation's bodies of water and maintaining quality standards of the surface water. The National Pollutant Discharge Elimination System (NPDES), managed by the Environmental Protection Agency (EPA), actively regulates stormwater pollution at industries and construction sites, but much of the pollution washed into bodies of water by stormwater runoff is a result of events like animal excretion, littering, washing vehicles, and maintaining lawns (NPDES Stormwater Program | US EPA, 2022). Pesticides and fertilizers are widely utilized for improving growth of plants and grass; however they often contain significant amounts of phosphorus, nitrogen and potassium that when in excess can be washed away by stormwater runoff. Animal excrement of pets and local wildlife which contains significant amounts of phosphorus and nitrogen also affects the quality of stormwater runoff. These impacts also pertain to Salisbury Pond, the pond adjacent to Worcester Polytechnic Institute’s campus. By understanding how these different contaminants impact aquatic environments, we can work to better manage and protect surface water bodies.

Phosphorus, nitrogen, and other elements are necessary nutrients to the environment since they are consumed by plants and soil microbes for growth. However, excessive levels of certain elements can be dangerous to the health of aquatic systems as it causes eutrophication which is accelerated growth of algae and large aquatic plants. This leads to decreased dissolved oxygen (DO) levels in the water, leaving other aquatic plants and fish oxygen depleted. In severe cases the accelerated growth of algae can create algae blooms which also release algal toxins harmful to the quality of air.

The ultimate goal of this project is to reduce the negative impacts stormwater runoff has on Salisbury Pond by recommending well-designed practices to minimize the stormwater runoff flow and contaminant load. By examining the area around Salisbury Pond, mapping the contributing stormwater runoff, collecting samples of stormwater, and conducting lab tests on the samples, we were able to analyze the quality of local stormwater runoff regarding common contaminants based on location. From here, the recommendations of applicable stormwater Best Management Practices were developed to minimize the contaminant load of stormwater runoff relative to Salisbury Pond.

2.0 Background

This chapter provides relevant information on topics related to stormwater runoff, its effects on the environment, and how it is managed. First, information regarding stormwater runoff and common contaminants is presented, then this section looks at topics such as stormwater regulations and best management practices, which will be referenced later in the design process of the project. Finally, previous collaborations with Nitsch on stormwater projects are discussed, as well as other case studies examining the impact of land use on stormwater runoff.

2.1 Stormwater

Pollutants that are spread through stormwater runoff are a lesser known, yet impactful, danger to our environment. Stormwater runoff occurs when precipitation slides across hard, impervious surfaces, picking up contaminants along the way, until it eventually gets soaked up into the ground, goes down a catch basin or flows into a body of water. In Massachusetts, stormwater is the single largest source for water quality impairment in the state's open bodies of water (MassDEP, 2008a). Runoff contaminants include various different types of materials that get picked up on the journey, some more harmful than others.

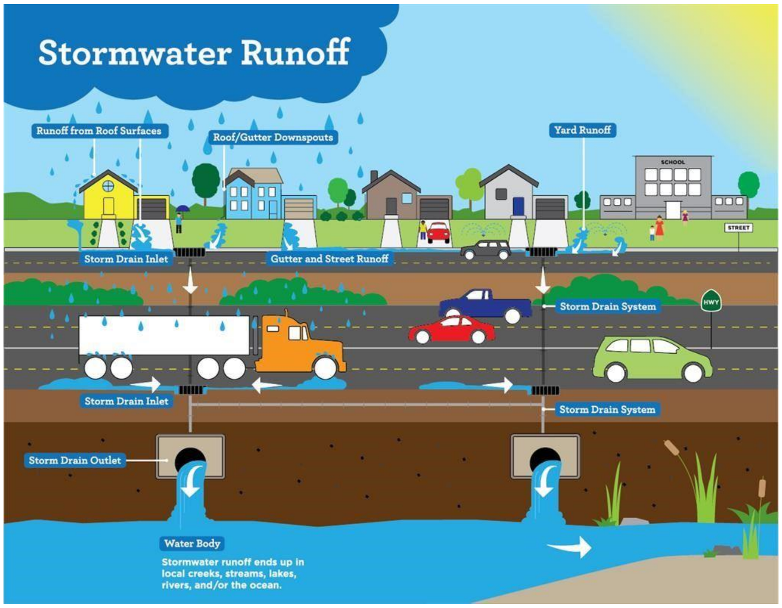

Figure 1*: Illustration of Stormwater Runoff (City of Bainbridge, n.d.)*

2.2 Common Contaminants

A majority of contaminants that get transported are results of human activity. A few of the substances that are commonly identified in stormwater runoff include pesticides, grease, antifreeze, and other everyday materials that can be dangerous to the environment. The main contaminants that these substances leave off are phosphorus, nitrogen, TSS (Total Suspended Solids), and heavy metals.

Phosphorus and nitrogen are naturally occurring nutrients essential to plants and animals. However, when there is an overabundance of them present, they can turn out to cause adverse health effects and detrimental ecological imbalances (USGS, n.d.). The primary sources of these nutrients in stormwater runoff include yard waste, pet waste, fertilizer, manure, and organic wastes (EPA, 2013c and USGS, n.d.). Both nitrogen and phosphorus have adverse effects on bodies of water when in high concentrations. This is because once the balance in which the rate of algae grows is thrown off, it can result in an overgrowth. Algae overgrowth in a lake, for example, can deplete the oxygen levels and essentially "suffocate" a lake and the living organisms that reside in them (EPA, 2013b and USGS, n.d.). This process is termed eutrophication, where an excess of nutrients in a body of water causes an accelerated growth of plant life and a death of animal life due to "dead zones" areas with little to no oxygen in the water (EPA, 2013a).

Figure 2*: Algae Overgrowth Near a Residential Community (EPA)*

Total suspended solids are particles greater than two microns found in water. TSS includes both inorganic and organic materials. These solids come from vehicle emissions, construction, road salt, pedestrian debris, atmospheric deposition of particles, and many other sources (Minnesota Stormwater Manual, 2021). Like phosphorus and nitrogen, TSS can also cause oxygen-depriving algal blooms, but there are a few other problems this contaminant can bring to bodies of water. Suspended solids that end up on the floor of a body of water can result in clogging and can end up altering their topography. Another high risk of TSS is its impact on the turbidity of water. Turbidity is the cloudiness in water that can block out sunlight, reduce light absorption, and negatively affect the natural balances of aquatic life.

Additional stormwater contaminants include heavy metals such as copper, zinc, cadmium, nickel, chromium, mercury, and lead. Sources of these metals include vehicle emissions, construction, and other industrial activities; when mildly acidic precipitation comes in contact with these metals, these metals can be dissolved and carried into bodies of water. Heavy metal contaminants are most commonly found in highly developed urban stormwater runoff due to the great amount of parking lots, roads, construction, and industrial activities (Brooks Applied Labs, 2016).

2.3 Stormwater Regulations

Stormwater regulation occurs at both a national and state level. In 1972, the National Pollutant Discharge Elimination System (NPDES) was created as part of the Clean Water Act to address water pollution in the United States. Per the Clean Water Act, NPDES regulates point sources of pollution to water through its permit controls: technology-based limits and water quality-based limits (EPA, 2015a). Regarding stormwater, the NPDES program regulates stormwater runoff from three potential sources. These sources are municipal stormwater sewer systems (MS4s), construction activities, and industrial activities. Typically, people who operate these sources must obtain a NPDES permit before they can discharge any stormwater (EPA, 2015b).

Acceptable amounts of runoff contaminants differ from state to state. In Massachusetts, the Stormwater Policy was issued in 1996, and the Massachusetts Stormwater Handbook was released the following year. The Massachusetts Stormwater Handbook was most recently updated in 2008 to improve treatment of runoff and promote pollution prevention (MassDEP, 2008a). MassDEP has also identified certain standards that stormwater management systems must meet in order to be implemented. The Stormwater Management Standards "address water quality and water quantity by establishing standards that require the implementation of a wide variety of stormwater management strategies" (MassDEP, 2008a). These standards are applied based on the Massachusetts Wetlands Protection Act, as well as the Massachusetts Clean Waters Act (MassDEP, 2008a). The standards in the handbook are summarized below:

11. No new stormwater conveyances may discharge untreated stormwater directly to or cause erosion in wetlands or waters of the Commonwealth.

12. Stormwater management systems shall be designed so that post-development peak discharge rates do not exceed pre-development peak discharge rates.

13. Loss of annual recharge to groundwater shall be eliminated or minimized through the use of infiltration measures including environmentally sensitive site design, low impact development techniques, stormwater best management practices, and good operation and maintenance. At a minimum, the annual recharge from the post-development site shall approximate the annual recharge from pre-development conditions based on soil type. This Standard is met when the stormwater management system is designed to infiltrate the required recharge volume.

14. Stormwater management systems shall be designed to remove 80% of the average annual post-construction load of Total Suspended Solids (TSS).

15. For land uses with higher potential pollutant loads, source control and pollution prevention shall be implemented in accordance with the Massachusetts Stormwater Handbook to eliminate or reduce the discharge of stormwater runoff from such land uses to the maximum extent practicable.

16. Stormwater discharges within the Zone II or Interim Wellhead Protection Area of a public water supply, and stormwater discharges near or to any other critical area, require the use of the specific source control and pollution prevention measures and the specific structural stormwater best management practices determined by the Department to be suitable for managing discharges to such areas, as provided in the Massachusetts Stormwater Handbook.

17. A redevelopment project is required to meet the following Stormwater Management Standards only to the maximum extent practicable: Standard 2, Standard 3, and the pretreatment and structural best management practice requirements of Standards 4, 5, and 6. Existing stormwater discharges shall comply with Standard 1 only to the maximum extent practicable. A redevelopment project shall also comply with all other requirements of the Stormwater Management Standards and improve existing conditions.

18. A plan to control construction-related impacts including erosion, sedimentation and other pollutant sources during construction and land disturbance activities shall be developed and implemented.

19. A long-term operation and maintenance plan shall be developed and implemented to ensure that stormwater management systems function as designed.

20. All illicit discharges to the stormwater management system are prohibited (MassDEP, 2008a).

In Massachusetts, whether one or more BMPs are being utilized, the practice(s) must have a cumulative effect of at least 80% TSS removal. According to the Massachusetts Stormwater Handbook Volume 1 Chapter 2, TSS includes contaminants such as nitrogen and phosphorus. It is noted that if other particular contaminants need to be removed, there are other standard guidelines to be in compliance with. One method of ensuring 80% TSS total removal is to implement one BMP and calculate the amount of TSS removed. For example, if results come out to 60% TSS removed, then another BMP may be added to get rid of the other 20%. The following table describes different Best Management Practices for the removal of TSS and the effectiveness of each (MassDEP, 2008c).

Table TSS

TSS Removal Efficiencies for Best Management Practices	
Best Management Practice (BMP)	**TSS Removal Efficiency**
Non-Structural Pretreatment BMPs	
Street Sweeping	0-10%, See Volume 2, Chapter 1.
Structural Pretreatment BMPs	
Deep Sump Catch Basins	25% only if used for pretreatment and only if off-line
Oil Grit Separator	25% only if used for pretreatment and only if off-line
Proprietary Separators	Varies – see Volume 2, Chapter 4.
Sediment Forebays	25% if used for pretreatment
Vegetated filter strips	10% if at least 25 feet wide, 45% if at least 50 feet wide
Treatment BMPs	
Bioretention Areas including rain gardens	90% provided it is combined with adequate pretreatment
Constructed Stormwater Wetlands	80% provided it is combined with a sediment forebay
Extended Dry Detention Basins	50% provided it is combined with a sediment forebay
Gravel Wetlands	80% provided it is combined with a sediment forebay
Proprietary Media Filters	Varies – see Volume 2, Chapter 4
Sand/Organic Filters	80% provided it is combined with sediment forebay
Treebox filter	80% provided it is combined with adequate pretreatment
Wet Basins	80% provided it is combined with sediment forebay
Conveyance	
Drainage Channels	For conveyance only. No TSS Removal credit.
Grass Channels (formerly biofilter swales)	50% if combined with sediment forebay or equivalent
Water Quality Swale – wet & dry	70% provided it is combined with sediment forebay or equivalent
Infiltration BMPs	
Dry Wells	80% for runoff from non-metal roofs; may also be used for runoff from metal roofs but only if metal roof is not located within a Zone II, or IWPA or at an industrial site
Infiltration Basins & Infiltration Trenches	80% provided it is combined with adequate pretreatment (sediment forebay or vegetated filter strip, grass channel, water quality swale) prior to infiltration
Leaching Catch Basins	80% provided a deep sump catch basin is used for pretreatment
Subsurface Structure	80% provided they are combined with one or more pretreatment BMPs prior to infiltration.
Other BMPs	
Dry Detention Basins	For peak rate attenuation only. No TSS Removal credit.
Green Roofs	See Volume 2. Chapter 2. May reduce required water quality volume. No TSS Removal Credit.
Porous Pavement	80% if designed to prevent runon and with adequate storage capacity. Limited to uses identified in Volume 2, Chapter 2.
Rain Barrels and Cisterns	May reduce required water quality volume. No TSS Removal Credit.

***Figure 3**: MassDEP Table Displaying BMPs and Respective Efficiencies (MassDEP, 2008c)*

2.4 Best Management Practices

In the realm of stormwater treatment, discoveries are being made every day. Scientists have begun to search for greener solutions to stormwater treatment in various different ways. BMPs, or Best Management Practices, are one of the primary ways in which stormwater is treated sustainably. Originally, BMPs were used strictly in the realm of hydrology, to help mitigate the effects of flooding and natural hydrologic issues that arose. However, with increased traffic and construction in the modern day, BMPs have been restructured to help mitigate the increased effects of pollution as well.

The EPA defines Best Management Practices (BMPs) as techniques, measures, or structural controls used to manage volume and quality of stormwater runoff (OC Public Works, n.d.). According to the EPA, BMPs should "filter out pollutants and/or prevent pollution by controlling it at its source" (EPA, 2015b).

According to the *Massachusetts Stormwater Handbook*, MassDEP categorizes BMPs into five classes: Structural Pretreatment, Treatment, Conveyance, Infiltration, and Other BMPs which do not fit into the previous four classes (MassDEP, 2008c).

Structural Pretreatment BMPs collect the first flow of stormwater during a rain event. This class removes large sediment particles to prevent the clogging of other BMPs. These are used primarily for areas with high-risk of pollution such as busy roads and gas stations. Pretreatment BMPs can be constructed as on-line or off-line structures. On-line structures are designed to treat the full water volume. Off-line structures are designed to collect a certain amount of flow (MassDEP, 2008c). Structural BMPs include deep sump catch Basins, oil/grit Separators, proprietary separators, sediment forebays, and vegetated filter strips (MassDEP, 2008b).

Treatment BMPs are classified as Stormwater Treatment Basins, Constructed Stormwater Wetlands, or Filtration BMPs. Stormwater Treatment Basins provide attenuation for the peak flow rate by collecting runoff and settling out sediment. Constructed Stormwater Wetlands aim to remove pollution by vegetation uptake, collection, and settling. Filtration BMPs use media to remove sediment, and are used commonly if space is limited (MassDEP, 2008c). Specific kinds of Treatment BMPs are bioretention areas, rain gardens, constructed stormwater wetlands, extended dry detention basins, proprietary media filters, sand and organic filters, and wet basins (MassDEP, 2008b).

Conveyance BMPs are designed to collect and move runoff to other BMPs. Some also include measures to treat runoff using infiltration, filtration, or temporary storage (MassDEP, 2008c). Conveyance BMPs include drainage channels, grassed channels, and water quality swales (MassDEP, 2008b).

Infiltration BMPs decrease runoff volume by reducing surface flow and promoting groundwater recharge. However, these structures are not designed to give channel protection or flood water storage (MassDEP, 2008c). Examples of Infiltration BMPs are infiltration basins, infiltration trenches, leaching catch basins, subsurface structures, and dry wells (MassDEP, 2008b).

Other miscellaneous BMPs that do not fit into any of the above classes include dry retention basins, green roofs, porous pavements, and rain barrels and cisterns (MassDEP, 2008b).

A summary of types of BMPs and the specific BMPs that fall under each type is shown in Figure 3 below.

Table 2.1		
BMPs for Controlling Stormwater Quantity		
	Pretreatment BMP	BMP that requires pretreatment
Pretreatment		
Deep Sump Catch Basin	Yes	No
Oil Grit Separators	Yes	No
Proprietary Separators	Yes	No
Sediment Forebays	Yes	No
Vegetated Filter Strips	Yes	No
Treatment		
Bioretention areas/rain gardens	No	Yes
Constructed stormwater wetlands	No	Yes
Extended Dry Detention Basins	No	Yes
Gravel Wetlands	No	Yes
Proprietary Media Filters	No	Yes
Sand/Organic Filters	No	Yes
Tree Box filters	No	Yes
Wet basins	No	Yes
Conveyance		
Grass Channels	No	Yes
Water Quality Swales – Dry	No	Yes
Water Quality Swales – wet	No	Yes
Infiltration BMPs		
Dry Wells	No	No pretreatment required for runoff from non-metal roofs and metal roofs outside Zone II, IWPA and industrial site.
Infiltration Basins	No	Yes
Infiltration Trenches	No	Yes
Leaching Catch Basins	No	Yes
Subsurface Structures	No	Yes
Other BMPs		
Dry Detention Basins	No	No
Green Roofs	No	No
Porous Pavements	No	No
Rain Barrels & Cisterns	No	No

Figure 4*: MassDEP Table Displaying Types of BMPs (MassDEP, 2008c)*

2.5 Past Analysis of Salisbury Pond and Other Ponds

In recent years, WPI has increasingly examined the impacts of stormwater runoff in Salisbury Pond and other similar ponds. As Salisbury Pond is right next to WPI's campus, there is a concern as to how WPI's stormwater quality may negatively affect Salisbury Pond and the surrounding Institute Park. To examine the impact of stormwater runoff and how it is affected by varying surface types (i.e., a grassy hill versus a heavily-used road), WPI has partnered with Nitsch Engineering for several MQPs around and beyond WPI's campus.

2.5.1 Salisbury Pond

Salisbury Pond has been a staple of Institute Park since the 1800's. The pond, pictured in Figure 5 below, is an artificial lake created by the dam on Grove Street. In 1834, the pond was originally utilized as a mill pond that supplied power to Stephen Salisbury II's wire mill (City of Worcester, n.d.). Eventually, Salisbury Pond (aptly named after the Salisbury family) would go on to power the Washburn and Moen Northworks complex. In 1887, Stephen Salisbury III donated eighteen acres of his family's farmland to serve as a green space for both the citizens of Worcester and the students of WPI, named "Institute Park" (Friends of Institute Park, n.d.). Many WPI students and Worcester residents attend concerts at the park, organize games and activities at the park, or even just go for a walk around Institute Park. Despite being the centerpiece of Institute Park, Salisbury Pond has suffered from environmental pollution since its creation.

Figure 5*: An Aerial Photo of Institute Park and Salisbury Pond (City of Worcester, n.d.)*

Salisbury Pond currently has years of sedimentation buildup polluting the body of water. A 2013 study conducted by Weston & Sampson Engineers found that Salisbury Pond's average depth is three feet, a significant decrease from its original twelve foot depth; in some parts of the pond, the sedimentation build-up is at least five feet deep (Kotsopoulos, 2013). Sources of pollution include drainage from construction and industrial sites, parking lots, and weeds and algae in Salisbury Pond (Friends of Salisbury Pond, n.d.). The most concerning contaminants found were heavy metals, petroleum hydrocarbons, and semivolatile organic compounds (SVOCs). Weston & Sampson recommended dredging the pond and removing 50,000 cubic yards of sediment to improve the recreational value and ecological quality of the pond, but the city of Worcester is concerned about the cost of dredging, which would be upward of $7 million (Kotsopoulos, 2013).

Still, there have been other efforts to clean up Salisbury Pond and examine its water quality. In 1970, a Task Force (including WPI students) was created to clean up pollution in Salisbury Pond, and they were able to remove 5,000 cubic yards in sediment. In 2005, the Friend of Institute Park organization was founded to advocate for park improvements and "securing funds to cleanse Salisbury Pond via dredging and the installation of a forebay" (Friends of Institute Park, n.d.). Additionally, several MQPs from WPI have been based on improving the water quality and stormwater management of Salisbury Pond and similar ponds.

2.5.2 Previous Stormwater MQPs with Nitsch

Nitsch Engineering is a civil engineering firm founded in 1989 by WPI graduate Judy Nitsch (Nitsch Engineering, n.d.). They have been ranked in the top twenty-five engineering firms every year in Massachusetts since 2011, according to *Boston Business Journal* (Nitsch Engineering, 2021). Nitsch Engineering embodies their tagline of "building better communities with you" with a goal of positively impacting their clients, employees, and communities. Nitsch Engineering is also familiar and committed to helping the WPI community as they have been sponsoring WPI project work on stormwater management for several years. Nitsch has worked with several MQP teams to develop stormwater management systems for the WPI campus and other organizations in Worcester. To complete our project goal, we will be looking at these projects' results and conclusions and expanding upon the work they have accomplished.

In 2019, Nitsch sponsored an MQP team to examine the water quality of stormwater runoff on the WPI campus from several surface types. These surface types include a parking lot, a light road, a heavy road, a walkway, a green roof, a gray roof, a grassy hill, and Salisbury Pond. The overall goal of this project was to analyze the composition of the stormwater runoff on campus to determine the relationship between land type and contaminant loading in stormwater, and then develop a BMP design based on this relationship. The team tested for nitrogen, total phosphorus, TSS, and other pollutants. After collecting and analyzing stormwater samples from each of the land surface types, the MQP team concluded that surface types do impact contaminant loading in stormwater. In particular, they found that the walkway had the highest concentration of TSS, while the grassy hill had the highest concentration of total phosphorus. The team then designed a rain garden, a level spreader, a swale, and a sediment forebay to reduce the runoff entering Salisbury Pond and effectively remove pollutants. These BMP designs would be placed near areas of concern, such as the walkway or the grassy hill (Acaba et. al, 2019).

More recently, in 2020, Nitsch sponsored an MQP team to examine the contaminants in stormwater runoff going into two ponds at the EcoTarium Science Center in Worcester. The purpose of the project was to look at the contaminant concentrations in different stormwater flows around the EcoTarium, and then design an appropriate BMP. The MQP team collected samples from seven different locations: the upper pond, the lower pond, the upper parking lot, the lower parking lot, the stream, the stream outflow, and the roof. After collecting samples, the team tested for pH, total phosphorus, ammonia, anions and metals, bacteria, and TSS. Analysis of the data showed that all of the locations had higher concentrations of total phosphorus, coliform, and E. coli than the New Jersey Surface Water Standard, which the team used for comparison. Based on the data, the MQP team recommended that the EcoTarium build a vegetation filter strip and a rain garden in the upper lot area, and an oil/grit separator and an infiltration tank for the lower lot area (Vogel et. al, 2020).

3.0 Methodology

Our project is a collaboration with Nitsch Engineering involving land analyses, testing, and designing new stormwater management systems. The scope for this project can be broken down into four processes or tasks. The first task was sampling from a variety of surface types. The next task was to quantify pollutant loading from various stormwater runoff catchments, while also assessing how the contaminants and flow differ from location to location. Then, after categorizing each location by its contaminants, we could perform a detailed analysis on the land and direction of flow from that area. Then finally, the last process involved taking all data from our analysis of different contaminant levels and loadings, and using this information to design and recommend different BMPs, or applicable green infrastructure changes for areas of the campus. To carry out these processes, we had to develop a plan. As a team, we aimed to accomplish 4 main objectives, in order to make project processes as effective and clean as possible.

5. Collect and sample water from our selected sites during precipitation events.
6. Conduct laboratory analyses for various contaminants in the pond water and stormwater.
7. Analyze contaminant data and runoff characteristics to gain a better understanding of the impacts of surface and land characteristics on water quality.
8. Develop possible stormwater solutions to reduce the concentration of contaminants in the stormwater.

Although it is not the only focus of our project, the overall goal of this project is to help mitigate the effects of stormwater runoff on Salisbury Pond. Thus, to achieve this goal, we had to collect samples from locations on and around the WPI campus during various rain events. Then, by analyzing the contaminants in these samples, we were able to characterize areas based on contaminants and get a better sense of what was going into the pond. This would allow us to develop our recommendations. The section of the report presents and explains the necessary aspects of the objectives that were required for our methodology.

3.1 Sampling Locations

The goal for location selection was to sample stormwater runoff from a variety of different surfaces, while expanding on the past work done. We wanted to filter sampling locations down to areas with different land uses and surface types. By doing so, we gained a better understanding of how stormwater management needs differ from one area to another. In total, we wanted to sample from seven different locations around campus. So, we utilized the sampling location summary chart generated by the 2019 team to determine which areas we wanted to repeat along with our new target areas for sampling around the pond. This process would allow us to achieve our goal of determining if surface types impacted contamination levels, and whether or not contamination levels increased or decreased over time in certain areas. This approach would be used to help us then decide what types of designs are best for certain areas, and subsequently develop our recommended improvements to the WPI stormwater management effort.

From the previously mentioned 2019 project, sampling was done for Salisbury Pond, the grassy hill by Skull Tomb, and the gray and green roofs of East Hall. For our project, we decided to resample these locations to provide the necessary comparison data. In addition, we decided to sample three new locations that had not been looked at in the past: Salisbury Street, the grassy hill near Salisbury Pond, and a catch basin on Rumford Ave at one of the entrances to the Salisbury Estate Townhouses. A rainwater sample was also collected to compare direct rainwater to runoff. These sampling locations and their surface types are described in Table 1, and a map showing our sampling locations is provided in Figure 6.

Table 1: Sampling Locations and Surface Types

Location	**Surface Type**	**New or Redone**
Skull Tomb	Grassy Hill	Redone
Gray Roof	Regular Roof	Redone
Green Roof	Vegetation Roof	Redone
Salisbury Pond	Pond	Redone
Salisbury Street	Heavy Traffic Road	New

Grassy Hill near Salisbury Pond	Grassy Hill	New
Salisbury Estates Catch Basin	Parking Lot / Light Traffic Road	New

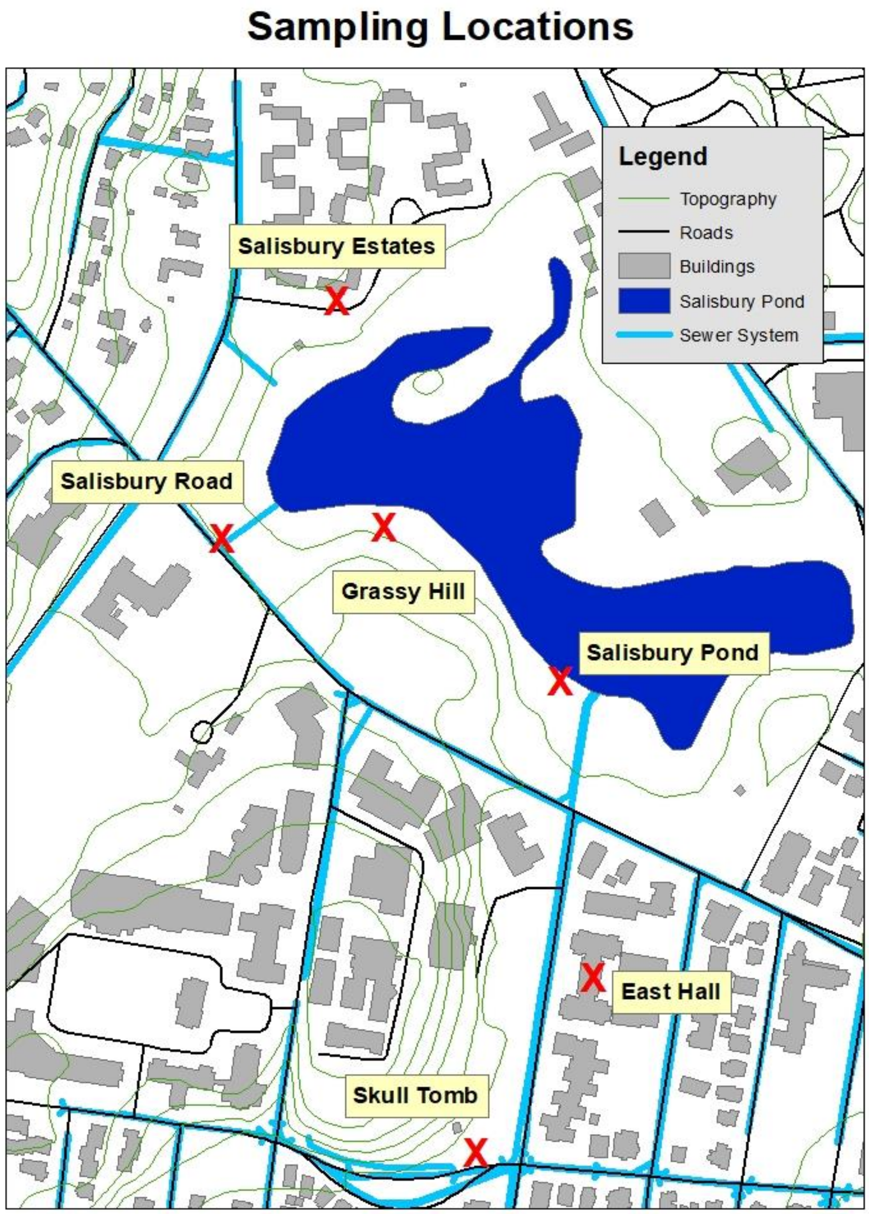

Figure 6*: GIS Map of Sampling Locations (Made on ArcMap)*

Figures 7-13 are pictures of the sampling locations for reference. Figure 7 is the grassy hill near the Skull Tomb, Figures 8 and 9 are the gray and green roofs of East Hall, Figure 10 is

Salisbury Pond, Figure 11 is Salisbury Street, Figure 12 is the grassy hill near Salisbury Pond and Salisbury Street, and Figure 13 is the catch basin near Salisbury Estates.

Figure 7*: Skull Tomb Grassy Hill*

Figure 8*: East Hall Gray Roof Stormwater Collector*

Figure 9*: East Hall Green Roof Stormwater Collector*

Figure 10*: Salisbury Pond*

Figure 11*: Salisbury Street*

Figure 12*: Salisbury Street Hill*

Figure 13*: Salisbury Estates*

3.1.1 Sampling Process

Samples were collected from the locations in the above section. One sample was collected from the Skull Tomb Hill and Salisbury Pond. Two samples from different storms were collected from Salisbury Street, the grassy hill leading to Salisbury pond, and the Salisbury Estates Catch Basin. Three samples were collected from the Gray and Green Roofs; two of the samples were from the same storm and the other was from an additional storm. The dates and times of sampling collections are located in Table 2.

Before sample collection at the location, bottles were rinsed three times with the distilled water in the lab to ensure proper quality assurance and control. The basis for our sampling protocol can be found in Appendix A. During each sampling trip, a clean 300 mL plastic bottle and 1 L DO glass bottle were filled, and the current weather temperature for the date of sampling was noted as well. Runoff was collected by using aluminum foil to funnel the water into the bottles at these locations: the Skull Tomb Hill, Salisbury Pond, Salisbury Street, Salisbury Street Hill, and Salisbury Estates catch basin. For the gray and green roofs, runoff was collected using the stormwater collectors in the lower floor of East Hall. Before the storm, these were fully drained to remove the old rainwater and allow new runoff to be collected for our samples. In addition to these samples, a rainwater sample was also collected before contact with any surface with the use of a large bowl. This water was then poured into a 300 mL plastic bottle for testing. After sample collection, the bottles were placed in the lab fridge.

Table 2: Sampling Dates and Times

Location	Date	Time	pH
Salisbury Pond	10/26/2021	12:00 PM	4.76
Grassy Hill near Skull Tomb	10/26/2021	12:20 PM	6.27
Salisbury Street	10/30/2021	8:20 AM	5.56
Grassy Hill near Salisbury Pond	10/30/2021	8:30 AM	4.88
Salisbury Estates Catch Basin	10/30/2021	8:45 AM	5.24
Green Roof	11/12/2021	11:30 AM	6.56
Gray Roof	11/12/2021	11:45 AM	5.76
Salisbury Street	11/12/2021	12:30 PM	5.37
Grassy Hill near Salisbury Pond	11/12/2021	12:45 PM	5.41
Salisbury Estates Catch Basin	11/12/2021	1:00 AM	5.27
Green Roof	11/12/2021	5:40 AM	6.24
Gray Roof	11/12/2021	5:50 AM	5.89
Rainwater	12/6/2021	8:00 AM	6.76
Gray Roof	12/7/2021	11:00 AM	6.15
Green Roof	12/7/2021	11:00 AM	6.49

For a baseline analysis after our pH testing, we assessed that the pond areas were very acidic compared to the others. All other pH levels were relatively normal for stormwater runoff.

3.2 Laboratory Testing

We completed a series of laboratory tests to obtain different measurements, and concentrations for our analysis. The lab testing equipment, and the contaminant level or concentration which they allowed us to test for, are listed below:

- pH probe for pH levels
- Spectrophotometer for total phosphorus concentrations
- Ion Chromatography Spectrometer (ICS) for fluoride, chloride, nitrite, sulfate, bromide, nitrate, and phosphate concentrations

- Inductively Conducted Plasma Mass Spectrometer (ICPMS) for manganese, copper, lead, sodium, magnesium, calcium, andiron
- A filtration device for TSS concentrations

These contaminants were selected because they were our main contaminants of concern that are often treated by many different types of BMPs, and they are also included in most water quality standards. The results of these laboratory tests can be found in Appendix H.

pH Testing

The pH of a water system has the tendency to change the type of aquatic life which can survive there. When the pH changes from what it naturally is by a lot, the aquatic life that the ecosystem supports there will begin to die out. The pH levels were obtained by using an [insert name of device] pH probe. Before testing the samples, the probe needed to be standardized using buffer solutions. We used 4, 7, and 10 pH buffers to standardize the probe. These pH buffers are essentially solutions typically made of a weak acid and its conjugate base. These solutions provide a fixed pH reference, which is then used to calibrate the probe. The probe was standardized before and after each sample was tested, to ensure QA/QC. After standardizing, the probe was placed into each of the sample bottles to obtain and record the pH levels. pH testing was conducted within the day after sample collection, to ensure more accurate pH readings.

Total Phosphorus

Total phosphorus concentrations need to be regulated often, because high concentrations of this contaminant can seriously harm an aquatic ecosystem. Phosphorus is a very important nutrient which supports life growth on our planet, but high concentrations in water can suffocate aquatic organisms, when it produces algae blooms. The total phosphorus concentrations were obtained by using spectrophotometry. Spectrophotometry is a testing method involving the measurement of how much light passes through a substance. Every substance absorbs light at a different wavelength. Thus, total phosphorus samples had to be prepared by digesting our unfiltered water samples, a sample of deionized (DI) water, and six standards with specific levels of phosphorus for calibration.

The digestion process was performed by adding nitric and sulfuric acid to a beaker of sample water, and heating the samples on a hot plate until approximately 1 mL of the sample was left, or the sample started fuming, and then drops of hydrogen peroxide were added if the sample was too cloudy or colored. After a day of this digesting process, DI water was added to the samples until the volume reached 25 mL. Once this step was done, a drop of phenolphthalein indicator was added to the samples, and they were titrated with sodium hydroxide. The complete titration is indicated by the sample turning a slight purple hue. After the titration, molybdovanadate was also added to the samples, and then they were mixed thoroughly and measured in the spectrophotometer.

Anion and Metals

The anions which we tested for, are the specific compounds and electrolytes such as nitrate and chloride which, like many other anions, exist naturally and produce nutrients that can have adverse health effects on water quality. Metals are also necessary in low concentrations, but they become toxic to organisms when seen in higher concentrations. Anion and metal analyses used ten mL of our filtered water samples. For the ICS Anion test, standards of 100, 200, 400, 800, 1200, and 3000 ppb were made. For the ICP-MS Metal test, 100µL of concentrated nitric acid was added to each of these filtered samples. After this preparation was completed, the samples and standards were then handed off to the lab manager to perform the rest of the ICS Anion and ICP-MS Metal test procedure.

Total Suspended Solids

The amount of total suspended solids in bodies of water can have very serious effects on the environment as a whole. TSS is the measure of how many non-dissolved solids exist in a water system. When TSS concentrations are high, this can lead to an increase in the turbidity of water. Turbidity is simply the measure of relative clarity of a liquid. With increased turbidity, the amount of light which the water can absorb goes down, which leads to heat, in the form of light, being reflected out into the environment. This phenomenon contributes to global warming by raising the temperature of the atmosphere. In addition to this, toxins and nutrients will often attach to solids in water. TSS measurements were taken by first measuring out an amount of our sample water. Then a filter of a measured weight was used to filter that measured water sample, leaving the suspended solids on the filter. The filter was then dried and weighed. After the first round of weighing, the filters with solids on them were placed back into the oven for another hour to dry further before being weighed again. This process of re-drying the filters ensures that the measurement is of a consistent, completely dry weight. If the consecutive weight measurements of one dried filter were not within 4% of each other, the sample would continue to be dried and weighed each hour until a consistent weight was found. These consistent weights, and the total volume of sampling filtered, were then used to calculate the average TSS concentration for each sample.

Full Lab Procedures

The more detailed testing procedures are outlined in Appendices B-F. Each of the tests identified different contaminants in the collected samples. To ensure quality and control, only one person conducted an entire experiment rather than multiple people working on the same procedure. This was done in an attempt to minimize the variation of human error in collecting data. Multiple rain events were also sampled to ensure that the data was accurate for the general trends. The results from the lab testing influenced which BMPs were considered in the design process for the project.

3.3 Watershed Characterization Through GIS and HydroCAD Analysis

In order to hit our objective of analyzing and understanding the water quality on campus, we had to utilize the software systems: HydroCAD, Google Earth, ArcMap, and ArcGIS. We needed these systems so that we could outline and map the full watershed of the WPI campus. HydroCAD is a computer-aided design tool used by civil engineers to model stormwater runoff (HydroCAD Software Solutions, n.d.). ArcMap, ArcGIS, and Google Earth are some of many Geographical Information Systems (GIS) available for use by the public. GIS systems help provide and connect data layers for certain locations on a map, in order to help discover and analyze patterns or relationships geographically (ESRI, n.d.). By using a combination of the maps generated by past teams, along with the maps generated by us, we were able to define the location of structures, surface boundaries, soil classifications, and sub-watershed boundaries. The complete set of data collected utilizing these systems, allowed us to visually comprehend surface features, drainage flow directions, boundaries of watersheds draining into the pond, and any other stormwater drainage conditions. These systems were also very helpful for us to initially decide our sampling sites. Thus, by using the different GIS systems and HydroCAD, we were able to characterize the stormwater runoff based on the NRCS method guidelines and determine the flow going into Salisbury Pond.

3.3.1 GIS

Google Earth and ArcMap were utilized to create and analyze all map data. First, tributary areas for Salisbury Pond were identified by looking at topography, sewer lines, catch basins, and hydrography data on ArcMap. The data was layered on top of each other to be able to predict where water would be flowing into Salisbury Pond. Boundaries for the tributary area were marked on a map using Google Earth. The entire tributary area was broken up into three main catchment sections: the area section directly around Salisbury Pond, an area section to the Northwest, and an area section to the South. Next, each of these three areas were further divided into 4 or 5 sections depending on their soil type, found by using data tables from ArcMap. In Figure 14 below, the three tributary areas for the Pond are displayed.

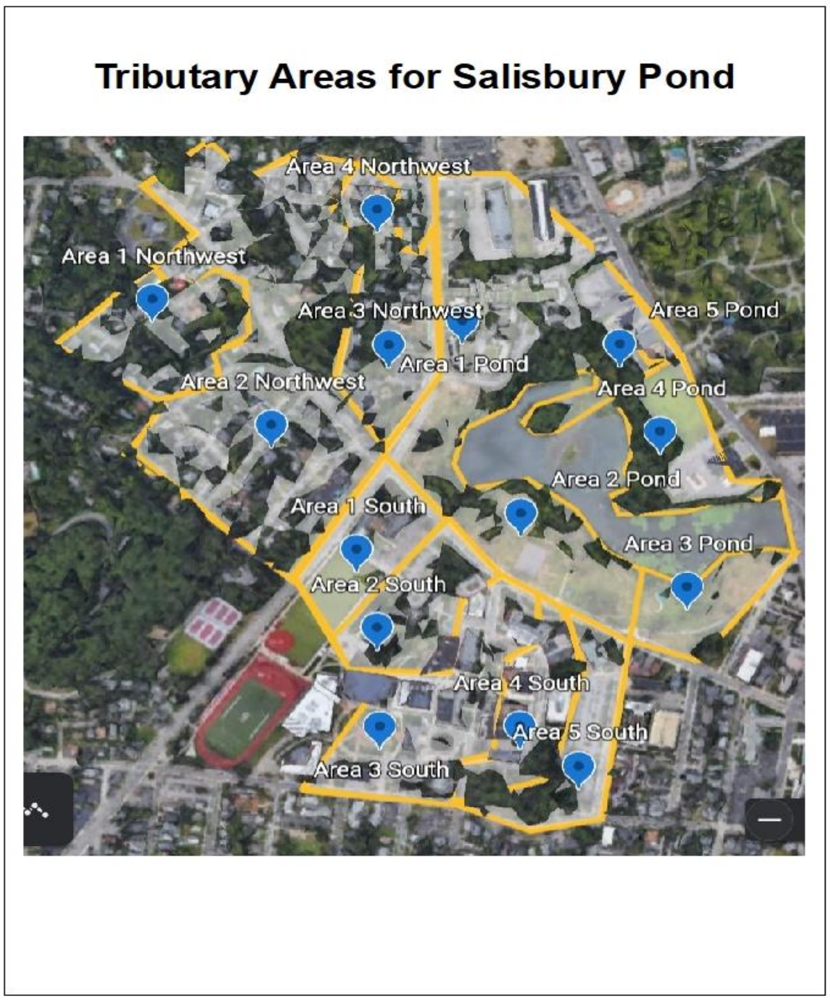

Figure 14: *Tributary Areas to Salisbury Pond for HydroCAD Analysis (Made with Google Earth)*

After sectioning off the larger tributary areas for the pond, we obtained land characteristics such as area, soil type, and land use for each catchment, and recorded them for our HydroCAD analysis, described in the section below. However, while there may be three total catchment areas shown here, for the purposes of our project, we decided to focus on the main pond catchment area and its subcatchments, for further analysis in our project results section.

3.3.2 HydroCAD

After acquiring the soil characteristics, the areas, the land use, the slope, and the hydraulic length for each of the subcatchments, this information was used to create a HydroCAD model for Salisbury Pond and the previously stated three designated areas. The HydroCAD model created is depicted in Figure 15 below. Additionally, rainfall events based on one, two, five, ten, and twenty-year storms from NOAA were added to the HydroCAD analysis. These rainfall events were based on information from the Worcester Airport rain gauge.

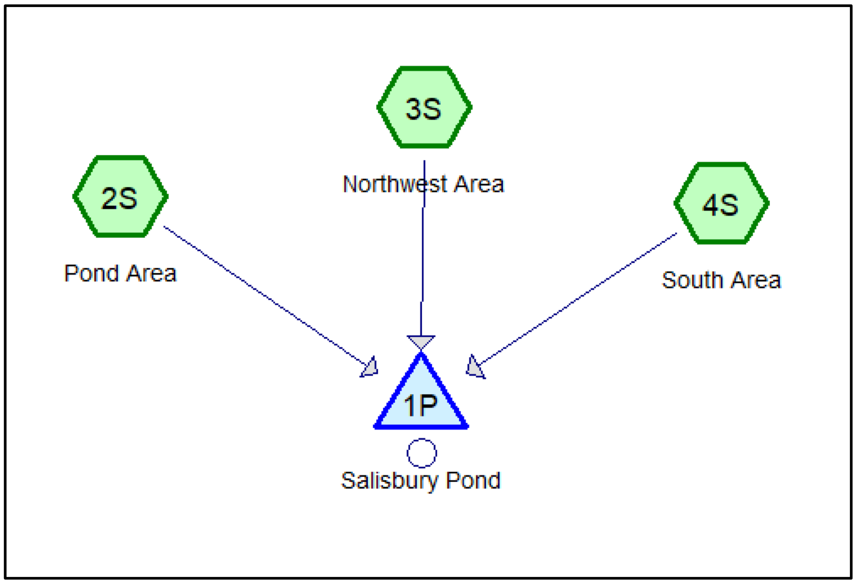

***Figure 15**: HydroCAD Model with Catchments and Pond*

The slope and hydraulic length for each catchment were used to calculate the respective time of concentration in HydroCAD; specifically, HydroCAD used the Lag/CN method to calculate each time of concentration value. These calculations yielded a hydrograph for each area, demonstrating the flow of the stormwater runoff over twenty-four hours. HydroCAD used the SCS TR-20 method to calculate runoff flow (in cfs), as well as providing the velocity (in ft/sec) for each subcatchment within the catchments. For our project, we were looking to mitigate the effects of high flow and TSS concentrated runoff from hilly or sloped areas. These areas tend to have the highest flow rates due to gravity.

3.4 BMP Design Ideas

We geared our design ideas and process towards recommending new BMPs for Salisbury Pond. In aiming to design and recommend BMPs, we were specifically focused on pollutant removal through flow mitigation and sediment filtration. Our team wanted to develop one detailed design recommendation and two theoretical design recommendations. To narrow down our viable options, we created a chart displaying the different uses and descriptions of a couple of different BMP designs. We chose to circle in on the most relevant or applicable BMP designs and how they could be useful for certain surface types or land areas, specifically around Salisbury Pond. Table 3 displays the 4 BMPs and their respective descriptions and area requirements on the page down below:

Table 3: BMP Design Feasibility Comparison

BMP Type	Description	Locations & Areas	Typical Management Needs	Min. Area Requirements
Grass Swale	Shallow, vegetated channel, also called bioswale or vegetated swale	Near edges of roads/At least 10 feet from buildings or urbanized areas	Vegetation mowing, erosion checkups, trash removal, replanting, sediment buildup removal, and mulch replacement (for roadways, or parking lots	Width must be 2-8 ft. Must be designed to treat either 2-year, or 10-year storm flow. Minimum soil bed depth of 18 in. Must be designed to hold at least a foot of ponding. Seasonal water table must not be within 2-4 ft. away from the swale bottom
Infiltration Trench	Rock and soil-filled trench	Urbanized areas Sites with limited space/between buildings or properties, or along road rights-of-way	Pea gravel and topsoil needs to be replaced monthly, inlet needs to be cleaned monthly, grass needs to be mowed monthly, and system needs to be checked semi-annually, and pretreatment basin needs to be aired out yearly and cleared every 5 years	Contributing drainage area to any individual infiltration trench should be restricted to 5 acres or less. The minimum depth to the seasonal high-water table, bedrock, and/or impermeable layer should be 2 ft. from the bottom of the trench. Many additional spacing requirements as well.

Vegetated Filter Strip	Vegetated areas designed to accept laterally distributed sheet flow, also called buffer strips or vegetated buffers.	Urban areas/Adjacent to impervious surfaces or buildings	Minimal management needed after first 2 years; 2-4 seasonal checkups in each of first 2 years	For TSS removal credit, the strip must be at least 25 feet long and generally as wide as the drainage area for the strip. Minimum width of the filter strip must be 20% of the length of the flow path or greater than or equal to 8ft.
Bioretention (Rain Garden, Trickling Filters)	Shallow, vegetated basins with a variety of planting/filtration media, often including underdrains.	Urban or Suburban areas/Near parking lots, parks, or heavy traffic roads	Regular watering if no precipitation occurs for 2 weeks, clearing of unwanted plant debris every so often, sediment cleaning and vegetation mowing 6x a year, yearly inspections, replace plants and reinforce every 5-7 years	The depth of the soil media must be between 2 and 4 feet, to allow for pollutant removal in soil, and excavations deeper than 4 ft. are expensive

All of the designs which we decided to focus on, were meant to be applicable for the pond area. However, not all of these designs are necessarily feasible for maintenance and construction requirements, due to the amount of recreational area for the pond. While we were trying to improve the quality of the pond, we also had to take aesthetics and community use into account as well. Thus, by creating Table 3 above, we were able to establish a baseline sense of the possible design recommendations for certain areas around the pond. We realized that the limited or small unused areas around the Salisbury Estate area of the pond would require more feasible BMP ideas, which also take into account the aesthetics aspect for our design recommendations. Thus, after completing our land and flow analysis for these areas as previously mentioned in Section 3.3, we would limit our recommended BMPs to ones which could run along the entire, or just a portion of the edge of the pond.

3.5 Deliverable

For the purposes of our project, we tried to find unique solutions to stormwater quality issues, which may not be fully addressed or properly managed by the existing management systems that we have in place today in general.

In deciding potential deliverables, we were aiming to address the issue of stormwater quality in an innovative, efficient, and simplistic process. We wanted to build upon the previous work done, and hopefully provide new insights for discoveries in improving stormwater quality going forward. As a team, we decided that by characterizing main areas of interest by their flow and specific pollutant concentration loads, we would then be able to develop our recommendations for each area, in ways which allow others to think about and envision solutions for their own communities. In doing so, we not only aimed to simplify the testing and design process for treating stormwater at WPI, but for other communities as well. The general public knows very little about treating stormwater quality as it is.

The proposed BMP designs and suggestions utilize both conventional BMP designs, and new technology or ideas, for the purpose of future work and environmental impact. Our design locations and recommendations were displayed on our project poster along with the potential benefits which they present for each area. The final deliverables for our project consist of the final MQP report, the proposed BMP design recommendations, and our project poster for our presentation day.

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Appendix A: Sampling Protocol

Sampling Protocol

Adapted from "WPI Nitsch Engineering MQP Field Sampling Protocol"

Equipment:

- Sampling bottles (size TBD)
  - Need to be cleaned ahead of sampling time
- Cooler
  - Ice
- Labels
- Field notebook/sample spreadsheet
- Permanent writing material (preferably Sharpie or pen)
- Disposable safety gloves
- Clear packing tape
- Thermometer
- YSI Model 85 probe

Prior to Sampling:

1. Check that all necessary materials for sampling are present, and make sure that these materials are clean and functionable.
   a. Rinse out the sampling bottles three times with distilled water.
2. Ensure that sampling bottles are correctly labeled.
   a. Write out labels beforehand.
3. Ensure that sampling crews know where they will be sampling and the purpose of sampling (a two-person crew is recommended).
4. Ensure that equipment is fully charged.
5. Record the weather conditions.
   a. Take a picture of the area upon arrival.
6. Record the amount of rain in the rain gauge.

Sampling:

1. Before collecting the samples, put on a pair of new gloves. Gloves should be changed for a new location.
2. Fill sampling bottles as much as possible, ensuring that the inside of the bottle is not touched.
3. Record the time, date, location, and label ID on the collected sample's label.
4. Place the sample into the cooler until further testing.
5. Repeat steps 3-5 for additional sampling at the same location.

Sample Sheet:

Sample ID	Location	Date	Time	Weather	Tests	Temperature	Notes

Appendix B: pH Procedure

pH Testing Procedure

1. Standardize the probe using 4, 7, and 10 pH buffers.
    a. Remove the probe from the storing solution and open the filling hole seal.
    b. Rinse the pH electrode with DI water and dry it with a Kimwipe.
    c. Place the probe into the 4-pH buffer solution.
    d. Press the STD button and wait for the screen to Stable.
    e. Accept the new standardized value by pressing STD again.
    f. Remove the probe from the buffer solution.
    g. Clean and place the probe into the next buffer solution.
    h. Repeat the above steps with each buffer solution.
2. Clean probe and place it into a 300 mL sample.
3. Wait 5 to 10 minutes for the probe to read as Stable.
    a. Note the final pH.
4. Repeat steps 1-3 for other samples.

Appendix C: Total Phosphorus Procedure

Total Phosphorus Testing Procedure

1. Clean glassware (100 mL beakers, 100 mL volumetric flasks, 25 mL volumetric flasks).
    a. Soak the glassware in an acid bath overnight, rinse 3 times with tap water, and then rinse 3 times with DI water.
2. Label 100 mL beakers with blank, standards, and sample IDs.
3. Make the standards.
    a. Take out the labeled bottle of standard from the refrigerator.
    b. Get the 100 mL volumetric flasks.
    c. Label flasks for standards.
    d. Pipette standard amounts according to the sheet.
    e. Fill flasks with DI water from an e-pure tap, then use a spray bottle to fill the flask to the line.
    f. Add parafilm to the flasks.
    g. Invert each flask 5 times.
4. Pour the blank, standards, and samples into 25 mL volumetric flasks.
    a. Rinse the flasks before filling.
        i. Add a little, swirl, dump out (do this twice).
    b. Use disposable, plastic pipette if over the line.
    c. Pour into the corresponding beaker, rinse the flask with a spray bottle twice.
5. Digest samples (about 1 mL of standards and samples will be left over in the beakers).
    a. Add 5 mL of nitric acid and 1 mL of sulfuric acid to each beaker.
    b. Heat on a hot plate until approx. 1 mL left or it starts fuming.
    c. Add drops of H_2O_2 if there are too many organics in the sample (sample would be cloudy and colored).
6. Turn on the spectrophotometer.

7. Make sure the spectrophotometer is on a single wavelength and that the wavelength is set to 400 nm.
    a. Change the wavelength by pressing Manual Program.
8. Filter samples (may not be necessary for all samples, depends on sediment amount).
    a. #4 filter paper, Whatman
    b. Funnels
9. Get 3 solutions.
    a. Phenolphthalein: 1000 mL, white/clear bottle, clear solution
    b. Molybdovanadate: 1000 mL, white/clear bottle, yellow solution
    c. NaOH: 6.25 N, white bottle, clear solution
10. Get supplies for each solution
    a. (2) Disposable dropper, 100 mL beaker
    b. 1 mL pipette and tip (1-5 mL)
11. Get DI water (in a squirt bottle), paper towels, gloves, "my" cell from the water lab, and a large waste beaker.
12. Transfer the blank solution from the beaker into the cell; rinse with DI water to get all of the sample.
13. Add 1 drop of Phenolphthalein.
14. Add NaOH with a dropper until the sample turns pink.
15. Add e-pure water to the line on the cell with the squirt bottle.
16. Add/pipette 1 mL of Molybdovanadate.
17. Set the spectrophotometer timer to 3 minutes.
18. Place the cell into the spectrophotometer (kimwipe first) with the white line mark facing outwards when the timer reaches 0.
19. Press Zero.
20. Rinse the cell into the large waste beaker.
21. Repeat steps 12-20 for the rest of the samples and standards, except press Read for step 19.
22. Dispose the waste into the hazardous waste bottle for total phosphorus.

Appendix D: Ammonia Procedure

Ammonia Procedure

1. Filter samples.
    a. Centrifuge tube.
    b. Syringes and 0.45 μm syringe filters.
2. Turn on the spectrophotometer (not necessary to wait hours before using).
3. Make sure the spectrophotometer is set to single wavelength and the wavelength is set to 425 nm.
4. Make the standards.
    a. Get Nitrogen-Ammonium Standard Solution 100 mg/L.
    b. Get 100 mL volumetric flasks.
    c. Label flasks for standards.
    d. Pipette standard amounts according to sheet.
    e. Fill flasks with DI water from an e-pure tap, then use a spray bottle to fill the flask to the line.
    f. Add parafilm to the flasks.
    g. Invert each flask 5 times.
5. Get 3 solutions.
    a. Mineral Stabilizer: clear solution; small dropper bottle.
    b. Polyvinyl Alcohol Dispersing Agent (PADA): purple solution; small, dropper bottle.
    c. Nessler Reagent: yellow solution; larger bottle.
6. Get supplies for each solution.
    a. 1 mL pipette and tip.
    b. 25 mL UV-vis cell.
    c. Rubber stopper.
7. Add e-pure water to the 25 mL line of the cell; for samples, pour from the bottle (shake first), use a disposable dropper for each one if filled over the line.
8. Add 3 drops of the Mineral Stabilizer, cap and invert several times.
9. Add 3 drops of PADA, cap and invert several times.
10. Add/pipette 1 mL of Nessler, cap and invert several times.

11. On the spectrophotometer, press Timer and set it to 1 minute.
12. Place the cell in the machine, with the white line facing outwards.
13. Start the timer. When the timer reaches 0, press Zero.
14. Rinse the cell with DI water into the waste beaker.
15. Repeat steps 7-14 for the rest of the samples and standards, express press Read.
16. Dispose of the waste into Nessler Reagent hazardous waste bottle.

Appendix E: ICS Anions Procedure

ICS Anions Procedure

1. Sample preparation:
    a. Filter samples through 0.45 µm syringe filter (sample should be at least 10 mL), store sample in refrigerator until analysis.
2. On the test day:
    a. Get vials, caps, a marker, the tool (black cylinder), and a plastic tray.
    b. Label vials.
    c. Use the tray when filling (fill to the top of the tray, roughly 8 mL).
    d. Use the tool to put on caps (use the "hole" end first and the other end further down).
    e. Carousel release/align, then set up the autosampler in this order:
        i. 2 blanks.
        ii. Standards = 100, 200,400, 800, 1200, 3000 ppb.
        iii. Samples.
        iv. 3 blanks (2 blanks and 1 one for auto shutdown).

Appendix F: TSS Procedure

Total Suspended Solids (TSS) Procedure

1. Set up the filtration apparatus, insert a filter, and apply a vacuum.
2. Wet the filter with a small amount of deionized water to seat it.
3. Shake the sample vigorously, and then measure out the predetermined sample volume using a graduated cylinder.
    a. Record the volume filtered in liters on the bench sheet.
4. Rinse the graduated cylinder and filter with three 20 mL volumes of DI water, allowing complete drainage between washings.
5. Continue suction for three minutes after filtration is complete.
6. Carefully transfer the filter to an aluminum weighing dish and place the filter on a cookie sheet.
7. Place filters on the sheet into an oven set to 104 ± 1 °C, and dry for a minimum of one hour.
8. Remove the filters from the oven and transfer them to a desiccator to cool at room temperature.
9. Weigh one sample filter to the nearest 0.1 mg.
    a. On the bench sheet, record the sample ID and the mass (Mass 1) in the "Weight check" section.
10. Repeat steps 7 - 9 for all samples.
11. Repeat steps 7 -10 and record the mass as "Mass 2" in the "Weight Check" section of the bench sheet.
    a. If the mass of the filter increases less than 0.5 mg or the change in the mass of the solids is less than 4% of the previously measured mass, then continue with TSS calculations.
    b. If the mass of the filter increases by more than 0.5 mg or the change in the mass of the solids is less than 4% of the previously measured mass. Record each additional mass on the bench sheet as "Mass 3", "Mass 4", etc. Use the back of the bench sheet if necessary.
12. Record the Oven Dry Mass (in mg) on the bench sheet.
13. Calculate TSS.

14. Dump the remaining sample down the drain, remove the label, and rinse with tap water to remove any solids from the bottle.
    a. Wash bottles according to the bottle prep non-metals SOP 0150R01.

Appendix G: ICP-MS Metal Test Procedure

ICP-MS Procedure

1. Label the 15 mL test tubes.
2. Filter samples through a 0.45 μm syringe filter into 15 mL test tubes to reach the 10 mL line.
3. Add 100 μL of concentrated nitric acid (HNO3) to each test tube.
4. Mix well.
5. Store samples in the refrigerator until analysis.