Worcester Polytechnic Institute MQP-PPM-1891

Quantifying the Pollutant Removal Effectiveness of Best Management Practices in Urban Watersheds

A Major Qualifying Project Submitted to the faculty of
WORCESTER POLYTECHNIC INSTITUTE
In Partial Fulfillment of the Requirements for the
Degree of Bachelor of Science
In
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Abstract

This project quantified the water quality of stormwater runoff from various surface types and used this information to design cost efficient Best Management Practices (BMPs) with high contaminant removal rates. On the WPI campus, the grass areas, access roads, and walkways had higher concentrations of contaminants than parking lots, main roads, and roofs. By targeting these surfaces, BMPs were designed with a contaminant removal rate of approximately 50% of a full downstream design but at 33% of the cost.

Acknowledgements

Throughout our project, we have received helped 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 through this department, we would have neither the knowledge nor the tools to complete this work. Next, we would like to thank our Professors Paul Mathisen and Harold Walker for advising our project and providing feedback and guidance throughout our project. We would also like to thank the CEE Lab Manager III Wenwen Yao for all her work in teaching us the testing procedures and assisting in analyzing our samples. Finally we would like to thank Nitsch Engineering and their representatives Coleman Horsley and Anna Valdez. Without Nitsch, this project would not have come to fruition. Without Coleman and Anna and their guidance, we would not have gotten the project to where it is today.

Executive Summary

Without treatment of stormwater runoff, local water bodies can surpass their Total Maximum Daily Loads and suffer consequences including toxic nutrients and metals introduction, uncontrolled plant growth, plant death, and decreased levels of dissolved oxygen. These consequences are due to the nutrients, suspended solids, and metals found in runoff. These constituents are found in water naturally, but human activities and increased runoff volumes add to the loading. Stormwater runoff volumes are increased in urban areas as they continue to develop and produce more impervious surfaces. In order to control this runoff, stormwater management plans are implemented. One aspect of stormwater management plans are Best Management Practices (BMPs). BMPs are used to treat runoff before it returns to the surrounding environment. They are designed based mainly on TSS removal and runoff volume. However, since different BMPs can remove different contaminants, it is important to know the water quality of runoff coming off the land. Different land surfaces come into contact with different contaminants, and knowing these contaminants can have an influence on BMP selection. This can prevent over or under designing a BMP.

The goal of this project was to quantify and analyze stormwater runoff composition from various land types to draw conclusions on the relationship between surface type and contaminant loading in stormwater and to determine the effects of these relationships on BMP design. This project was sponsored by Nitsch Engineering, a consulting firm. They were interested in stormwater runoff, specifically from the following surfaces: roads, walkway pavement, parking lot pavement, grassy area, standard roof, and green roof. The project goal was completed by researching BMPs, analyzing the WPI campus for optimal sampling sites, utilizing our sampling protocol, and analyzing the data to assess water quality issues. The stormwater runoff collection and sampling took place during three storms and at various times during the storm. Each sample was collected and immediately brought to the lab to the data testing and analysis could begin. The data analysis consisted of determining the levels of total suspended solids (TSS), alkalinity, total phosphorus, ammonia, manganese, iron, copper, lead, sodium, magnesium, calcium, phosphate, nitrate, nitrite, sulfate, bromide, chloride, and fluoride. Afterwards, the loadings per surface area were calculated and the surface types were compared, which provided a basis for the determination of BMP locations and designs.

Without taking the surface type and contaminant loading into consideration, the resulting design was a constructed wetland by Salisbury Pond as a downstream treatment system. This design would treat the all of the stormwater runoff from campus without differentiating by surface type. This design provided 80% of TSS removal, 50% of total phosphorus removal, and 38% of total nitrogen removal. A constructed wetland large enough to accommodate all of the runoff would cost approximately $87,000. Through analyzing the data based on surface type, we found that grass areas, access roads, and walkways and roads contained the highest loadings of

TSS and nutrients on the WPI campus. Given this loading information, we created a design to target these surfaces utilizing rain gardens to treat the grass areas and insertable catch basin filters to treat the access roads and walkways. This design provided an overall TSS removal of 46%, total phosphorus removal of 28%, and total nitrogen removal of 10%. The design based on surface type achieved approximately 50% of the removal rates of the full downstream design however, the surface based design treated only 38% of the runoff with a cost of $28,325, approximately 33% of the cost of the downstream design. This demonstrates that BMPs that are design to target surfaces with the largest contaminant loadings capable of removing comparable amounts of contaminants at a fraction of the cost of a design that does not consider surface types.

Capstone Design

This Major Qualifying Project (MQP) satisfies the capstone design requirements specified by the Civil and Environmental Engineering Department at Worcester Polytechnic Institute (WPI). This design component, which is part of a senior capstone and is necessary for graduation, is also consistent with the guidelines developed by the American Society of Civil Engineers (ASCE). ASCE defines a design component as a process involving an open-ended, ill-defined problem with iterative analysis and synthesis. The design process involves defining the problem in order to analyze the current system to synthesize a new system, while keeping various constraints in mind. The designs must meet specifications implemented by a state board, as the specifications for design differ based on zoning and local laws (American Society of Civil Engineers, 2018). In addition to specifications there are other constraints to consider when designing. Some examples of these constraints include environmental, economic, social, accessibility, and feasibility.

Our design was a Best Management Practice (BMP) for a portion of campus. We determined that three rain gardens and a series of catch basin inserts would provide an appropriate approach for reducing the impacts of stormwater runoff from campus. This design manages the stormwater in the area and reduces pollutant loading, while following the requirements established by ASCE. Included is a plan to ensure the contaminants are held within the BMP, reducing the pollution in Salisbury Pond. The major constraints were performance in winter conditions, impact on student life, and constructability. The final design selected needed to survive harsh Worcester winters. It also needed to have minimal negative impact on student life, this means being in an area that does not cause inconvenience or propose safety risks. Constructability means minimizing both the time required to build and the size of the build area. Since the WPI campus is small, it is hard to have large excavations for design installment. Additionally, the cost of construction should not be so great that it is less expensive to remain with the current conditions. Also considered are the impacts of the following areas: environmental, constructability, sustainability, economic, social, and health & safety. For environmental, the design was constructed to minimize negative impact. Due to the nature of this project, it was desired that there was only a positive environmental impact as the reduction on runoff contaminants benefit the surrounding environment. For constructability, the design needed to be feasible for the WPI campus shape and size. The design was chosen to ensure sustainability, as it needs to last a longer time and continue to provide runoff treatment. For economic impacts, we wanted a design that was affordable. Cost was something we took into consideration with the downstream design versus the spot design. Social and health & safety were considered in respect to WPI students. The design was chosen and designed for areas that would not negatively impact the campus in a way that affects the students and/or their health & safety in a negative way.

Licensure

According to the National Council of Examiners for Engineering and Surveying (NCEES), professional licensure is necessary to protect the health, safety and welfare of the public from engineering malpractice. Consequently, standards have been determined, which define that an engineer must: acquire a degree from an Accreditation Board for Engineering and Technology (ABET) approved program, gain experience under the supervision of an existing licensed engineer, and pass a series of exams. By standardizing this licensure process, the public can know that the practicing members are knowledgeable, experienced, and accountable.

The regulatory process for engineers in Massachusetts is defined in 250 Code of Massachusetts Regulation (CMR) sections 1-7. In this section: general provisions, registration, professional practice guidelines, surveying standards, and disciplinary enforcements are stated. The regulatory authority for licensing engineers and land surveyors, 250 CMR 3.00, is pursuant of Massachusetts General Law (M.G.L) ch. 112, § 81D through 84T and MGL ch. 13, § 45. These regulations state that in addition to the educational accreditation, experience, and examination any engineer or surveyor pursuing a license must obtain character reference letters and in some cases, a board conducted interview. The driving force behind these requirements is the level of education an applicant fulfills.

For example, an applicant who receives a Bachelor of Science degree in engineering, from an ABET accredited program, will additionally require: three years of supervised experience, passing the Fundamentals of Engineering (FE) & Professional Engineers (PE) exams, a character reference letter, and does not require an interview unless some or all of the experience is accumulated prior to passing the examinations. An applicant who has received a Bachelors of Science in engineering technology requires the same standards in addition to four more years of experience. These requirements are outlined in 250 CMR 3.04 Table I and II of Appendix A & B. When obtaining a professional license in engineering and/or surveying it is essential to abide by a standard of care which will assure that the public's health, safety, and welfare are protected.

1.0 Introduction

Water quality of stormwater runoff is quite variable and is often discharged directly to a local water body. This approach has historically been allowed because stormwater runoff tends to have significantly lower concentrations of contaminants as compared to wastewater. However, particularly during major storm events, high contaminant loads can enter a water body due to large runoff flow rates. These surrounding water bodies are assigned Total Maximum Daily Loads (TMDLs). TMDLs are the calculated levels of pollutants a specific water body can handle, while still meeting water quality standards (Environmental Protection Agency, 2018). High contaminant loads that exceed TMDLs resulting from major storm events carry possible consequences. These consequences include the introduction of metals and other toxic materials to vulnerable water bodies, uncontrolled plant growth due to unnaturally high nutrient levels, and limited plant growth through suspended solid contamination or lowered levels of dissolved oxygen.

Contaminants of concern in stormwater can occur naturally but these contaminants are increased by human activity and are transferred to stormwater as it runs over a surface. Mitigation of these contaminants is usually performed through the implementation of a stormwater management plan. Stormwater management plans are guidelines for controlling stormwater runoff during and after construction of a new site. These plans typically consist of site and vicinity maps, information on non-structural controls such as hazard water and industrial waste discharges, and information on structural controls (Stormwater Management Joint Task Force, 2006). Surfaces are often characterized as either pervious or impervious. Continued development of urban areas results in an increase in impervious surface. That increase can impact the contaminant loads of local stormwater and create more concern for stormwater contamination in vulnerable water bodies. These impervious surfaces limit the opportunities for contaminants to be absorbed by soil and plants, resulting in more runoff reaching the nearby water body (Environmental Protection Agency, 2017). However, urban areas consist of a variety of land surfaces including open spaces, parks, streets, walkways, parking lots, grey roofs, and green roofs which can have different contaminant contributions.

BMPs commonly are an important part of a stormwater management plans. BMPs help to manage stormwater by reducing nutrient pollution concentrations and contaminant loading in runoff through the use of structures such as rain gardens, detention basins, and stone swales. The type of BMP and its design characteristics is determined using specific design criteria. Such criteria includes wet weather conditions, local regulations, rainfall frequency, large storm hydrology, small storm hydrology, and ground water recharge hydrology (Clar, Barfield, & O'Connor, 2004). One concept missing from the design specifications is the variability of contaminant contribution by surface type. Different land types produce different levels of storm water quality. Comparing various land uses and their levels of contaminant loading in stormwater runoff can help determine if full stormwater management plans are optimally designed in certain areas. Determining if the plan is over or under designed will allow adjustments to be made which can ensure that all runoff is adequately treated with optimal cost efficiency.

The goal of this project was to quantify the relationship between surface land type and contaminant loading in stormwater and to determine the effects of these relationships on BMPs design. In order to meet this goal, we sampled stormwater runoff during rain events at eight different points on the WPI campus that illustrate a variety of different land uses. These sites included: the Boynton parking lot, lightly traveled roadway next to Boynton parking lot, Institute Road, the grey and green roof sections of East Hall, sidewalk in front of Kaven Hall, grassy hill next to Boynton parking lot, and Salisbury Pond. The method for determining these location and a map of said locations can be found in methodology and results of this report. The samples were tested for the various nutrients and contaminants and compared to determine the variability in contaminant concentrations. This information was evaluated in relation to the design process of a stormwater management plan for a selected section of the campus. Two designs were created: a downstream design that would treat all runoff from the WPI campus, and a design based on surface type to target surfaces of concern to maximize pollutant removal. The removal rates and construction costs of the two designs were then compared to determine effectiveness of designing BMPs by surface type.

2.0 Background

This section will provide the background knowledge necessary to understand the purpose of this project, the basis for this project, and the involved parties. The purpose is outline by the sections detailing contaminants of concern in stormwater and the importance of managing stormwater runoff. The basis for this project is outlined by information on stormwater management techniques, various Best Management Practices, and previous work done on this topic. The involved parties are Nitsch Engineering and Worcester Polytechnic Institute, both having their own sections that include their interest and previous work on the subject of stormwater management. Understanding all of this information will give more meaning to our results as it helps provide context and importance.

2.1 Stormwater Contaminants of Concern

As stormwater flows over different surfaces, it picks up a variety of contaminants. Even if the surfaces are relatively free of contaminants, rainwater can contain constituents before it hits the ground. Rainwater has major constituents such as sodium, potassium, magnesium, calcium, chloride, bicarbonate, and sulfate and minor constituents including iodine, bromine, boron, iron, alumina, and silica. Rainwater also contains dust particles, that carry other contaminants (Carroll, 1962). The three most important types of contaminants present are nutrients, suspended solids, and metals. Since these contaminants are important concerns for this research, this section provides an overview of these contaminants.

2.1.1 Nutrients in Stormwater

Some of the major types of contaminants of concern in stormwater runoff are nutrients, primarily nitrogen and phosphorous compounds. Nitrogen and phosphorous can enter water bodies through natural processes such as the weathering of rocks, fixation of nitrogen from the atmosphere by leguminous plants, decomposition of organic material, leaching from surrounding soil, and acid rain (Khwanboonbumpen, 2006). However, the amount of nutrients reaching water bodies is dramatically increased by human contamination in stormwater. This can come from landscape runoff from fertilizers and plant debris, pet and animal waste, detergents from car washing, and vehicle emissions (Environmental Protection Agency, 2018). Industrial discharges and improperly treated wastewater are also major contributors to nutrient pollution (Khwanboonbumpen, 2006). Although wastewater discharges tend to have a significantly higher concentration of nutrients than stormwater runoff, large volumes of stormwater during rain events can lead to water bodies receiving high amounts of nutrients (Environmental Protection Agency, 2018). This problem is further amplified in areas with a high percentage of impervious surfaces since there is no soil or plants to absorb some of the nutrients before the runoff is discharged into a water body or storm drain (Environmental Protection Agency, 2017). The high loading of nutrients can then cause an imbalance in the natural ecosystem of the receiving water body.

The growth of plants in a water body is normally kept in check by limiting growth factors, which are essential nutrients that are lowest in concentration. Phosphorous tends to be the limiting growth factor in freshwater systems while nitrogen is usually limiting in coastal marine ecosystems (Khwanboonbumpen, 2006). Therefore, when excessive amounts of nitrogen or phosphorus enter a water body, it can cause uncontrolled plant growth and begin a process called eutrophication (Environmental Protection Agency, 2018). Eutrophication is, “the process by which a body of water becomes enriched with organic material [that] is formed in the system by primary productivity and may be stimulated to excessive levels by anthropogenic introduction of high concentrations of nutrients” (Khwanboonbumpen, 2006). Eutrophic conditions lead to large, nuisance algal blooms or other excessive plant growth that is unaesthetic and limits the use of the water body (see Figure 1) (Environmental Protection Agency, 2018). Certain algae species can also have public health effects in areas where people swim or fish (Khwanboonbumpen, 2006). Some of these algal blooms can be harmful, causing negative effects on plants, animals, and humans. Additionally, when these plants and algal blooms fall to the bottom of water body and decompose, they release more nutrients into the ecosystem and add to sediment oxygen demand (Khwanboonbumpen, 2006). This can continue the eutrophic conditions and eventually deplete dissolved oxygen which is detrimental to plant and animal life. Some of these algal blooms can be harmful, causing negative effects on plants, animals, and humans. These harmful algal blooms do occur naturally, but human disturbances to the ecosystems increase their frequency (US Department of Commerce & National Oceanic and Atmospheric Administration, 2009).

Figure 1: Eutrophication in the Mississippi River from agricultural runoff, source: (Lake Forest College, 2018)

2.1.2 Suspended Solids

Total Suspended Solids (TSS) are one of the most common forms of contaminants found in urban stormwater. While solids can be contributed from natural sources, such as stream bank erosion, the presence of TSS is greatly increased by various human activities. As water from a rain event flows across impervious and pervious surfaces, solids are accumulated and contribute to the pollutant load of stormwater. Major contributors to TSS in stormwater include streets and roads, the erosion of drainage channels, construction sites, and pervious surfaces, and atmospheric deposition of solid particulate matter (Environmental Protection Agency, 2018). The presence of high levels of suspended solids in a water body can negatively impact water quality and cause habitat issues due to increased turbidity levels and sedimentation. Reduction in the ability of light to penetrate the water body resulting from high turbidity levels can limit the growth of photosynthesizing organisms. Sedimentation of bottom deposits can alter the habitats of bottom-dwelling organisms (Environmental Protection Agency, 2018). The presence of solids in stormwater can also encourage the accumulation of other pollutants, including metals and nutrients, as the sediment acts as a medium for accumulation and transport of sediment-bound pollutants.

2.1.3 Metals

Some particular metals of concern in stormwater include copper, lead, zinc, chromium, mercury, nickel, and arsenic. Copper, lead, and zinc are the most prevalent. Heavy metals are primarily sourced from automobiles, construction, and industrial areas which can have significant impacts on receiving water bodies (Environmental Protection Agency, 2018). Vehicle exhaust residues from diesel and gasoline fuel have been identified as important sources of lead, mercury, zinc, silver, and copper. Automobile brake pads have also been identified as contributors of copper in stormwater (Lee, 1993). The presence of elevated levels of copper, lead, and zinc in stormwater is of concern because it is toxic to phytoplankton and can therefore negatively impact aquatic food chains. Lead is highly toxic to humans and aquatic life and serves no biological purpose, while the presence of zinc can impact gill function for various fish populations (Brooks Applied Labs, 2016). As communities continue to develop, the presence of heavy metals in stormwater is becoming more severe and there are already thousands of surface water bodies considered impaired due to heavy metal pollution from stormwater.

2.2 Stormwater Management

Stormwater Management is a vital component in decreasing the environmental impact of stormwater runoff and its contaminants. Managing runoff is also important to achieve the goal of reducing down gradient flooding and improvement of water quality (Dzurik, 2003; LePage, 2010). A large contributor to the degradation of water quality is contamination from nonpoint source pollution (NPS) (Tsihrintzis, Hamid, 1996). NPS pollution is the buildup of residual contaminants in between precipitation events that are washed away during each storm. One approach to address these contaminants makes up of a buildup-wash off model (Wang, 2011). NPS is a specific type of pollution. In NPS there is no specific point of origin, but instead there are various contributing points to the pollution. For example, the water running off of a roadway often has no one specific party responsible for the pollutants found. Instead, multiple parties, such as vehicles, building runoff, litter, pedestrians, etc. play a part in the buildup of pollutants. NPS is not exclusive to roadways, but can be found in many land use areas. In particular, urban areas contain a variety of land uses which may introduce different contaminants, making water quality a serious concern.

Water quality can be improved through the implementation of Best Management Practices (BMP) by removing contaminants from runoff from a variety of urban surfaces. BMPs provide a way for communities to both lessen their environmental impact through pollution mitigation and comply with guideline set down by the Massachusetts Stormwater handbook. This handbook outlines that no untreated outfall can be released directly to wetlands or waterways, peak discharge must remain the same pre and post-development, groundwater recharge must remain constant or maximized and TSS must be reduced by at least 80% (MassDEP, 2008). However, in the shandbook, there is no quantification of contaminant concentrations in runoff from specific types which is an area of concern because urban areas consist of a variety of different land uses. Figure 2 shows the characteristics that dictate the management practices of runoff.

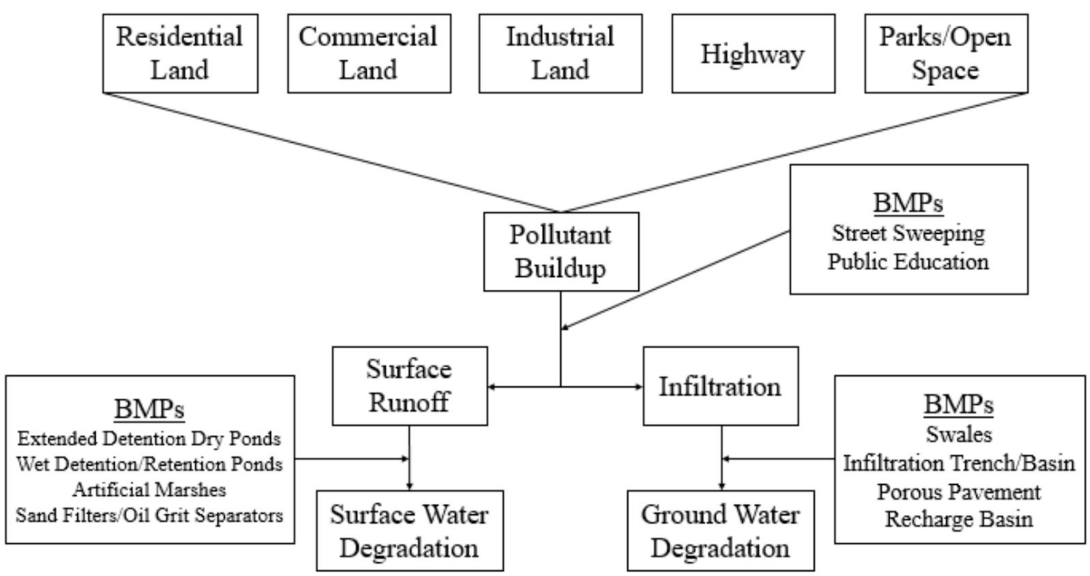

Figure 2: Outlined land uses and the methods for choosing BMP design to mitigate runoff contamination to stormwater. Source: (Tsihrintzis and Hamid 1996)

As outlined by Figure 2, urban land can be used in a variety of different ways which then can dictate the methods of treating NPS pollutants. However, these land-uses defined above are mainly composed of impervious and pervious surfaces. Knowing these levels of contaminants for each land surface type can have an effect on treatment selected. As previously stated, BMPs are one way to help treat these pollutants. There are various types of BMPs, and each remove different contaminants at different methods. The follow section explores the different BMPs available.

2.2.1 Best Management Practices

There are multiple types of BMPs in order to solve issues of stormwater management in various locations. These BMPs are covered in the Massachusetts Stormwater Handbook (MassDEP, 2008). This handbook outlines six different categories structural pretreatment, treatment, conveyance, infiltration, other, and accessories. These categories and examples of structures can be seen in Table 1 below.

Table 1: Best Management Practice Possibilities (MassDEP, 2008)

BMP Category	BMP Examples
Structural Pretreatment	● Deep Sump Catch Basin ● Oil/Grit Separators ● Proprietary Separators ● Sediment Forebays ● Vegetated Filter Strips
Treatment	● Bioretention Areas and Rain Gardens ● Constructed Stormwater Wetlands ● Extended Dry Detention Basins ● Proprietary Media Filters ● Sand and Organic Filters ● Wet Basins
Conveyances	● Drainage Channels ● Grassed Channels ● Water Quality Swale
Infiltration	● Dry Wells ● Infiltration Basins ● Infiltration Trenches ● Leaching Catch Basins ● Subsurface Structures
Accessory/Other	● Dry Detention Basins ● Green Roofs ● Porous Pavement ● Rain Barrels and Cisterns ● Level Spreaders ● Check Dams ● Outlet Structures ● Catch Basin Inserts

Structural pretreatment BMPs are built into the area and treat the stormwater before sending it off to another treatment structure. Treatment BMPs treat the stormwater before the stormwater flows back into the surrounding environment. Conveyance BMPs treat the water, direct the flow, and control the volume of runoff and its final location. Infiltration BMPs focus on treating the stormwater and allowing it to infiltrate back into the groundwater. Other BMPs provide stormwater management and nutrient removal, but do not fall under the other categories. BMP accessories are not BMPs themselves, but may be necessary for the function of other BMP systems (MassDEP, 2008). There are various BMPs available, and each one has different levels of nutrient and TSS removal.

2.2.2 BMPs and Contaminant Concentrations

Choosing a BMP based on nutrients and contaminants present ensures that the BMP design can maximize pollutant removal. For example, an industrial facility which contains a large quantity of impervious surfaces may contain a greater number of deep sump catch basins. As outlined by Volume 2, Chapter 2 of the Massachusetts Stormwater Handbook, this form of BMP is valuable when removing trash, debris, and coarse sediment which may carry oils and grease because of the associated low infiltration rate. However, this form of BMP would lack effectiveness when treating TSS because of its low removal rating of 25% (MassDEP, 2008). The accumulated contaminants vary from land use to land use, as should the BMP design. In essence, the determination of constituent contaminations based on surface types will better the design, use, and cost efficiency of BMPs when managing stormwater runoff.

In addition to determining the concentrations of runoff contaminants based on land surface, the volumetric loading rate will be necessary to determine the quantity of contaminant that are required to be treated. First flush analysis is important because contaminant concentration will be affected during this period. It was found that the first flush affected the concentration, in descending order, of solids, organics, and nutrients (Kim, Kim, & Yur, 2007). The largest contributing factors to the volumetric rate is the slope of the surface and soil composition (in pervious areas).

Through the investigation of contamination composition based on surface type and volumetric flow rates from these areas, it will be possible to significantly improve the management of stormwater by tailoring stormwater management practices to specific areas based on the quantities of contaminants present in its runoff, advancing the protection of water quality. This is work that piques the interest of many, including Nitsch Engineering.

2.3 Previous Work in this Area

A common thread in the research referenced for this project was the reduction of pollutant loading in urban stormwater off impervious surfaces in order to protect vulnerable discharge water bodies. Overall, it was consistently noted that an increase in impervious surface area in urban settings increases the volume of stormwater discharged. However, when it came to further analyzing the runoff and determining the relationship between surface type and runoff quality we found that the research was largely based outside of the United States (barring the information provided by Nitsch). In looking to studies conducted around the world on the relationship between surface type and stormwater runoff quality it was found that a number of studies have identified runoff as originating from a number of small catchments that encompass different kinds of urban surface types. Three studies in particular conducted research to determine how surface type and contaminant loading are related.

One project, conducted in Patiala City in India sought to "investigate stormwater quality from five different urban sub-watersheds (that differ in land use and development activities)" (Amarpreet, 2013). Stormwater runoff off on the five different urban sub-watersheds was analyzed for 5-day biochemical oxygen demand, chemical oxygen demand, total suspended solids, oil and grease, total phosphorus, heavy metals and other contaminants; of the pollutants analyzed total suspended solids, chemical oxygen demand, oil, and grease were found to be the major pollutants of concern in the runoff sampled. Catchments were characterized according to land use (commercial, residential, rural acreage-residential, mixed urban, and heavily traveled urbanized) and further broken down into percent grass cover, impervious cover, bare soil, and tree canopy. The results of this study drew strong correlation between land use and development activities and the stormwater quality sampled.

An ongoing water quality project based in Queensland State, Australia (established in 1999) analyzed stormwater runoff quality data off of three major catchments and 3 subcatchments (Goonetilleke, 2005). Much like the previously cited study conducted in India, the catchments were broken down based on land use characteristics (forest, rural acreage residential, urban residential, townhouses, duplex housing, and detached housing) and percent pervious and impervious land cover. The stormwater sampled was analyzed for pH, total suspended solids, total nitrogen, total phosphorus, total organic carbon, and other contaminants with total suspended solids, total organic carbon, total nitrogen, and total phosphorus being identified as the major contaminants of concern. This study draws relationships between land use and stormwater quality but also explores the uncertainty in urban stormwater quality. The urban catchments investigated displayed the highest variability (standard deviation) in values for the aforementioned parameters, indicating a high level of variability in the quality of urban stormwater. Such findings are indicative of the difficulties in developing urban stormwater models and developing relationships between specific surface types and pollutant loading.

Another similar study was conducted over the course of three years in Chongju, Korea. This investigation broke down the areas sampled into residential (commercial, multi-family, single family) and industrial (metal, food, textile) zones and tested the runoff water quality for 5-day biochemical oxygen demand, chemical oxygen demand, total suspended solids, total phosphorus, and heavy metals (Choe, 2002). The results of this study indicated differences in pollutant loading between the residential and industrial zones overall, but no significant differences between the subcategories of each zone type. All of the above mentioned studies sought to determine how stormwater is affected by the landscape and surfaces it runs over. While all of these studies seek to break down the catchments sampled into land use types, they don't quite focus on smaller scale surface types as we seek to do within this project. What can be gained from the results of this previous research is that land use and surface type has a relationship with pollutant loading in stormwater, what is more unclear is how each individual surface in the urban landscape contributes to the pollutant load.

In order to further investigate the impact of surface type on urban stormwater we turned to research supplied to us by our contacts at Nitsch Engineering. Two articles in particular further explored the effects of surface type. In a study conducted in Wisconsin published in 1993, the concept of stormwater micro-monitoring was first pioneering by Roger Bannerman and his colleagues (Bannerman, 1993). Over 300 samples from 46 micro-sites in two watersheds were analyzed for water quality. The result of this study concluded that streets were the number one contributor to pollutant loads in stormwater (four to eight times the expected load if all areas contributed the same. The same study observed that rooftop runoff was relatively clean and lawns and grassy areas contributed the highest overall phosphorus concentrations, potentially linking the results to excessive fertilizer use.

Another stormwater micro-monitoring study was published in 1997 by Jeff Stauer and his colleagues that focused on a 289 acre subwatershed that drained to Lake Superior in Michigan. The team collected over 550 samples targeting key source areas identified as commercial parking lots, medium and high traffic streets, commercial and residential rooftops, and residential driveways and lawns (Steuer 1997). More than 40 different pollutants were tested for in the samples, including TSS, nitrogen, and phosphorous. The study found that the concentration of nutrients was quite high in pervious areas; samples from residential lawns had five to ten times the nitrogen and phosphorus concentrations of any other source area and were identified as the largest contributors of phosphorus in the subwatershed. Rooftop runoff had lowest nutrient concentrations, which corroborates the Rogerman study's findings. Commercial Parking lots and medium and high traffic streets were also found to contribute disproportionate amounts of loading compared to the percentage of surface area of the subwatershed they covered. By concentrating such analysis on various surface types and the direct contributions of a kind of surface to the pollutant loading in a subcatchment more effective stormwater models can be generated and treatment for various pollutants can become more effective.

2.4 Nitsch Engineering

Stormwater management is a major component of civil and environmental engineering. It is something that consulting firms need to be consider in design and planning both during and after the construction of a new project. Nitsch Engineering is a consulting firm that specializes in providing communities with civil engineering, land surveying, transportation engineering, structural engineering, green infrastructure, planning and GIS services (Nitsch Engineering, 2018). Further research into stormwater qualities from specific surfaces will aid Nitsch Engineering in their various projects. These include projects such as the improvements made to Taxiway D of the Logan International Airport where Nitsch performed a site visit and stormwater analysis in order to provide insight into optimal management practices (Nitsch

Engineering, 2018). Nitsch also works in commercial areas such as the Upper Harbor Terminal in Minneapolis, Minnesota where best management practices are recommended in certain areas in order to meet stringent discharge guidelines like those of the Mississippi Water Management Organization (Nitsch Engineering, 2018). In addition, Nitsch collaborates with developers to create comprehensive stormwater management plans that promote sustainability such as the Stormwater Master Plan that they are making with the Harvard Business School (Nitsch Engineering, 2018). In all of these areas, knowledge of stormwater flows and qualities is essential. This information can be used to ensure that stormwater management practices are designed to adequately address contaminants from each type of area without overdesigning and unnecessarily increasing development costs. In an effort to explore this concept further, we will sample stormwater runoff from various land types on the WPIs campus. More information on WPI and stormwater management on campus can be found in the following section.

2.5 Worcester Polytechnic Institute

Our site of interest was the eastern portion of WPI's campus. Within this site are eight points of interest where we focused our sampling. To decide on the specific sample locations we first needed to understand the campus and the current stormwater runoff management system. This included drainage systems, catchment basins, and even the green roof. Based on observations and computer modeling, it was concluded that the stormwater runs off of the impervious surfaces on campus into catch basins. The water flows from the catch basins to storm drains that lead to Salisbury Pond, taking the pollutants and nutrients from campus and polluting already damaged waters. In fact, Salisbury Pond suffers from polluted sediment, diminishing its recreational value and water quality. This sediment has built up due to years of stormwater runoff. The City of Worcester hopes to clean the pond, and part of that solution requires implementing better stormwater management systems around the pond, to prevent further sediment buildup (Kotsopoulos, 2013). The area of WPI campus that flows into Salisbury Pond can be seen in Figure 3 below.

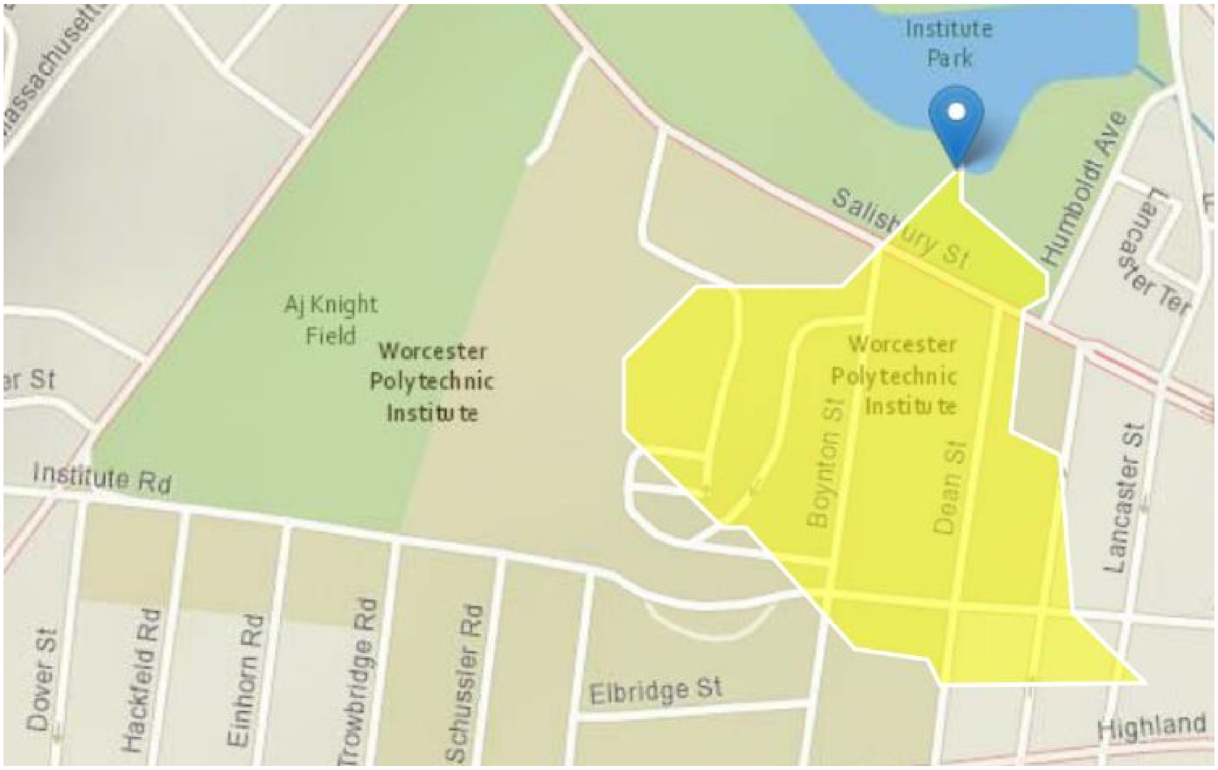

Figure 3: Area of WPI Campus that drains to Institute Pond from StreamStats

In order to improve upon stormwater runoff management on the WPI campus, the current campus runoff conditions and WPI-specific related work were examined. The Water Research Outreach Center (WROC) is a local WPI project center that explores issues related to stormwater. These issues include cost - benefit analyses of best management processes, educating the community on stormwater management, and tracking information on stormwater via databasing (WPI, 2018). A recent on-campus Interactive Qualifying Project (IQP) completed in April 2018 and based in the WROC project center, *Stormwater Runoff Reduction on the Worcester Polytechnic Institute Campus*, explored stormwater across campus and explored possible BMP sites that could help mitigate the impacts of runoff. The project considered runoff flow and designed based on volume, aesthetics, and cost of implementation. The result showed that one area of campus, the grass Skull Tomb lawn located by the intersection of Boynton St and Institute Rd, contains about 25% of all of the campus drainage (Marsan, et al., 2018). The results of this project assisted in informing the team of the runoff conditions and delineating the need for improved management on the Eastern side of campus.

A Major Qualifying Project (MQP), completed in May of 2014, focused on the development of a Campus Stormwater Management Plan and provided a design for the use of permeable pavement on campus as a means of reducing stormwater runoff. The management plan developed by this project included "an overview, public education and outreach, illicit discharge detection and elimination, construction site control measure, post-construction site control measure, and pollution prevention control measures," and identified Boynton lot, the Quadrangle area, and the access roads on campus as priority areas for design (Marsan et al, 2018). Another MQP project completed in April of the following year (2015) sought to develop a "stormwater management strategy and design a BMP on campus to reduce WPI's contribution to discharge water bodies" with a focus on reducing TSS loads being contributed to Salisbury Pond. The MQP team completed GIS and load analyses of current campus conditions in order to identify areas that contribute high percentages of the campus's stormwater runoff and pollutant loads for TSS, nitrogen, and phosphorus to Salisbury Pond. Resulting from the team's analysis, the Library downhill drive was identified as effective placement for a BMP design to reduce TSS loading. The tree box filter design proposed for this area has an expected annual reduction in suspended solids by 1800 lbs, phosphorous by 1.5 lbs and nitrogen by 12 lbs, resulting in a remaining annual loads of 317 lbs TSS, 0.86 lbs phosphorous, and 16.03 lbs nitrogen (Marsan et al, 2018).

3.0 Project Approach, Scope, and Objectives

This section outlines the project approach, goal, and objectives. These three matters are explored to clarify and detail how this project was approached. The section addresses the constraints on the project, the objectives, and how they were developed to achieve the goal.

3.1 Project Approach

Our approach for this project included two steps. First, we quantified pollutant loading in various stormwater runoff catchments and determined how these values differ by surface type. Second, we analyzed these effects and loadings in respect to applications of green infrastructure and BMPs to determine what was most effective. The approach included sampling and analysis of stormwater runoff at different locations in the area of the WPI campus to gain a better understanding of how runoff water quality varies by surface type. The analyses were then used to recommend improvements to WPI's stormwater management through the recommendation of various BMPs. This project was sponsored by Nitsch Engineering, a consulting firm that was interested in characterizing the quality of stormwater runoff, from the following surfaces: walkway pavement, parking lot pavement, grassy area, standard roof, and green roof. Characterization of stormwater runoff quality was completed by researching BMPs, analyzing the WPI campus for optimal sampling sites, utilizing our sampling protocol, and analyzing the data to assess water quality issues. We then were able to determine where and how to best implement a BMP for the betterment of WPI's stormwater management.

3.2 Project Scope

This project was done on the Worcester Polytechnic Institute campus from August 2018 to March 2019. For the project, we collected samples from the WPI campus during rain events in the fall. These samples were sampled for contaminants that can be analyzed using the WPI lab. The resulting analysis will aid in BMP design. The designs were based on the current layout of the WPI campus, but without including the City of Worcester land nearby. The final deliverables of this project will be detailed analyses of various surface type runoff, BMP designs for the WPI campus, a report detailing the project, and a poster for project presentation day.

3.3 Objectives

In order to accomplish our goals we used the following objectives:

1. Map and characterize the campus watershed and sampling sites.
2. Sample various stormwater subcatchment areas to test for nitrogen, phosphorus, TSS, and other pollutants.

3. Analyze the results to identify where different contaminants flow and how they might be mitigated.
4. Use the research, sampled data, and analysis to design a BMP to implement on campus.

4.0 Methodology

This section of the report outlines the steps necessary to complete this project. It elaborates on on how each of the following objectives were achieved: characterizing the campus watershed, sampling stormwater runoff at various locations, results analysis for contaminant flows and possible mitigation, and designing a BMP for the WPI campus. Each section explains the steps for each objective in enough detail so that people can understand and possible recreate if necessary. These steps and objectives were necessary to complete the project goal of quantifying pollutant loading in various stormwater runoff catchments and determining how these values differ by surface type for analysis of these loadings in respect to applications of green infrastructure and BMPs to determine what was most effective.

4.2 Use of GIS to characterize the campus watershed and sampling sites

In order to achieve our first objective of mapping the campus watershed, we used Google maps and a variety of GIS software to create a watershed map of the WPI campus. In particular, we defined the location of structures, surface boundaries (pervious & impervious), soil classifications, and sub-watershed boundaries. The data was collected from Arcmap, Oliver GIS, Natural Resources Conservation Services (NRCS), and StreamStats. The data from each source was as follows:

- Arcmap- surfaces boundaries, structure polylines, subsurface drainage systems, and t topographical polylines.
- Oliver GIS- wetland boundary, topographical polylines, tax parcels
- StreamStats- subwatershed boundary polyline
- NRCS- soil classification with descriptions
- Google maps- aerial images

This data was exported from each source as a shapefiles or tiff images and imported to AutoCad Civil 3D. They were then translated and rotated together to make one base map of the eastern portion of campus.

This process allowed us to visually comprehend an initial understanding of: area surface features, drainage flow direction (surface & subsurface), the boundary of the sub watershed that drains to Salisbury Pond, and any other drainage conditions. This crucially aided in our determination of sampling sites. With this map several areas were determined to be adequate for sampling. Following this procedure we took the map and walked the campus to view the sites. This allowed us to further our decision of sampling locations.

During our campus analysis we finalized our sampling locations. The sites that we determine to be adequate were chosen based on multiple characteristics. The first characteristic in this determination was an easily accessible location. Secondly, we isolated several surfaces types so we could understand contaminants from various isolated land uses. Finally, we chose locations that minimized surface cross contamination.

Our final assessment was another campus tour during a measurable rain event. This was important to back up our initial assessments of the sample locations by witnessing runoff flow paths. Additionally, we were able to see which locations had measurable surface runoff. At the conclusion of our assessment we chose eight sample locations.

4.3 Field Sampling Program

This field sampling objective was reached by conducting research on existing sampling collection plans, and then using them to create our own. The purpose of the field sampling protocol guide was to provide a set of working directions to perform sampling activities in a safe and consistent manner. The sampling protocol was modeled after both The United States Environmental Protection Agency's Field Sampling Quality Control (US EPA, 2017) and The Nitsch Engineering Field Sampling Control Guide (Nitsch Engineering, 2018). Stormwater samples for water quality analysis were collected using one of three methods. Sampling Method 1 applied to outdoor sampling surfaces, Method 2 applied to roof sampling surfaces and Method 3 applied to standing bodies of water. Velocity and area were calculated also using one of two methods. Method A was used for surfaces with pervious and impervious and Method B was used for roof sampling surfaces due to location. For more information on these methods, the locations they were applied to, and the full sampling protocol see Appendix C.

In order to ensure the accuracy of our sampling, multiple quality assurance and quality control (QA/QC) steps are included in our sampling protocol including rinsing all sample bottles before use and using a plastic barrier between the surface and the sample bottle. Full QA/QC steps can be found in the sampling protocol in Appendix C. Duplicate samples were taken at several sites to test the effectiveness of quality assurance measures. These samples were collected at the same site as the original, at approximately the same time,
Additionally, all laboratory tests were performed using consistent procedures (see Appendices E-K).

When collecting samples, it was also important to label them properly so that QA/QC was maintained throughout the sampling process. For every sample a standard label was filled out before sampling commenced. The field characteristics of interest on the label were location, sample type, and date. Furthermore, all samples had the project type and a point of contact to eliminate any confusion in the community laboratory. See Figure 4 for the standard label for this project. The full description of our label naming conventions can be found in Appendix L.

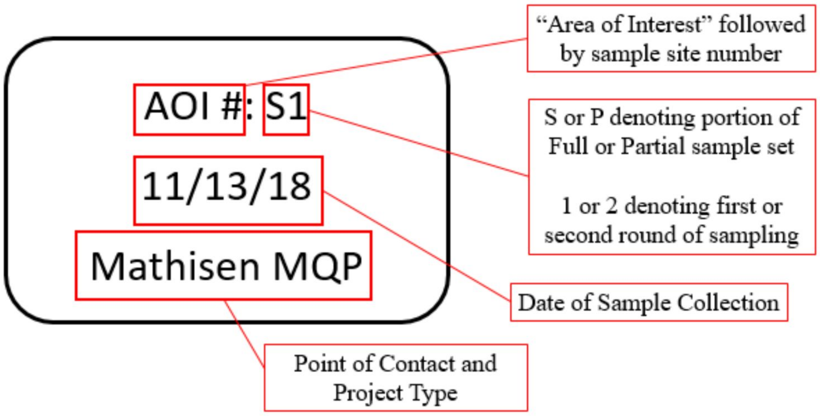

Figure 4: Standard sample label

In addition to properly labeling and collecting samples, the storm data needed to be recorded shortly after the storm. To determine the magnitude of the storms that were sampled, two monitoring locations were reviewed. The monitoring sites included: The Worcester Regional Airport and Stillwater River in Sterling. As a result of the data being eliminated from the respective websites after several days, the data was compiled shortly after the storm ended. These records can be seen below in Tables 2 and 3, while the full collected raw data can be found in Appendix L.

Table 2: Recorded storm event classification of monitoring site one.

Worcester Regional Airport, Worcester MA					
Storm Event	**Rainfall Total (in.)**	**Rainfall Duration (hr.)**	**Antecedent Dry Period (hr.)**	**Antecedent Rainfall (in.)**	**Antecedent Storm Duration (hr.)**
10/27/18	1.5	24	*	*	*
11/3/18	1.4	24	*	*	*
11/13/18	1.1	12	*	*	*

* Data not provided by monitoring site

Table 3: Recorded storm event classification of monitoring site two.

Stillwater River Gauge, Sterling MA					
Storm Event	**Rainfall Total (in.)**	**Rainfall Duration (hr.)**	**Antecedent Dry Period (hr.)**	**Antecedent Rainfall (in.)**	**Antecedent Storm Duration (hr.)**
10/27/18	1	24	72	0.25	36
11/3/18	2.5	12	12	0.5	24
11/13/18	1.4	12	72	1	12

4.4 Analysis to identify contaminants courses and mitigation options

This section will serve as a guide for how we accomplished analyzing the results of the samples to identify where different contaminants flow and possible mitigation. It will explain the measurements we took in the field as well as the analytes and their lab procedures.

4.4.1 Field Measurements

There are several characteristics that were measured in the field when analyzing stormwater runoff. The velocity and cross sectional area were measured to understand the volumetric loading or flow rate of subsequent contaminants. Additionally, the temperature of the sample was taken before it reached the ice chest to conclude if there are changes in runoff and source water. Finally, the pH and dissolved oxygen (DO) were measured and recorded using a pH and DO probe. It was important to test the DO concentration immediately due to its time sensitive diffusion characteristics. All records will be documented prior to sampling conclusion. Following field sampling, concentrations of various analytes were determined through several laboratory procedures.

4.4.2 Lab Procedures

In order to better understand the pollutants and runoff collected, it was necessary to complete several different lab procedure and techniques to test for specific analytes. These procedures were important in safely and properly understanding the specific constituents of stormwater runoff from the WPI campus. For this project, many of the lab procedures were taken directly from the WPI Laboratory Procedures archive. Per Nitsch Engineering, the analytes we tested for were total suspended solids (TSS), alkalinity, total phosphorus, ammonia, manganese, iron, copper, lead, sodium, magnesium, calcium, phosphate, nitrate, nitrite, sulfate, bromide, chloride, and fluoride. In order to conduct the analysis of all constituents, 1350ml of runoff were collected per sample.

Total phosphorus, ammonia, and TSS concentrations were determined using separate procedures; see Appendix E, Appendix, F, and Appendix G respectively. The alkalinity was analyzed using a titration based analysis, see Appendix H. Many of the analyses were processed using an ion chromatography system (ICS). These included: phosphate, nitrate, nitrite, sulfate, bromide, chloride, and fluoride. See Appendix I for the procedure of using the ICS system. The concentration of manganese, iron, copper, lead, sodium, magnesium, and calcium were processed by an inductively coupled plasma mass spectrometry (ICP MS) system, see Appendix J. Following a rain event and field sampling the samples were taken directly to the Environmental Laboratory at Worcester Polytechnic Institute. As previously mentioned, duplicates were collected as well. These duplicate samples were tested with the rest, to ensure both sampling and equipment quality. Additionally, lab duplicates were performed on the same sample from a location to ensure that the results were consistent. A summary of the average percent differences can be found in Table 4 as follows.

Table 4: Average Percent Differences with Exclusion of Major Outliers

Alkalinity	**TSS**	**Manganese**	**Iron**	**Copper**	**Lead**	**Sodium**	**Magnesium**	**Calcium**
34.4%	8.85%	18.9%	13.7%	11.0%	7.86%	14.1%	7.07%	17.1%
Ammonia	**Total Phosphorus**	**Phosphate**	**Nitrate**	**Nitrite**	**Sulfate**	**Bromide**	**Chloride**	**Fluoride**
1.93%	15.1%	8.56%	17.2%	12.0%	18.1%	0.00%	14.6%	26.6%

It should be noted that the percent differences account for variability in both the specific lab test and in sample collection. These percent differences represent the variability inherent in our approach and should be considered when assessing the validity of the results.

4.5 Use the research, sampling, and analysis to design a best management practice to implement on the WPI campus

This section will outline the steps necessary to complete the Best Management Practice (BMP) design based on research, sampling, and analysis. This section demonstrates how water quality information can inform the design of BMPs, using the WPI campus as a case study. Two designs were created for the WPI campus. The first used subwatershed areas to determine locations for specific BMPs. The other used our water quality data based on surface type to determine the types of land areas for specific BMPs. This allowed for comparison between the designs and for the evaluation of the merit of utilizing water quality data based on specific land types.

4.5.1 Downstream Design

The first step, using the created map in Autocad Civil 3D, was to delineate the eastern part of the campus watershed into several catchments to determine the number of catchments and the total area of each catchment. These catchments were delineated using their drainage patterns as determined by topography as well as roof pitches and catch basin drainage systems. This information was gathered from Arcmap and Google maps and their surface areas were calculated using Auto Civil 3D. This information was then used along with rainfall amounts for typical design storms in Massachusetts (one & two year storm for frequent events and 10, 25 and 100 year for flooding events) to calculate volumetric flow rates from each catchment. See Table 5 for design storms for Massachusetts.

Table 5: The precipitation frequency for Massachusetts (US Department of Commerce, et al, 2005)

Partial Duration Series frequency estimates with 90% confidence interval (inches)					
Duration	**Average Recurrence Interval (years)**				
	1	2	10	25	100
24-hr	2.5	3.12	4.06	5.92	7.57

The volumetric flow rates from each catchment were used to determine the size requirement of a single downstream design that would treat the total flow. This was modeled using HydroCAD for the designated rain events. An area located downstream of all of the drainage catchments, as indicated by their individual drainage patterns, was chosen as the location for the downstream design. BMPs were then selected to meet adequate treatment rates, accommodate constraints of the specific design location, and to maximize construction feasibility. Since this downstream design does not take into account ways in which runoff water quality varies by surface type, it was taken as the baseline for comparison to our final design.

4.5.2 Design Based on Surface Type

In order to identify surfaces of most concern in the eastern portion of the WPI campus, both the concentrations of contaminants from each surface and the total area of the surface need to be considered. This allows us to quantify the contaminant contributions in mass loadings to find surfaces that contribute the most during a rain event. To do this, Civil 3D and Google Maps were used to divide the eastern portion of WPI campus by surface type: parking lot, light road, heavy road, walkway, grass, green roof, and grey roof. The rainfall from a one year storm was used as a point of comparison to determine volumetric flow rates from each total surface area. This information was then combined with the data we found through our laboratory procedures to determine relative loadings of each contaminant that would be discharged during a storm from each type of surface. The types of surfaces with the greatest contaminant loads became the focus for our design to most effectively improve the overall stormwater runoff from the campus. Locations were identified on campus that would allow a BMP design to treat the greatest amount of runoff from the surfaces of most concern. BMPs were then selected to most effectively treat surface runoff and mitigate any constraints for the design at each location. HydroCAD was used to model flows into each BMP during specific design storms (one & two year storm for frequent events and 10, 25 and 100 year for flooding events) in order to determine adequate sizings for the systems. Ease of implementation, maintenance, construction costs, as well as aesthetics were also taken into account when considering the overall design.

5.0 Results

This section presents the results illustrating the various concentrations of contaminants, and their relation to surface type and their effect on BMP design. This chapter provides information on the final sampling sites chosen, and the samples gathered. It also includes the results from the lab analyses and the conclusions related to surface type and contaminant concentrations and loading. Finally, it detail our final BMP designs with their respective cost and nutrient removal. There is also information on how designing based on surface type compares to designing based on volume for both removal and cost.

5.1 Campus Mapping and Areas of Interest

The result of the site analysis and locations can be seen in Figure 5. This figure shows the Areas of Interest (AOIs) and the sampling sites. The AOIs were chosen in order to represent walkway pavement, parking lot pavement, grassy area, standard roof, and green roof surfaces as well as Salisbury Pond, the water body that receives stormwater runoff from the WPI campus. Therefore, the types of areas shown in Table 6, were sampled.

Table 6: Summary of AOI Surfaces types and land uses

AOI #1	AOI #2	AOI #3	AOI #4	AOI #5	AOI #6	AOI #7	AOI #8
Parking Lot	Lightly Trafficked Road	Heavily Trafficked Road	Walkway	Grass Hillside	Salisbury Pond	Green Roof	Grey Roof

The specific sites were also chosen based on the fact that they all were accessible for sampling and that, during a rain event, they were observed to be high flow areas. The AOI locations can be seen in Figure 5.

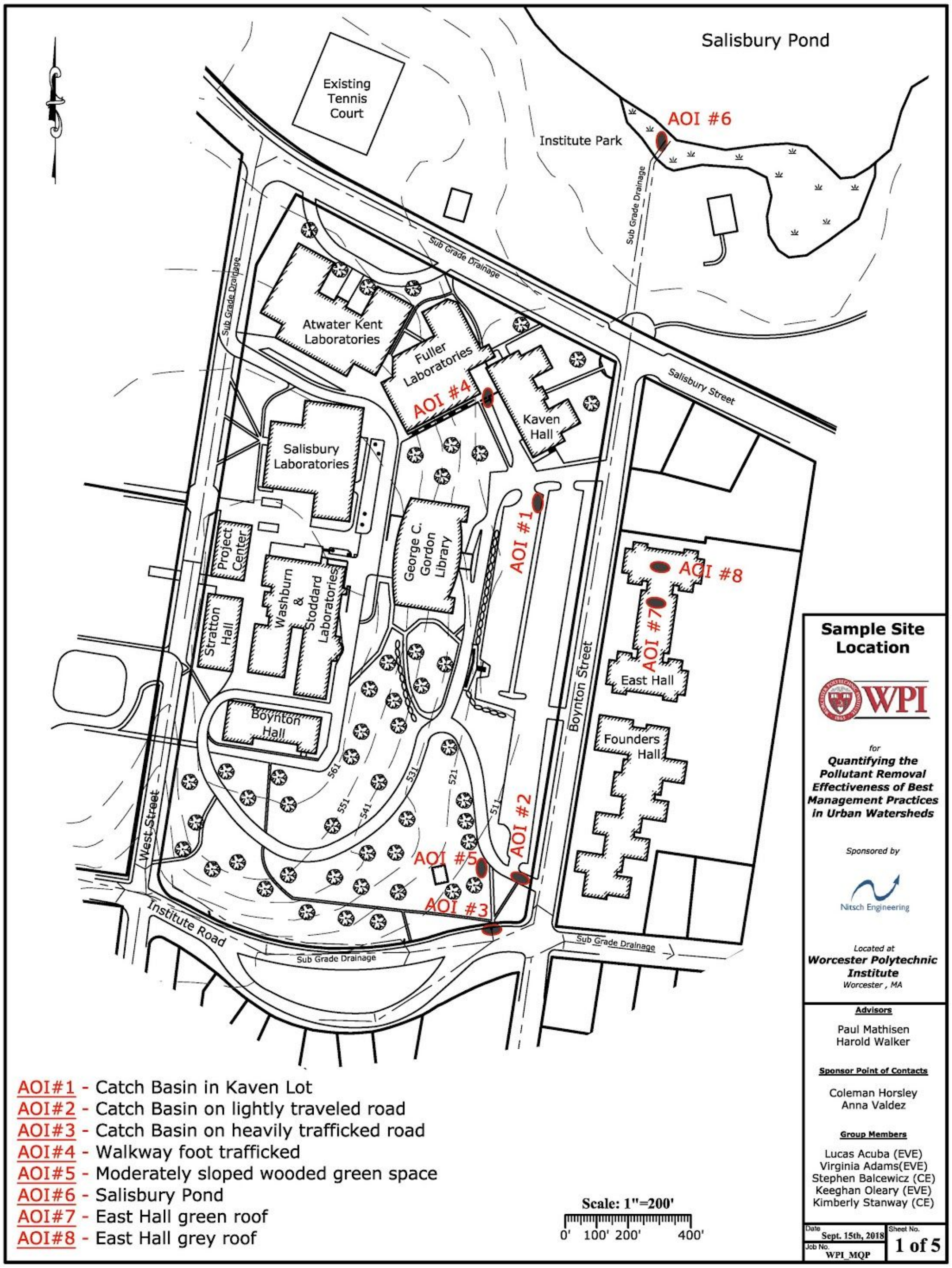

Figure 5: Map of Sampling Points of Interest on the WPI Campus. Derived from OliverGIS, Arcmap, NRCS, Streamstats, and Google maps.

These sites have several different criteria that made them areas of interest. This can be seen in Table 7. Table 7 also details the surface type, location, and sampling method that was implemented.

Table 7: Summary of Sampled Surfaces

Surface Type	Criteria	Location	Sampling Method
Parking Lot	-Heavily used parking lot -Minimal Pervious Surface -Accessible drains/catch basins with decent flow in light rain	-Boynton Street Lot WPI Campus -Parking lot catch basin	1A
Light Traffic Road	-Lightly trafficked road -Minimal pervious surface -Gradual slope ~5-15% -Accessible drain with decent flow in light rain	-Private WPI way adjacent to Boynton Street Parking Lot -Road drain	1A
Discharge Water Body	-Receiving water body for stormwater from sampling areas	-Salisbury Pond	4-
Heavy Traffic Road	-Heavily trafficked road -Minimal pervious surface -Accessible drain with decent flow in light rain	-Road drain at corner of Institute Road and Boynton Street	1A
Walkway	-Isolated Sidewalk Drain -Accessible drains/catch basins with decent flow in light rain -Flat	-Sidewalk catch Basin at the Bottom of the Steps beside Fuller Labs -Near Kaven Hall 111b	1-
Green Roof	-Isolated Green Roof drain -Accessible drain with decent flow in light rain	-East Hall Green Roof Effluent (Mechanical Room)	3C
Grey Roof	-Isolated Grey Roof drain -Accessible drain with decent flow in light rain	-East Hall Grey Roof Effluent (Mechanical Room)	3C
Grassy Hill	-Steep slope ~15-30% grassy area -Maximum pervious surface -Area free of heavy tree cover or manmade structures	-Grassy hill adjacent to skull tomb (Corner of Institute rd. and Boynton st.)	2-

5.2 Objectives 2 and 3: Sample Collection and Analysis

As stated in the Methodology (section 4.4.2), our constituents of interest were; total suspended solids (TSS), alkalinity, total phosphorus, ammonia, manganese, iron, copper, lead, sodium, magnesium, calcium, phosphate, nitrate, nitrite, sulfate, bromide, chloride, and fluoride. The hypothesis driving this project was that concentrations of these constituents would differ by type of surface: parking lot, lightly trafficked road, heavily trafficked road, walkway, green roof, grey roof, and grass hill. Therefore, data in this report are presented in order to compare concentrations of each pollutant between the various surfaces. Data was also collected within a close proximity to the discharge water body (Salisbury Pond). This was necessary to provide information about contaminants polluting the adjacent water body that are likely to have been contributed, in part, by stormwater runoff from the WPI campus. Averages of the concentrations measured from the samples taken during the different storms and times during storms are presented as follows in Figure 6.

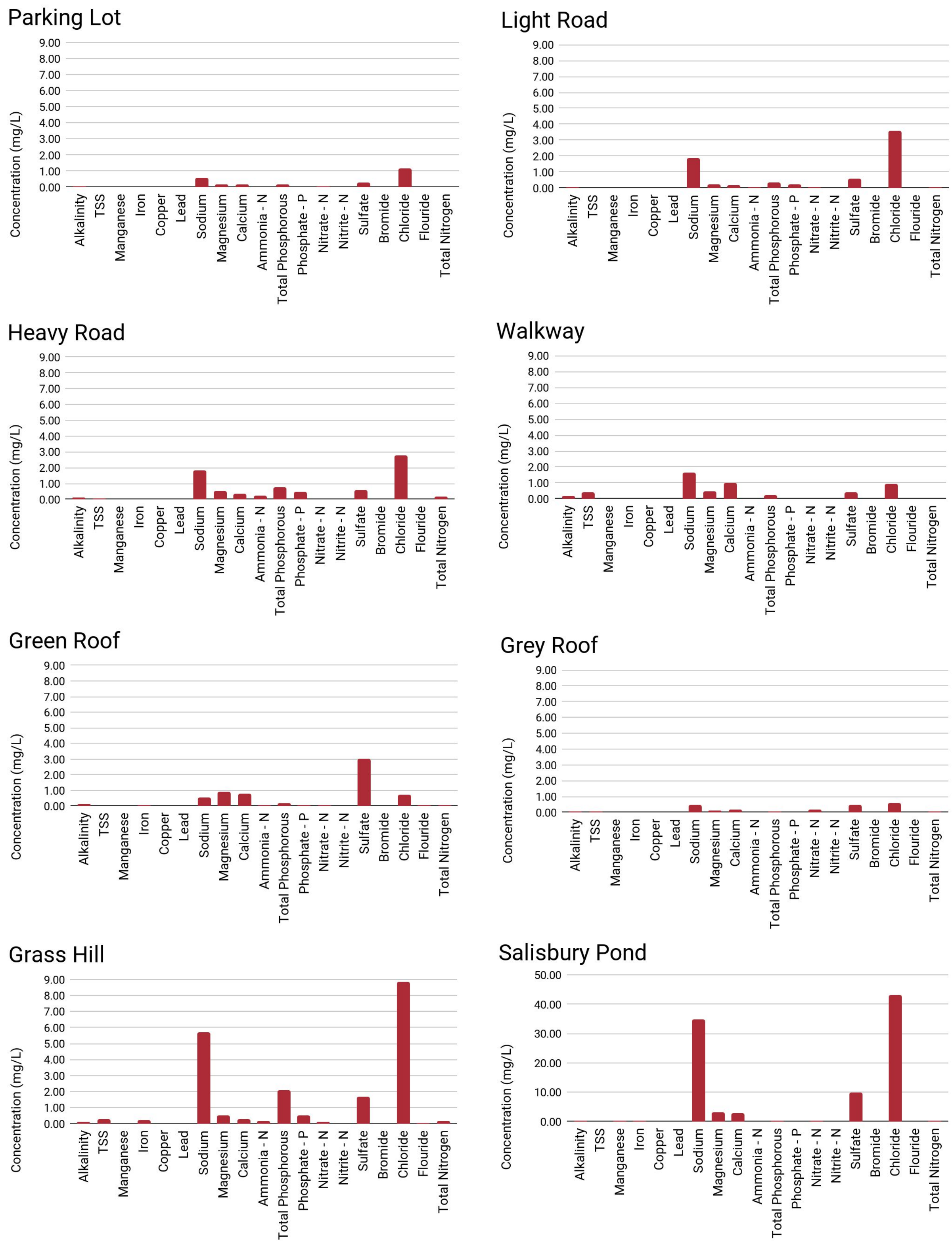

Figure 6: Average Concentrations of Analytes by Surface

Note that the concentrations plotted in Figure 6 are averages of all concentrations measured. This include values from samples taken from different storms and at different times during these storms. To view data specific to each storm and sample time, see Appendix L. Also note that the values for Salisbury Pond are plotted in the range of 0 to 50 mg/L while the other sites are plotted in the range of 0 to 9 mg/L because of the elevated concentrations measured in samples from Salisbury Pond. Additionally, the measures of ammonia, total phosphorus, phosphate, nitrate, and nitrite and presented in units of mg/L as phosphorus and nitrogen respectively.

The highest overall magnitudes of pollutant concentrations are shown in the Grass Hill and Heavy Road graphs in Figure 6 with the lowest magnitudes coming from samples of the Parking Lot and Grey Roof surfaces. This would begin to indicate that grassy areas and heavily trafficked roads should be considered areas of focus for BMP implementation as this would treat runoff with the highest concentrations of contaminants, while parking lots and grey roofs should be considered nearly negligible. This would allow runoff of the most concern to be specifically treated while maintaining a set budget. However, as will be discussed in section 4.4, the amount of area of each surface in a particular urban environment influences the determination of prioritized locations for BMPs as this determines the volumetric flow from the area. Therefore, the loading by mass of the analytes from each area is a more effective method of comparison as it takes into account both concentrations and volumetric flow.

It can also be observed in Figure 6 that there are high concentrations of both sodium and chloride at all sample sites likely from road salt. This came as a surprise because all samples were taken during the fall season before the first snowfall and the roads and walkways on the WPI campus were not visibly salted until after our last sample was taken. This indicates that sodium and chloride have accumulated on a wide range of surfaces from previous winter seasons. It is especially concerning because these contaminants are then transferred into Salisbury Pond as runoff, where we found the average sodium and chloride levels to already be 35 and 43 mg/L respectively.

It should also be considered that contaminant concentrations varied during the duration on a single storm. This is due to variance in flowrate and the degree to which runoff removes and picks up contaminants from a surface. An example is shown in Figure 7 of the grass hill and light road surfaces using the cation and anion concentrations which were sampled at four points during each storm.

Figure 7: Concentration Curves over Duration of 11/3 Storm

This storm began at approximately 12:00 am on November 3rd (11/3) and the first sample was taken at 7:18 am. Therefore, the first flush of contaminants in the storm was missed. However, the concentrations of both anions and cations at each storm follow a similar distribution of increasing to peak at around 8:30 am, decreasing, then increasing again at 10:38 am. This follows the changes in storm intensity as the quantity of rainfall increased at approximately 8:00 am and 10:00 am as shown in Figure 8 below.

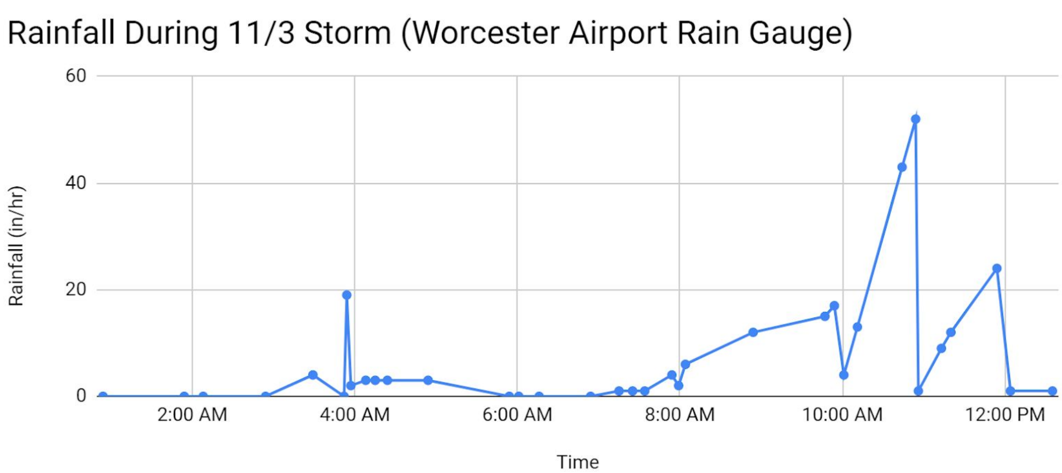

Figure 8: Rainfall during 11/3 Storm from Worcester Airport Rain Gauge

The rainfall data is measured as a rate of inches per hour as collected by a rain gauge located at the Worcester Airport.

Total suspended solids and total phosphorus are contaminants of particular concern for stormwater quality and for BMP design in general. The Massachusetts Stormwater Management Standards include a requirement to remove 80% off total suspended solids from stormwater runoff (MassDEP, 2018). Concentrations of these two contaminants that are contributed from each surface can be seen more closely in Figure 9 as follows.

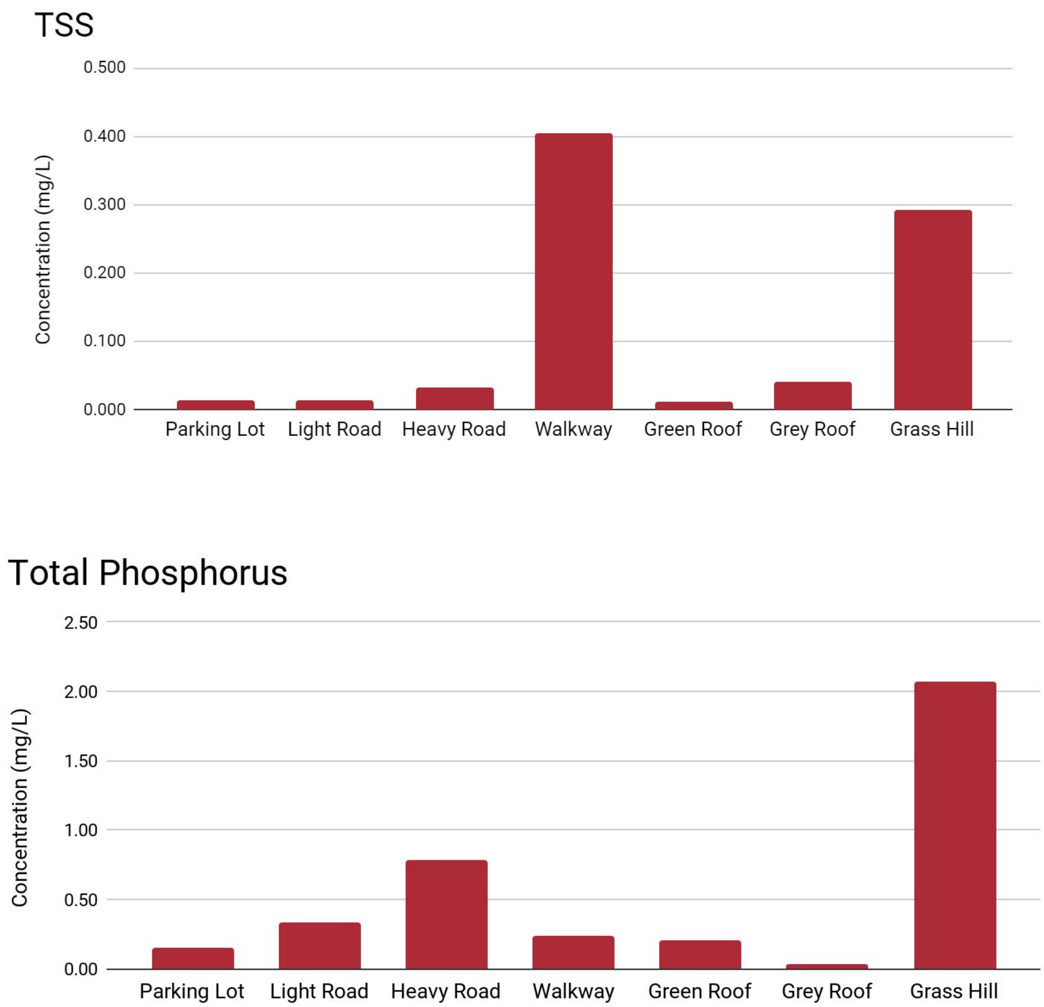

Figure 9: TSS and Total Phosphorus Concentrations by Surface

The grass hill area exhibits high concentrations in both total suspended solids and total phosphorus in Figure 9. The walkway area had the highest concentration of TSS however, it had one of the lowest concentrations of total phosphorus. This shows that the major contributors of contamination vary.. When attempting to reduce TSS contamination, grass hills and walkway would be target areas for improvement. However, heavily used roads and grass hills would be of greater concern if the focus is to reduce nutrient contamination. Though the areas with the greatest contribution of contaminants on a site depends of the amount of area of each surface type on the site, as will be explained in Section 4.4. It can also be observed in Figure 9 that the grass hill area contained a concentration of total phosphorus that was significantly greater than the other sampling sites. Initially, we believed the elevated phosphorus levels were due to the fertilizer being used on campus. The specific fertilizer composition can be found in Table 8.

Table 8: WPI Fertilizer Composition in 2018 Season Applications (WPI Facilities, 2019)

Date Applied	Nitrogen	Phosphorus	Potassium	Note
5/2/18	19%	0%	7%	With Dimension (crabgrass control)
6/5/18	25%	0%	5%	-
8/15/18	19%	0%	2%	With Merit (grub control)
9/10/18	25%	0%	5%	-
10/9/18	25%	0%	5%	-

The fertilizer applied on the WPI campus during the study period does not contain phosphorus and therefore is not contributing to the high levels of phosphorus in the grass areas. This indicates that the phosphorus contamination is likely not as result of the fertilizer and may be result of natural phenomena such as weathering of rocks, atmospheric deposition, decomposition of organic material, or leaching from surrounding soil. However, the presence of nitrogen in the fertilizer could have affected measured total nitrogen concentrations at the grass hill site as shown in Figure 10 below.

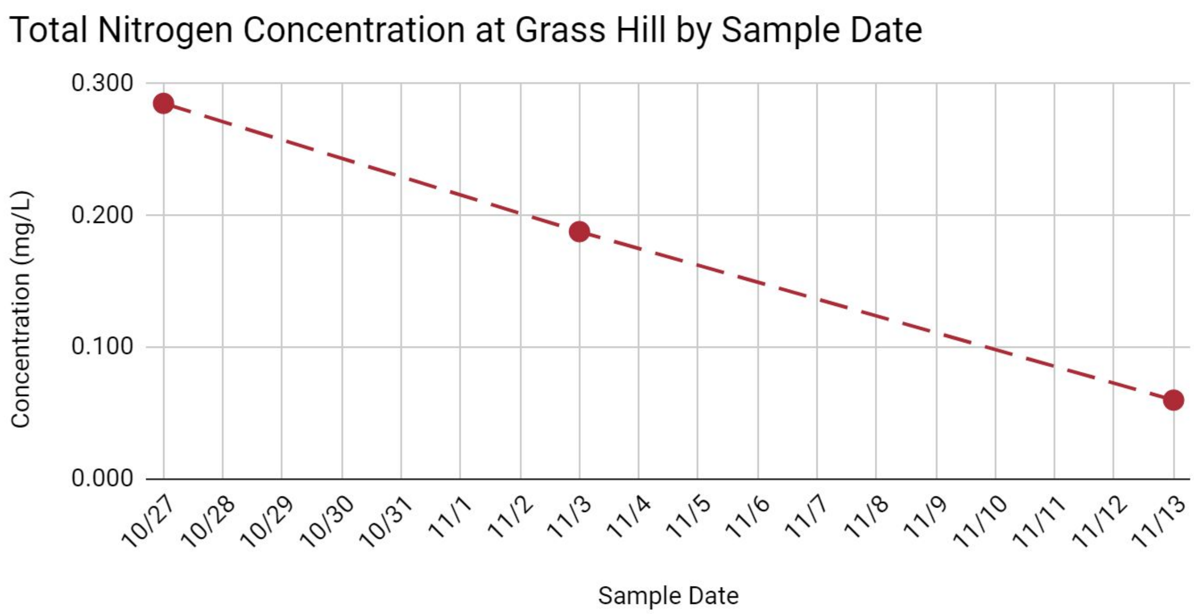

Figure 10: Total Nitrogen Concentrations as a Function of Sample Date

The last application date of fertilizer was October 9th (10/9) and our first sample collection date was on October 27th (10/27). Samples were then also collected on November 3rd (11/3) and November 13th (11/13). Figure 10 shows a steady decrease in total nitrogen concentrations from 1027 to 1/13. The could indicate that total nitrogen levels were high on 10/27 due to the last fertilizer application on 10/9 and decreased as time passed and stormwater runoff washed away residual fertilizer.

5.3 Objective 4: Best Management Practice (BMP) Design

This section will outline the delineation of the subcatchments, the analyzed contaminant loading by surface, and the determined locations of interest for BMP Design.

5.3.1 Delineation of Subcatchments

In order to complete a downstream BMP design, the stormwater runoff from the eastern side of the WPI campus needed to be quantified. This included delineating the area into separate catchments based on their drainage patterns as well as determining the size of the catchment and the percentages of the urban surface within its delineated boundaries. After this, it was determined that there were five subcatchments existing within the eastern side of WPI's campus with a sixth catchment including Institute Park, city property. It is important to note that two decisions were made when executing this objective.

The first decision was whether to include off campus surfaces. In two subcatchments, WPI runoff was combined, off site, on city property in subsurface drainage systems. Therefore, these subcatchments include city property (Institute Road and Boynton Street) because campus runoff could not be isolated from the contributions of the city. Additionally, it was determined that AOI #4 was on city property, within the catchment, so the contributions were relevant.

Secondly, an accurate understanding of the roof drainage system could not be determined. A Google map image was used to subdivide the roofs accordingly. Pitched roofs were subdivided by pitch direction and added to the respective subcatchments. Flat roofs were approximately subdivided and added to adjacent catchments. Roofs that were completely within a catchment were determined to contribute its runoff directly to the catchment.

The complete catchment delineation map can be seen in Figure 11 and the catchments were numbered in a counterclockwise manner starting with catchment #1 in green and catchment #5 in magenta.

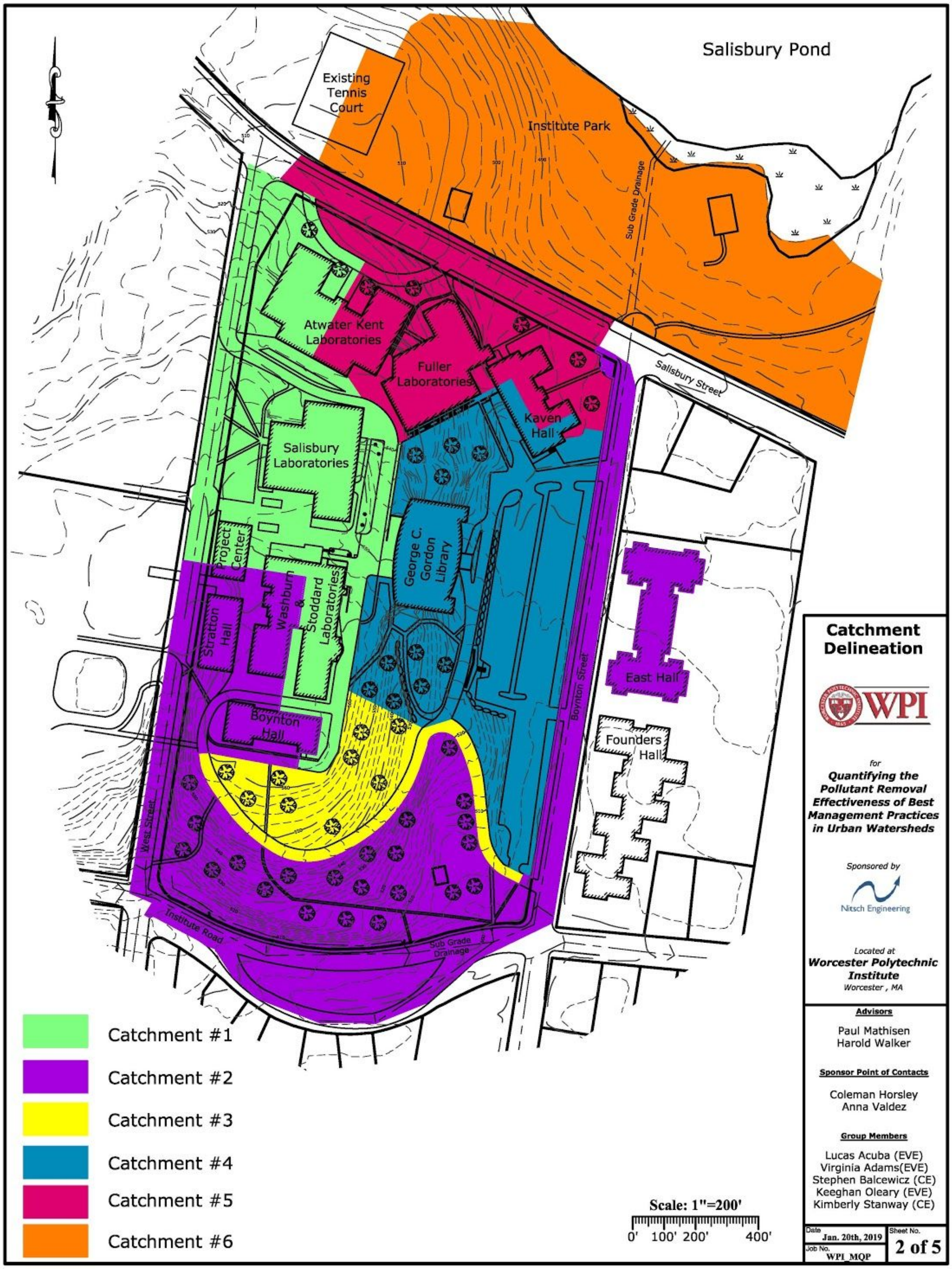

Figure 11: Delineated Subcatchments on the eastern portion of WPI's campus

Catchment areas were characterized as either pervious or impervious surface in order to define the quantity and flow rate of runoff from each catchment. When quantifying the percentages of surface type within each subcatchment the data taken from Arcmap and a Google map images were utilized. To improve the surface type understanding, within each subcatchment, additional surface boundaries were drafted from the Google image that were not included in the exported data from Arcmap. Within Autocad Civil 3D, the surface type areas were determined and compiled in Table 9.

Table 9: The determined surface quantity in acres of each subcatchment (1 acre = 43,560 s.f.)

	Catchment #1	Catchment #2	Catchment #3	Catchment #4	Catchment #5	Catchment #6
Impervious	2.19	3.38	0.41	2.47	2.38	0.41
Pervious	1.08	3.27	0.92	1.23	0.89	6.29

5.3.2 Contaminant Loadings by Surface Type

In order to design BMPs based on surface type, it was necessary to determine the contribution of contaminants from each type of surface. This involved the use of the concentrations of analytes at each surface as presented in section 5.2 of the Results. The total area of each surface type were calculated with Auto Civil 3D using data from both Arcmap and Google map images. The surface type areas are shown in Table 10.

Table 10: Total Area of each Surface Type within Eastern WPI Campus

	Parking Lot	Light Road	Heavy Road	Walkway	Green Roof	Grey Roof	Grass
Total Area (acres)	1.25	2.03	1.95	2.31	0.13	3.54	7.39

Loadings of each contaminant by surface type were calculated using the concentrations of contaminants at each surface and their total areas of campus. Runoff volumes were determined based on the rainfall depth of a 1 year storm (2.55 in). This provided information on the quantity of contaminants that were contributed by each surface type to the total load of contaminants in runoff from the WPI campus. Therefore, BMPs can be designed to treat runoff from specific surfaces that would provide the highest amount of pollutant load while treating minimal volumetric and thereby minimizing sizing and implementation costs. It is important to note that the relative load depends on the contributing area, which in this case is the total area of a contributing surface type. Surface loading data can be seen in the loading graphs in Figure 12.

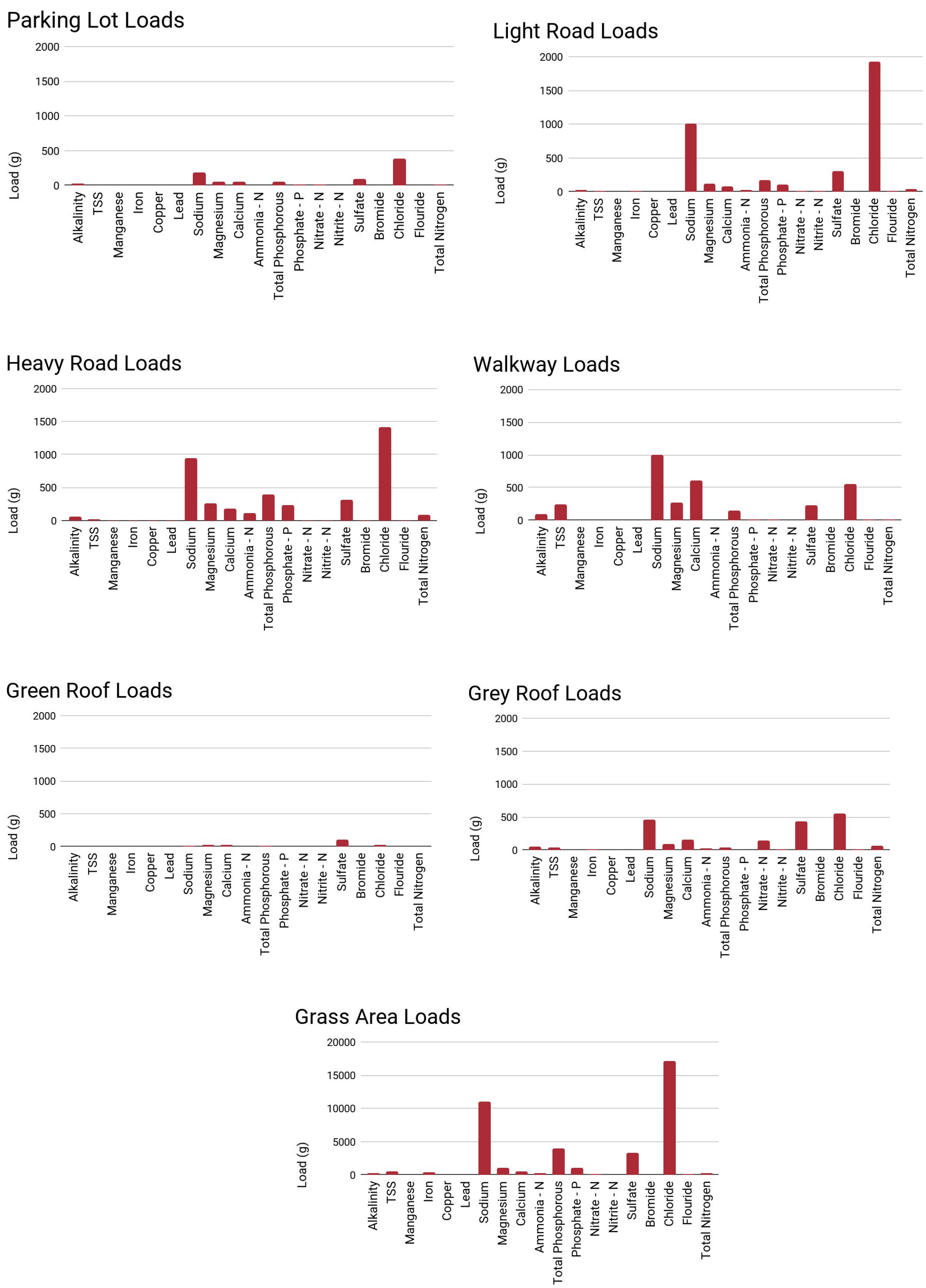

Figure 12: Loading of Contaminants from each Surface Type on WPI Campus

Note that all graphs are presented on an axis from 0 to 2,000 g except for the grass area which is presented on an axis from 0 to 40,000 g due to its large magnitude. As seen in Figure 12*,* the largest loading came in the grass area followed by both the light road and walkways. With this, the BMPs were chosen for the design based on surface type in order to mitigate the pollutants from the two largest contributing surfaces: grass areas, lightly trafficked roads, and walkways.

5.3.3 Determination of BMP Design Locations

After completing the sample analysis, it was determined that there were three surfaces on WPI's campus which had high concentrations of contaminants per square foot. These surfaces include grass areas, lightly trafficked roads, and walkways. The locations of the BMP design were specifically chosen to be at locations on campus with high percentages of these surface types. In particular, there was a significant amount of grass and roadways within Catchments #1 and #2. Within these catchments there were three areas of design. The first, was located in the grass area next to the Atwater Kent building on the corner of Salisbury Street and West Street (Lightly traveled access road). The second and third locations were on the grass hill near Skull Tomb, which runs parallel to Institute Road in front of Boynton Hall. These three surface design locations are represented with green X's on Figure 13 as follows.

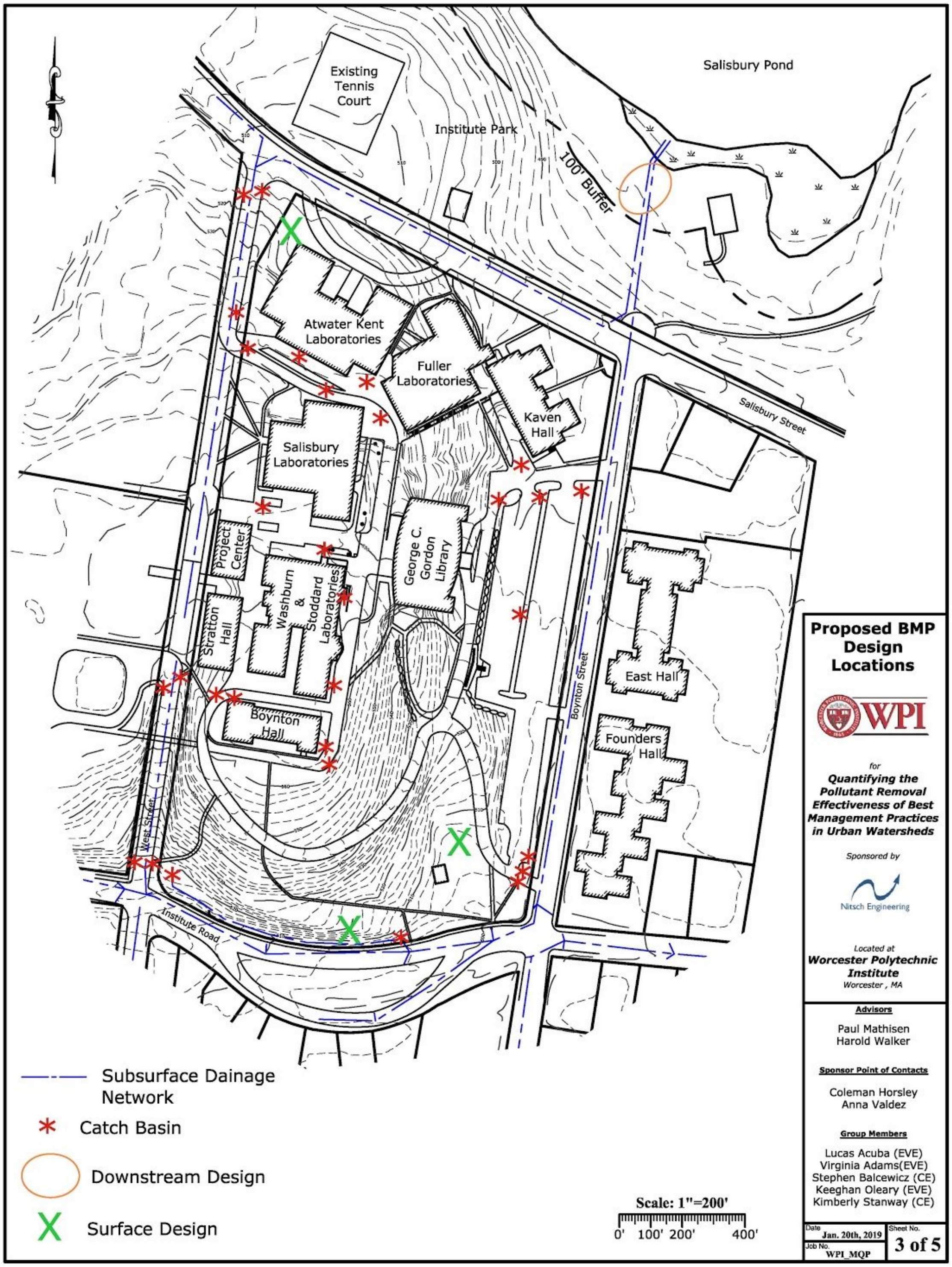

Figure 13: The expected BMP design locations.

The red asterisks mark catch basins which are of concern for the surface based design because they receive runoff from both lightly trafficked access roads and walkways. The orange circle represents the location for a downstream design as all runoff from the eastern portion of the WPI campus drains to this general area before discharging into Salisbury Pond.

5.3.4 Downstream Design

In order to create a baseline for comparison, a downstream BMP design was created. In a downstream design the runoff is directed into a system that is intended to treat all of the runoff coming from upstream. This would mean that the pollutants coming from all of the catch basins on the WPI campus and surface runoff would be collected and treated at a central downstream location.

When researching downstream designs, there were several options that did not meet the specific needs of the treatment system. The first limiting factor was the existing subsurface drainage system. Currently, most of the easterly part of the WPI campus drainage system is collected in catch basins, that pretreat the runoff, before it is diverted through pipes to the design point. As a result of the existing structural pretreatment BMPs (oil/grit separators, catch basins,etc.), there was no need for this component in the design. The next limiting factor, that voided certain BMPs, was the drainage network itself. The existing runoff is already being diverted to the design point, without treatment, and does not need to be transported to a treatment area. Therefore, Conveyance BMPs (drainage channels, water quality swales, etc.) were neglected. Finally, because the primary purpose was to maximize treatment and infiltration, any BMP that limited the amount of infiltration was eliminated from the prospected design.

The two options that were determined to be the best fit for design purposes were a constructed stormwater wetland and a subsurface infiltration system. The constructed wetland would have been designed to be located in Institute Park, adjacent to Salisbury Pond, at the end of the existing drainage network. The constructed wetland was a possibility because it could account for a large volume, resulting from the magnitude of the area it is treating, and it would add a pleasing appearance to the park. Additionally, because the existing catch basins pretreat the runoff (trash, oils, and debris) the primary focus of the design could be isolated to advance treatment and maximize infiltration. The second option was similar in this manner because pretreatment allowed for the design to be tailored to additional treatment and infiltration. By placing this design underground, no parking spaces would be compromised. Although, this type of design presented a more desirable characteristic by treating runoff underground; it was determined to be the least plausible because the water table was expected to be high in this area. The close proximity to Salisbury Pond and existing vegetation validated this decision when the location was reviewed in the field. Additionally, when making this analysis, the cost effectiveness of the construction was taken into consideration. By raising the system to meet groundwater offsets more material would be required, which would increase the cost of material associated with the design. After discussion and research it was decided that the constructed wetland would be the better downstream option.

The downstream control system would treat the majority of runoff from campus regardless of surface type. This wetland would allow for the removal of pollutants that come from the entire upstream system. The wetland would include a sediment forebay as pretreatment and a large constructed pond. This would provide removal rates of 80% removal of TSS, 20-55% of total nitrogen, 40-60% of total phosphorus, and 20-85% metals. Constructed stormwater wetlands provide for relatively high removal of pollutants and low maintenance cost (MassDEP, 2008). However, they tend to be large and costly to construct. When analyzing the downstream design flow it was vital to determine the flow capacity running off the six delineated Catchments. See Figure 14 for this analysis.

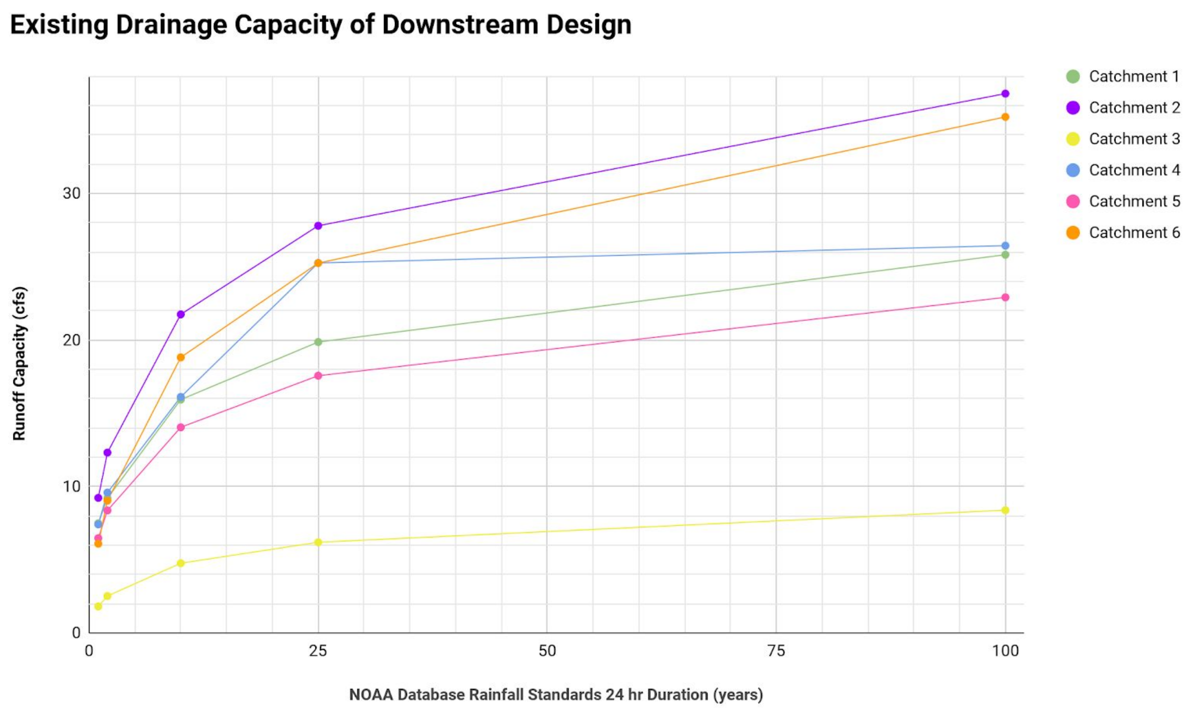

Figure 14: Drainage Capacity from each Sub Catchment into a Downstream Design utilizing HydroCAD and AutoCAD Civil 3D

Using a 25 year storm as an example, peak flow rates from each sub catchment do not exceed 30 cubic feet per second but their cumulative flow rate reaches 122 cubic feet per second. Because of this peak flow rate from the upstream catchments, the design would have to be quite large to have enough storage which would drive up construction costs. Another limitation of the downstream design is its proximity to the wetland surrounding Salisbury Pond. Construction in this location would need to take into account any regulations or special permits that required when building near a wetland and near protected plant species along the water's edge. This would include a 100 ft buffer from the water's edge which could interfere with the required size of the design in order to ensure adequate treatment. However, this may be able to be overcome with a special variance.

5.3.5 Design Based on Surface Type

A surface type design was addressed as a potential stormwater management improvement to WPI's campus for two reasons. The first reason, is that it would isolate and treat areas that contribute the most pollutant loading during a particular storm event. This characteristic allows for an immediate treatment to poor quality runoff before it can contaminate other surface runoff that is minimally or not contaminated at all. The next purpose for choosing surface design, is to minimize the overall size of the treatment system. By confining treatment to critical contaminated surfaces, the overall system size can be significantly reduced, while also maximizing the pollutant removal rate. Furthermore, the reduction in size is advantageous to the total cost associated with the stormwater management system implementation and maintenance. Rather than treating all stormwater as a whole, designs could be methodically placed to address surfaces with the most contamination to achieve a more efficient system.

The surfaces of most concern were grass areas, lightly trafficked roads, and walkways so the design based on surface type targeted these types of areas. The three design locations that would maximize the treatment of runoff from grassy surfaces are the grass area next to the Atwater Kent building on on the corner of Salisbury Street and West Street, and two locations on the grass hill near Skill Tomb and parallel to Institute Road. These locations can be seen mapped in the BMP Design Locations section previously (figure 13). There were several physical characteristics associated with these locations that dictated the form of BMP that would be implemented. With regards to the Atwater Kent location, there was minimal space to design a BMP. Therefore, the design had to be compact, while also effectively capable of removing pollutants. This physical trait restricted the possibility of treating multiple contaminated surface types in the area. This proposed stormwater management improvement is strictly limited to treat the grass area. Regarding the second and third locations, the existing slope varies between 8-23%. Although, this limiting factor restricted the type of BMP, it was determined to be a crucial location to improve runoff quality. The significant quantity of grass, within Catchment #2, and potential contaminant loading it contributed to the campus runoff placed it at the forefront of our design locations. It was concluded that the design at this location would attempt to capture and treat as much of the hill as possible. This was additionally reinforced because the area is naturally undisturbed and poses no size limitations.

As a result of these limitations the BMPs were chosen from a few potential candidates such as a Downstream Design, existing Structural and Conveyance BMP's within the campus boundaries made these BMPs irrelevant for this case. Additionally, the goals of minimizing storage capacity and maximizing infiltration were still of interest. The next standard involved the particular contaminants of interest. In many cases, such as dry detention basins for example, efficient removal could not be achieved and were therefore ruled out. Finally it was determined that rain gardens, at the isolated locations were the best option when choosing a BMP.

The rain gardens would not only improve aesthetics around campus with the planting of flowering plants and shrubs, but also increase the removal of pollutants to Salisbury Pond and the surrounding area. By diverting stormwater runoff and then treating it for pollutants (via plants) the BMP will mitigate the amount of nutrients leaving the WPI campus. Rain gardens are relatively low maintenance and have high removal installations. They provide for 90% TSS removal, 30-50% total nitrogen removal, 30-90% total phosphorus removal, and 40-90% metal removal (Mass DEP, 2008). The rain gardens will contain a multitude of plants that are salt tolerant and effective at removing different types of pollutants coming from grass, roadways, and walkways. When choosing these plants it is essential that they be salt tolerant (due to de-icing activities during the winter months) and native to the New England Area. Some examples are as follows; White and Red Oak trees, Buttonbush and Bayberry Shrubs, Birdsfoot trefoil and Perennial ryegrass, and a multitude of Perennials such as New England Aster, Butterfly weed, Cardinal Flower and Wild Ginger (Rain Garden, 2019).

There are three gardens proposed to be installed on the WPI campus; two are located on the steep hill by the Skull Tomb and one is proposed to be constructed in the grass area by the Atwater Kent building. See Table 11 and 12 for the existing drainage analysis, while Figure 15 illustrates these determinations. All calculations were performed using HydroCAD in reference to the created AutoCAD Civil 3D drawing with the corresponding soil classifications from (NRCS). It was determined that the soil classification were Paxton Fine Sandy Loam (305C) and Hinckley Urban Land Land Complex (325C).

Table 11: The existing drainage summary at the Skull Tomb location

Catchment	**Existing Drainage Summary**					
	Length (ft)	**Slope (ft/ft)**	**Velocity (ft/s)**	**Tc (min)**	**Capacity (cfs)**	**Description**
3	50	0.04	0.19	4.3	-	Sheet Flow, A-B Grass Short n=0.15
	200	0.071	5.41	0.6	-	Shallow Concentrated Flow, B-C Paved Kv=20.3fps
	600	0.070	5.24	1.9	7.86	Channel Flow, C-D Paved n=0.013 Area= 1.5 sq. ft.

Table 12: The existing drainage analysis at the Skull Tomb location for a NOAA Database Standard 24 hour duration

Existing Runoff Volumetric Flow Rates					
Storm Intensity	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 Catchment 3	1.82 cfs	2.53 cfs	4.77 cfs	6.20 cfs	8.39 cfs

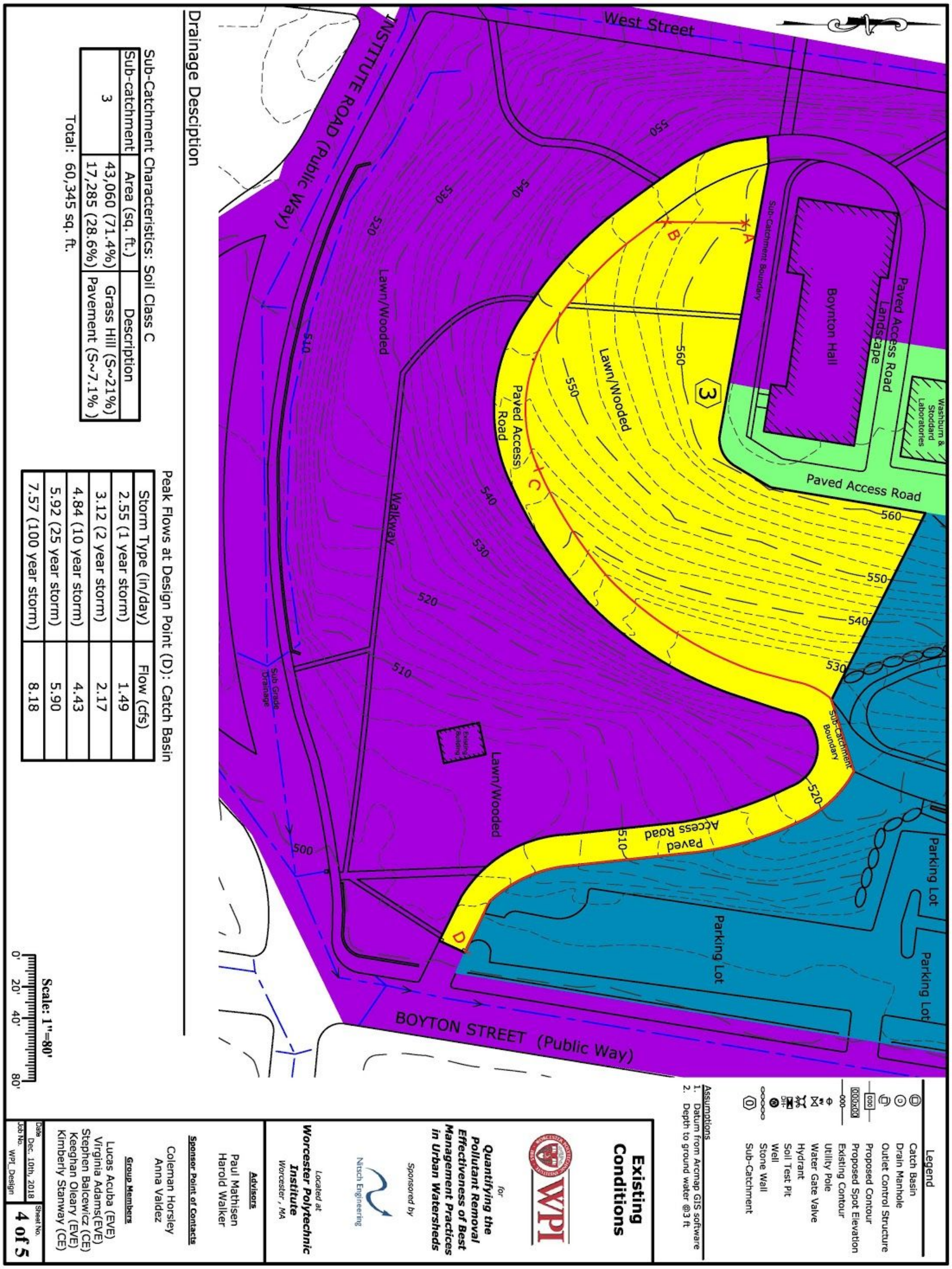

Figure 15: The existing drainage conditions near Skull Tomb.

Tables 13 and 14 and Figure 16 describe the proposed drainage analysis for Catchment 3. Again, all calculations were performed using HydroCAD with reference to the created AutoCAD Civil 3D drawing with the corresponding soil classifications from (NRCS).

Table 13: The proposed drainage analysis at the Skull Tomb location

<table>
<tr><th>Sub Catchment</th><th colspan="6">Proposed Drainage Analysis
NOAA Database Standard (1/2/10/25 yr. storm ~5.92”/day)</th></tr>
<tr><th></th><th>Length (ft)</th><th>Slope (ft/ft)</th><th>Velocity (ft/s)</th><th>Tc (min)</th><th>Capacity (cfs)</th><th>Description</th></tr>
<tr><td rowspan="3">3a</td><td>50</td><td>0.13</td><td>0.31</td><td>2.7</td><td>-</td><td>Sheet Flow, F-G
Grass Short n=0.15</td></tr>
<tr><td>200</td><td>0.07</td><td>5.37</td><td>0.6</td><td>-</td><td>Shallow Concentrated Flow, G-H
Paved Kv=20.3fps</td></tr>
<tr><td>260</td><td>0.07</td><td>5.26</td><td>0.8</td><td>7.88</td><td>Channel Flow, H-I
Paved n=0.013
Area= 1.5 sq. ft.</td></tr>
<tr><td rowspan="2">3b</td><td>50</td><td>0.08</td><td>0.25</td><td>3.3</td><td>-</td><td>Sheet Flow M-N
Grass Short n=0.15</td></tr>
<tr><td>120</td><td>0.10</td><td>5.09</td><td>0.4</td><td>-</td><td>Shallow Concentrated Flow N-O
Paved Kv=16.1 fps</td></tr>
<tr><td rowspan="2">3c</td><td>50</td><td>0.08</td><td>2.05</td><td>0.4</td><td>-</td><td>Sheet Flow, P-Q
Smooth Surface n=0.01</td></tr>
<tr><td>250</td><td>0.07</td><td>5.37</td><td>0.8</td><td>-</td><td>Shallow Concentrated Flow, Q-R
Paved Kv= 20.3 fps</td></tr>
</table>

Table 14: The proposed drainage analysis at the Skull Tomb location for a NOAA Database Standard 24 hour duration

Proposed Drainage Volumetric Flow Rates					
Storm Intensity	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 Subcatchment 3a	1.27 cfs	1.91 cfs	4.06 cfs	5.49 cfs	7.71 cfs
Runoff Of Subcatchment 3b	0.26 cfs	0.42 cfs	1.01 cfs	1.42 cfs	2.06 cfs
Runoff Of Subcatchment 3c	0.38 cfs	0.47 cfs	0.74 cfs	0.91 cfs	1.16 cfs

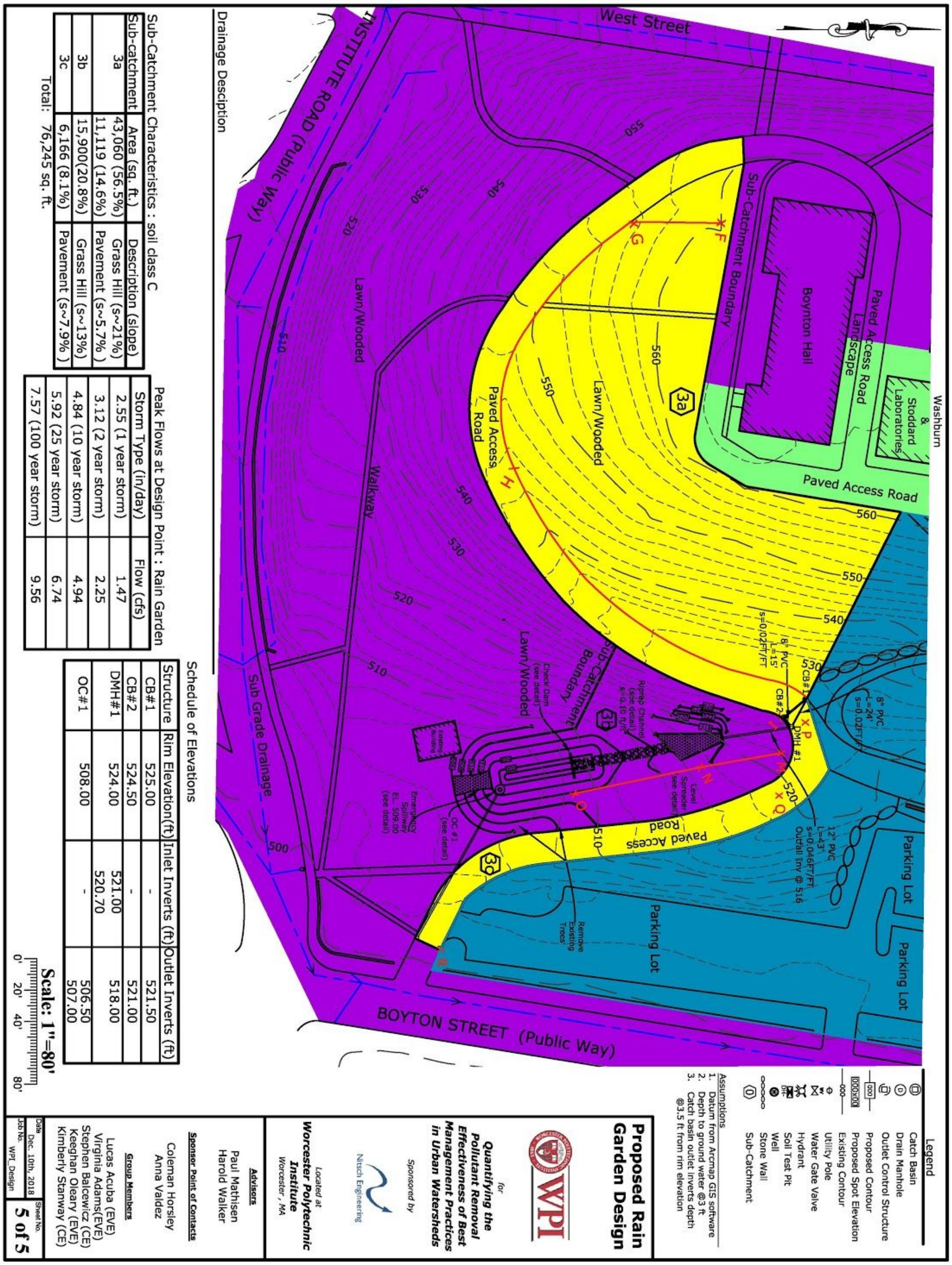

Figure 16: The proposed drainage design near Skull Tomb.

As shown in Figure 16, the stormwater management system design, located next to Skull Tomb, includes: two catch basins, one drain manhole, a level spreader, a riparian channel (swale), sediment forebay, rain garden, and an outlet control structure. This management system was design to maximize the treatment amount of grass and roadway runoff through: settlement, filtration, and infiltration. It is important to note that there are no structural pretreatment BMPs within Catchment #2, see Figure 13 for catch basin locations. For this reason, two catch basins were implemented to intercept all of the upgradient flow from the grass and access road north west of the proposed rain garden. The locations of the catch basins were determined to be just before the intersection so that a gravity system could be designed. Additionally, at this location the runoff could easily be intercepted and diverted into the grass area adjacent to the tomb itself. After the runoff was collected in the two Structural Pretreatment BMPs their flows were combined in a drain manhole through two eight inch Polyvinyl Chloride (PVC) pipes. This was crucial because if their flow were combined within one of the catch basins, flooding could occur because the basin could be overloaded. This would be detrimental to the design because the entire system would have been bypassed by allowing large quantities of runoff to surpass the system entirely. Once the flows have been combined in the drain manhole, the captured runoff was diverted to the undeveloped area next to the tomb through a 12 inch PVC pipe. After the flow exits the pipe a level spreader was utilized to slow the high velocity flow down in addition to promoting settlement. Following this, the flow was directed into a riparian channel (slope = 0.01) to continue the settlement, infiltration, and mitigate the possibility of runoff velocity increase from the proposed channel slope. Once the runoff reaches the bioretention area, a sediment forebay is utilized. This form of BMP promotes further pretreatment and settlement of TSS. Settlement is improved by the implementation of a check dam, which allows the runoff to be contained up to a certain elevation before it enters the rain garden. After this elevation is reached, under certain rain event conditions, the runoff will flow into the rain garden where vegetation can filter contaminants and infiltration can occur. To mitigate flooding of the rain garden, an outlet control structure (OCS) was used. This structure allowed outflow from the garden in a storm exceeding a 10 year storm (4.06” in a 24-hr duration). It includes two vertical orifices on the side of the structure and a horizontal catch basin grate on the top. This component is crucial so that the garden will not flood in a 100 year rain event (7.56 “ in a 24-hr duration). If this OCS allows outflow from the pond it is diverted to the existing catch basins at the bottom of the access road and re-enters the existing subsurface system. This outflow will continue to Salisbury Pond, treated by the entire system.

In order to treat runoff from lightly trafficked roads and walkways, the final BMP that is recommended is the use of catch basin filters that should be installed in all of the upstream catch basins on light roads within the sub-catchment area. Since stormwater from the walkways flow onto the access roads, a system in these catch basins would treat both light roads and walkways. The filters can be easily installed into the catch basins. They contain filters that that are effective for removing phosphorus, nitrogen, TSS and other materials. The filters are replaceable and durable. After online research the filter chosen was the DrainPac Filter. Correspondence with DrainPac Sales Manager and Filter Expert Terry Flury revealed the DrainPac Filter has a 90% reduction of hydrocarbons and 77% reductions of pathogens. It also has a total phosphorus and total nitrogen reduction of 75% (T. Flury, personal communication, February 19, 2019). This filter is also great for catching and containing debris such as garbage and other unwanted solids.

5.3.6 BMP Comparisons and Final Recommendation

While the surface and downstream designs are both capable of treating runoff from the WPI campus, there are advantages to using the design based on surface type. The design based on surface type, located at Skull Tomb, provides three district characteristics that make it a valuable contribution for to WPI's stormwater management. These characteristics include volumetric flow reduction, contaminant removal, and collection of sediment and debris.

The first is that it promotes a reduction in volumetric flow rates at Salisbury Pond. It was determined that treating flow at this upstream location, before it reaches Salisbury Pond, will decrease the flow rate by approximately 4.25% during a 10 year storm (4.84" in a 24 hr duration). Although this is not a significant reduction, it is important to note that catchment #3 is the smallest of the delineated catchments. If this design however, is combined with the other two proposed retention areas, Atwater Kent and the hill adjacent to Institute Road, the runoff capacity at Salisbury Pond would be reduced by 10%. Again it is important to note that the Atwater Kent design has size limitations and is only capable of treating a fractional portion (< 1%) of the total area of Catchment #1 (0.40 ac.). By treating larger surface area types, within each catchment, a significant reduction in flow rate at Salisbury Pond is expected.

Both designs have the ability to catch and store debris and sediment. Although the rain gardens and filters that make up the design based on surface type are much easier to clean and maintain. Regarding the size of each system, the constructed wetland would have to be considerably larger than the rain garden design. The volume flow rate from all of the upstream catchments would have to be accounted for in the downstream design. It was determined that the wetland will need a treatment volume of approximately 6.34 acre-feet (276,170 c.f.) .While the designed rain garden, near Skull Tomb, will only need a treatment/storage volume of approximately 0.40 acre feet (17,000 c.f.).

The constructed wetland would have a large removal efficiency and ability to hold a large amount of runoff. However, there is a problem with size requirements, available space, and cost. The wetland would have to be designed to be large in order to treat the flows from the catchment areas. This then creates a space problem within Institute Park. Additionally, in the existing area around Salisbury Pond there are protected species of plants. This means that in order to construct the downstream design special permits would be required. Also, the design would have to be constructed a minimum of 100 ft from the waters edge of the pond. The next BMP suggested is the catch basin filters. These are relatively small and can fit inside all of the catch basins. However, for a reasonable removal efficiency there would need to be an insert in all of the catch basins. This means that even though the catch basin filters will be relatively small compared to the other two BMPs, there will be many more of them spread out along the catchment areas. The final BMP that is suggested is the rain gardens. Rain gardens have a high removal efficiency, require less space than the wetland, and also add a pleasing aesthetic to the area in question. The gardens however do require more upkeep and maintenance than the other two BMPs.

The next comparison is in price. All BMPs vary in cost of construction and maintenance. This is true for the three BMPs that are suggested above. For downstream design, a constructed wetland has a general base cost of around $87,000 per acre (not including labor cost) (Newton, 2006). Also, when constructing the wetland the specific plants can also get costly depending on the plant choice. The design based on surface has a lower total cost because it treats only 38% of the runoff from campus. On average, the initial price for the rain gardens is around $4275.00 per 500 square foot. (Rain Garden, 2019) With this there are three rain gardens proposed bringing the estimated total to $12,825, again excluding construction labor (Rain Garden, 2019). The price may also vary depending on the types of plants that are selected. Additionally the rain garden near Skull Tomb, corner of Institute road and Boynton Street, proposes two new catch basins to collect access road runoff and adding it to the grass area near Skull Tomb, which will improve overall stormwater management and quality from WPI's campus. The cost per catch basin is approximately between $2,500-$5,000 depending on pre-existing variables such as location and type of material (Mr. Rooter, 2019). Also as part of the surface based design, the final BMP to be considered are the catch basin filters. In the sub watershed area there are 30 catch basins, including the two new ones that are proposed. It is recommended to add these filters to all of the catch basins on the eastern part of WPI's campus. With 30 separate catch basins the approximate cost is approximately $500 per DrainPac Filter and $15,500 total (T. Flury, personal communication, February 19, 2019). The total cost of implementing the three garden and catch basin filters is approximately $28, 325.

The next improvement is the contaminant removal from Catchment #3. When comparing the Skull Tomb rain garden the overall TSS removal was found to be 90% efficient, while the constructed wetland (downstream design) removal rate was 80%. The comparative analysis of TSS, Nitrogen and Phosphorus can be found in Table 15.

Table 15: Comparison of the BMP systems for pollutant removal.

BMP Design Type	TSS Removal	Total Phosphorus Removal	Total Nitrogen Removal
Downstream Constructed Wetland	80%	~50%	~38%
Rain Garden Design Based on Surface Type at Skull Tomb	90%	60%	40%
Catch Basin Inserts	80%	75%	75%

When comparing the downstream versus the design based on surface type, the design based on surface type treats 38% percent of the total runoff design and therefore provides only 46% TSS removal, 28% total phosphorus removal, 10% total nitrogen removal. The specific removal rates and construction costs of each design are summarized in Table 16.

Table 16: Comparison of the Downstream Design and the Spot Designs for Area, Removal, and Cost

Design	Total area Treated	TSS Removal	Total Phosphorus Removal	Total Nitrogen Removal	Cost Estimation
Downstream	100%	80%	~50%	~38%	~$87,000
Design Based on Surface Type	38%	46%	28%	10%	~$28,325

While the proposed design based on surface type only treats 38% of the total area of the WPI campus, quite a bit of removal is still achieved. The design based on surface type removes 57.5% of the TSS load removed by the downstream design, 56.0% of the total phosphorus load removal, and 26.3% of the total nitrogen load removal. Comparatively, the design based on surface type could be constructed at approximately a third of the cost of the downstream design. Based on a conservative estimate of the size requirements for the three proposed rain gardens totaling 1.2 acre-feet, our proposed surface type design would only require approximately 18.9% of the area required by the downstream design. In terms of feasibility of implementation based cost, space, and effectiveness we propose that the design set forth based on surface type is an effective approach to stormwater treatment.

6.0 Conclusion

The goal of this project was to quantify the relationship between surface land type and contaminant loading in stormwater and to determine the effects of these relationships on Best Management Practices (BMPs) design, using WPI as a case study. In order to determine the relationship between surface type and contaminant loading, multiple isolated sampling sites were identified based on distinct surface characteristics and stormwater runoff from these sites was sampled periodically over the course of three storms. The samples collected were then tested for a variety of contaminants including phosphorus, nitrogen, TSS, and heavy metals as well as various other cations and anions. From these results it was concluded that grassy areas, lightly trafficked roads, and walkways contributed the highest levels of contaminants and were identified as the most effective areas for BMP placement. By targeting and treating specific areas of concern we were able to propose a design with removal rates of 46% for TSS, 28% for phosphorous, and 10% for nitrogen contributed by the WPI campus while treating only 38% of the total campus surface.

From the results of this project, it is clear that different surface types have different concentrations in their stormwater runoff. These varying concentrations can help locate the areas with the highest loads of contaminants. This leads to being able to prioritize which areas to treat first, and the BMPs best suited to treat these areas. This work helped to design localized spot designs for the WPI campus. This allows for the BMPs to be selected that are comparable in removal while treating smaller flows making them less expensive. Careful consideration of land use characteristics, along with the contaminant concentrations and loads associated with the runoff can help to guide BMP selection and design.

The next steps for this project allow for expansion of sampling sites and more BMP design based on nutrient loadings and surface type. As a next step, it would be beneficial to look into expanding the sampling area first to include the other side of WPI campus, then to include the entire watershed in the area. Another next step is to use the data collected and do similar work with another zone of land. We worked in a college campus, but it could be beneficial to do this with a residential area and even a commercial area. A last major next step would be to work with any new construction projects, buildings, or campus expansions. With the help of our data and analysis, a BMP could be designed to add to these new additions to campus. The BMP can be added to the new design, chosen based on the land use type of this new construction. If other surface types change during construction, BMPs could be added accordingly. This analysis provides a basis for future studies to investigate the most effective approaches for designing BMPs to manage stormwater runoff. The findings of this project could help with the WPI campus or can even be taken to other places and different locations to help with their BMP design and stormwater management.

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Appendix A: 250 CMR 3.04

3.04: continued

250 CMR 3.04(4): Table I Engineering Application Requirements

Application Classification		Education Requirements	Engineering Experience Requirements*	Responsible Charge Requirements	FE Exam Req'd	PE Exam Req'd	Inter-view Req'd	Reference
(a)		A certificate of license/registration to practice Engineering issued by another Jurisdiction in addition to meeting all the requirements of one of the following classifications:			Yes (except (e))	Yes	No	M.G.L. c. 112, § 81J (1)(a)
(b)	(1)	A Bachelor of Science degree in engineering from an ABET accredited program or a program approved by the Massachusetts Legislature together with a Master's Degree in Engineering by a school in the US whose basic engineering program is ABET accredited.	3 years	-	Yes	Yes	No	M.G.L. c.112, § 81J (1)(b)
	(2)	A Bachelor of Science degree in engineering from an ABET accredited program.	4 years	-	Yes	Yes	No	M.G.L. c.112, § 81J (1)(b)
	(3)	A Bachelor of Science degree in engineering from a non-ABET accredited program granted by an institution authorized to grant such degree by the Massachusetts Legislature.	4 years	-	Yes	Yes	No	M.G.L. c.112, § 81J (1)(b)
	(4)	A Bachelor of Science degree in engineering from a non-ABET accredited program or related engineering science program such as a technology degree, foreign degree, physics degree, chemistry degree, etc. together with a degree from an ABET accredited advanced engineering program.	4 years	-	Yes	Yes	No	M.G.L. c.112, § 81J (1)(b)
	(5)	A foreign degree or non-ABET degree in engineering of four years or more and whose education has received an Equivalency Appraisal per 250 CMR 3.04(2).	4 years	-	Yes	Yes	No	M.G.L. c.112, § 81J (1)(b)
(c)		A Bachelor of Science engineering technology degree or any non-ABET accredited program in engineering or related engineering science such as a foreign degree, physics degree, chemistry degree, *etc.* (foreign degree holders are also required to submit evidence that the foreign degree is equivalent to a regionally accredited Bachelor of Science degree)	8 years	-	Yes	Yes	No	M.G.L. c.112, § 81J(1)(c)

Appendix B: 250 CMR 3.04

3.04: continued

250 CMR 3.04(4): Table II Land Surveying Application Requirements

Application Classification		Education Requirements	Land Survey Experience Requirements*	Responsible Charge Requirements	FS Req'd Exam	PS Exam Req'd	JP Exam Req'd	Oral Exam Req'd	Reference
(a)		A certificate of license/registration to practice Land Surveying issued by another Jurisdiction in addition to meeting all the requirements of one of the following classifications:			Yes (except (e))	Yes	Yes	Yes	M.G.L. c. 112, § 81J (2)(d)
(b)	(1)	A Bachelor of Science Degree in Land Surveying.	4 years	3 years	Yes	Yes	Yes	Yes	M.G.L. c. 112, § 81J (2)(a)
	(2)	A Bachelor of Science Degree in Civil Engineering including or in addition to at least 18 credit hours of Board-approved courses in land surveying	4 years	3 years	Yes	Yes	Yes	Yes	M.G.L. c. 112, § 81J (2)(a)
	(3)	A foreign degree in Land Surveying or Civil Engineering of four years or more that has been determined to be equivalent to 250 CMR 3.04(4): Table II (1) or (2).	4 years	3 years	Yes	Yes	Yes	Yes	M.G.L. c. 112, § 81J (2)(a)
(c)		Two or more years of formal education comprised of at least 60 semester credit hours of which as least 18 credit hours are Board-approved land surveying courses and 12 credit hours of Board-approved higher mathematics and applied science courses.	6 years	4 Years	Yes	Yes	Yes	Yes	M.G.L. c. 112, § 81J(2)(b)
(d)		No education requirement, however undergraduate study in a Board-approved surveying curriculum may be considered as surveying Work Experience on an equivalent full-time basis up to a maximum of 2 years.	12 years	6 years	Yes	Yes	Yes	Yes	M.G.L. c. 112, § 81J(2)(c) M.G.L. c. 112, § 81J(2)(e)
(e)		No education requirement, however undergraduate study in a Board-approved surveying curriculum may be considered as surveying Work Experience on an equivalent full-time basis up to a maximum of 2 years.	20 years	10 years	No	Yes	Yes	Yes	M.G.L. c. 112, § 81J(2)(f) M.G.L. c. 112, § 81J(2)(e)

Appendix C: Sampling Protocol

WPI Nitsch Engineering
MQP Field Sampling Protocol

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October 2018

FIELD SAMPLING PROTOCOL

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Acknowledgements

This document was modeled after both The United States Environmental Protection Agency's Field Sampling Quality Control (dated, April 26, 2017) and The Nitsch Engineering Field Sampling Control Guide (dated, September 5, 2018). See appendix for original sampling plans.

Goal and Objective

The purpose of this field sampling protocol guide is to provide a set of working directions for stormwater runoff sampling crews. When performing sampling collection activities it is important to do so in a safe and consistent manner. The procedures and information outlined in this document will provided the intended framework to ensure quality assurance and quality control of the sampling guidelines. By following these procedures and protocols, crews are able to obtain samples that are accurate and to a standard of care which WPI and Nitsch Engineering require. The procurement of precise and accurate data is vital when conducting such analyses.

Field Sampling Safety

Safety in the field is of the utmost importance when field sampling is to occur. Sampling crews should adhere to the Standard Health and Safety Practices (i.e. EPA Handbook for Sampling and Sample Preservation of water and WasteWater, OSHA Regulations, Standards and Policies, etc.).

When Sampling in the field, Crews should remember:

1) You are responsible for your own safety
2) Others are <u>NOT</u> Responsible for your safety
3) If you feel unsafe in the working conditions, you should not work
4) Never sample alone, always be with at least one other crew member
5) Make sure someone knows where you are
6) Wear appropriate field work apparel
7) Stay alert
8) If weather becomes too hazardous, find cover immediately
9) When working in areas were vehicles may be a hazard always use signs, cones and other traffic warning signals
10) When working in traffic, ensure that the local authority and facility staff is notified and on site.
11) When working with potential hazardous samples always wear protective gloves, clothing, etc.
12) When working with storm drains, grate, catch basins, etc. ensure that WPI Facilities are aware and present
13) When in the field use common sense and ensure that you and your crew are safe.

Supplies and Materials

Before going into the field ensure that you have all of the required materials need to samply correctly and safely. The crews typical list of materials should include:

General

1) Field notebook/ or spread sheet
2) Sharpie/permanent ink writing instrument
3) Appropriate personal protective equipment
4) Traffic cones, signs, flares,etc.
5) Reflective and personal safety apparel

Water Quality

1) Cooler
2) Ice
3) Clear Packing tape
4) Labels
5) Safety Gloves
6) 100mL plastic sampling bottles
    a) Number of bottles need to be based on the number of sampling locations & samples per location.
    b) Ensure that sampling bottles are clean and free of any residue
    c) If the bottles are being reused it is important that the bottles be cleaned with distilled water *only* and then allowed to dry completely
7) 50mL plastic sampling bottles
    a) Number of bottles need to be based on the number of sampling locations & samples per location.
8) Ziplock Sandwich Bag
    a) Number of Ziplock bags need to be based on the quantity of sampling crews
    b) Pre-cut with zipper strip remove
9) Large Zip Lock Bag
    a) Number of Ziplock bags need to be based on the quantity of sampling crews
    b) Pre-cut along 2 edges with zipper strip removed
10) Concrete Block
    a) Number of concrete blocks need to be based on the quantity of sampling crews
11) Plastic cup
    a) Number of Plastic cups need to be based on the quantity of grass based sampling locations

Velocity

1) Colored dye
2) Barrel
3) 6 ft. of clear hose
4) 3 sections of sheet metal studding 2’ long
5) Stop Watch
6) Several sand bags or zip lock bags with sand in them
7) Ruler/ Tape measure

Note: velocity measurement materials are base on a crew number basis.

Sampling Procedure

In order to ensure that the results of your field sampling are accurate and consistent results you should follow the procedure below. This procedure is as follows:

1) Prior to Field Sampling
    a) Check the Supplies and Materials list
        i) Ensure that you have all the necessary supplies and materials for the area that you will be sampling. (i.e. if you are sampling in a roadway you want to make sure that you have the necessary traffic supplies such as cones, flares, signs, and scheduled detail where necessary)
        ii) Check each item to ensure cleanliness and functionality
    b) Prepare the field sampling notes sheets
        i) This includes the sampling index sheet, notepads, and ensuring that you have all the correct labels filled out and administered to clean sample bottles.
    c) Ensure crews know the area where they will be sampling and the goal of the sampling that is to occur on that day
        i) Two person crews are recommended
    d) Ensure that all sampling bottles are completely cleaned and dry to ensure *Quality assurance and Quality Control*
    e) If manhole or storm drain covers are required to be opened ensure that the proper authority has been notified and that they will be present at the sampling site.
    f) If the crew will be working in a roadway, ensure that the proper authorities have been informed and will be present at the sampling location
    g) Review the weather report for the sampling day
        i) Ensure that the weather will not be to hazardous as to endanger the field sampling crew

2) Arrival in field and sampling area
    a) Familiarize yourself with the sample area
        i) Ensure that the area is going to obtain the best results
            (1) There is enough runoff to sample
            (2) There is enough flow to measure
        ii) Ensure that the area is safe
    b) Set up all of the supplies and materials that are required in the sampling area
        i) If working in roadway, set up your safety equipment first (i.e. cones, signs, flares, etc.) and that detail has arrived
        ii) If weirs and/or dams are required, set them up and check that they are giving you the desired execution/ flow restriction

iii) If manhole or storm drain cover need to be opened, open them in a safe and controlled manner under the supervision of the appropriate authority
iv) Ensure that your sampling bottles are correct and ready to go when sampling is to begin

c) Record the weather conditions
   i) Record the weather (i.e. Temperature, Conditions (i.e. Sunny, cloudy))

d) Record the amount or rain in the rain gauge

3) Sampling

a) Water Quality

<u>Method 1 (Outside Sampling Surfaces)</u>

i) Channel/dams all sheet flow to sampling location as to impede flow velocity minimally
ii) Use a clean bottle and a new, clean pair of gloves
iii) Place concrete block on the ground, perpendicular to flow at sampling location
iv) Place large zip lock bag strip on ground draped over block, parallel to flow
   (1) This process will promote pooling by restricting flow
   (2) The zip lock bag strip creates a buffer from contaminants at immediate sampling location
v) When pooling occurs, use smaller zip lock bag to collect runoff and transfer to the 100 mL sample bottle.
vi) Fill bottle as much as possible
vii) Record the temperature of the sample
viii) Place bottled sample into cooler for safekeeping until further testing
ix) In a 50 mL sample bottle collect another sample
x) Record the dissolved oxygen concentration
xi) Dispose of sample in safe manner

<u>Method 2 (Roof Surfaces)</u>

i) After testing the flow rate of the system (to flush pipes) Place hose connected to outlet pipe, into the sample bottle
   a) Do not contact the hose to the bottle so that external contaminations are introduced to the sample.
ii) Fill bottle as much as possible
iii) Record the temperature
iv) Place bottled sample into cooler for safe keeping until further testing
v) In a 50 mL sample bottle collect another sample
vi) Record the dissolved oxygen concentration
vii) Dispose of sample in safe manor

Method 3 (Standing Bodies of Water)

i) Locate a safe and suitable are in which to enter the body of water
ii) Find within this area a spot where the water is clear of plants and debris
iii) Take the 1L, 100 mL and 50 mL sampling bottles and submerge them in the water
iv) Capture the sample
v) Take dissolved Oxygen and Temperature
vi) Place the bottles into cooler for safe keeping for further testing

b) Velocity & Area

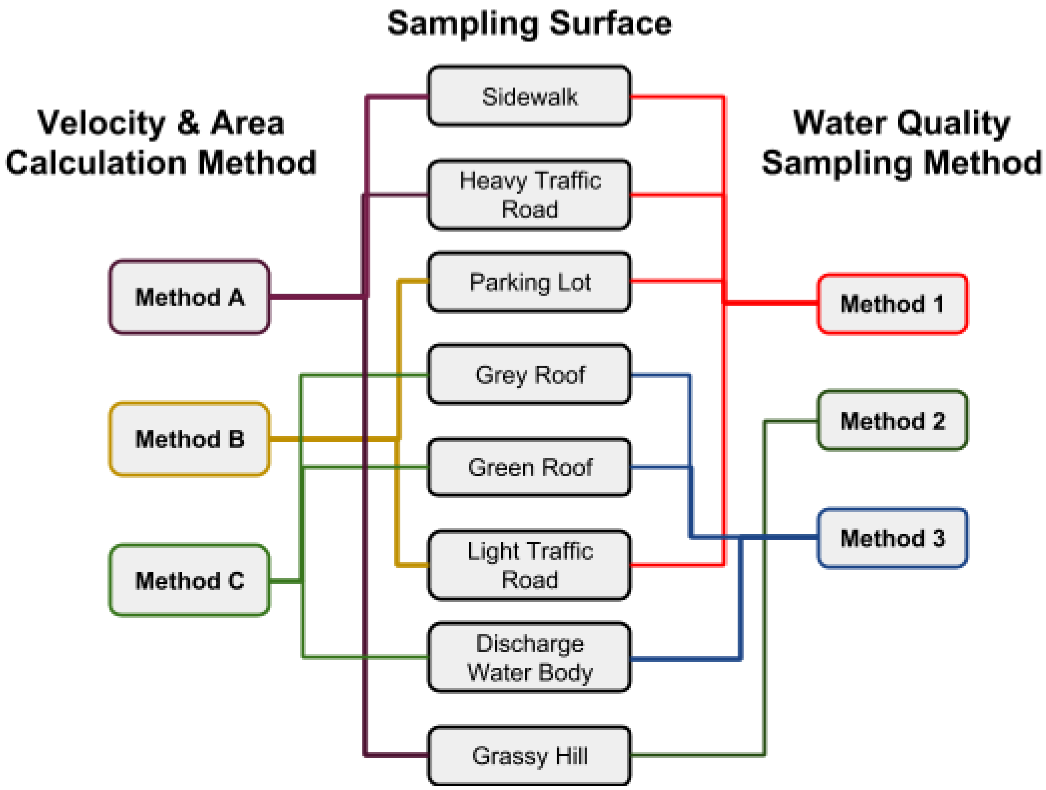
Method A

i) Locate a channel of flow within the area of interest
ii) Measure the length of channel and record the value
    a) Flow may vary so a larger section is recommended to understand the average
iii) Measure the depth and width of the channel within the area of interest
    a) Several measurements will be necessary due to possible variations in cross- sectional area
iv) Average the areas and record
v) Drip the dye at the upgradient location
vi) Record the time the trace of dye until it reaches the designated end location

Method B

i) Place hose, connected to outlet pipe, into the graduated barrel
ii) Open control valve and monitor flow
iii) Time the water level as it reaches graduated markings
iv) Record times on stopwatch

4) Storage and Transport
    a) In order to keep the samples viable, after sampling the bottle should be tightly and securely sealed. Then they should be placed into a cooler and encased in ice. The ice should be drained and replenished as it begins to melt. The label on the bottle should be cover in clear packing tape to ensure the writing stay visible and dry. As soon as possible, the samples should be moved directly from the cooler to a refrigerator until they are ready for lab testing.



Sampling Surface
Velocity & Area
Calculation Method
Water Quality
Sampling Method
Sidewalk
Heavy Traffic
Road
Parking Lot
Grey Roof
Green Roof
Light Traffic
Road
Discharge
Water Body
Grassy Hill
Method A
Method B
Method C
Method 1
Method 2
Method 3

Sampling Index Sheet

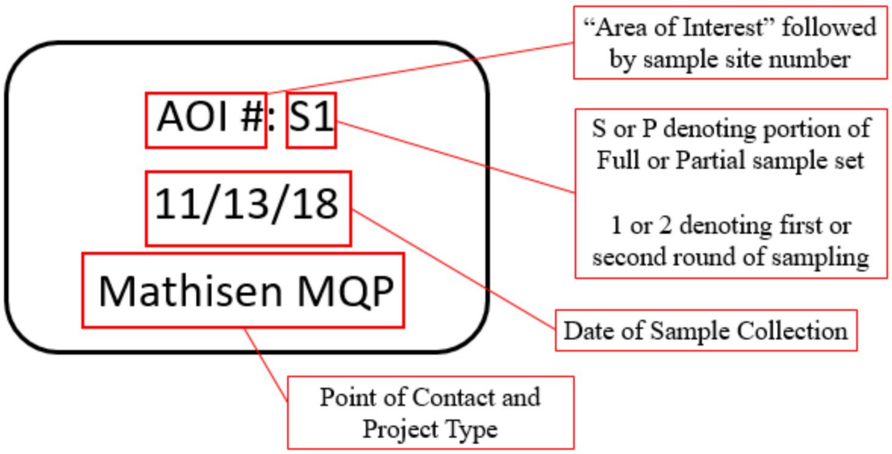
The table below should be partially completed on the the day of field testing. This type of sheet helps the sampling crew to identify many different aspects of the sampling. Further testing will take place to determine the quantity of contaminants.

Table 1: Sampling Index Sheet

Date	Time	Location	Sample Location Description	Specific Conductivity [%]	Water Temperature (In field) [C]	pH	DO	Runoff Channel Depth [ft]	Length of Channel (ft)	Width of Channel [ft]	Dye trace time [s]
10/27/18	8:40 AM	AOI 1	catch basin in parking lot	-	6.5	6.42	9.50	0.08	10.00	0.70	8.67
10/27/18	9:06 AM	AOI 3	catch basin @ institute-boyton st intersection	-	5.20	6.55	9.24	0.04	10.00	0.90	7.20
10/27/18	8:53 AM	AOI 2	access road between kaven lot and institute rd	-	5.20	6.41	10.63	0.04	10.00	2.5	6.71
10/27/18	9:35 AM	AOI 4	handicap ramp near kaven and fuller	-	5.70	6.85	9.45	0.02	5.10	1.40	6.41

Labeling

The figure below shows a recommended format for labeling the samples collected. It is important to record the location of the sample, date, and time to adequately identify where the runoff sample originated. Also, when sampling multiple times across a storm at a consistent location it is recommended to list the sample number so that the order of the collected samples can be understood when analysis commences in the laboratory. Finally, it is suggested to identify the owner, sampler, or organization in addition to its general contents. This will ensure that an outside person/persons who may encounter the sample can understand who the sample belongs to and what its contents are.



Surface Selection and Criteria

Table 2 details the criteria for each surface type sampled, the location of the sampling area, and the sampling method applicable for each surface. The following section outlines how each chosen sampling area fulfills the project objectives and provides visuals of the sampling surface for clarity. All surfaces, barring the Green Roof and Grey Roof, were observed during a light rain storm to determine suitability based on accessible flow for sampling.

Table 2: Summary of Sampled Surfaces

Surface Type	Criteria	Location	Sampling Method
Parking Lot	-Heavily used parking lot -Minimal Pervious Surface -Accessible drains/catch basins with decent flow in light rain	-Boynton Street Lot WPI Campus -Parking lot catch basin	1A
Light Traffic Road	-Lightly trafficked road -Minimal pervious surface -Gradual slope ~5-15% -Accessible drain with decent flow in light rain	-Private WPI way adjacent to Boynton Street Parking Lot -Road drain	1A
Discharge Water Body	-Receiving water body for stormwater from sampling areas	-Salisbury Pond	
Heavy Traffic Road	-Heavily trafficked road -Minimal pervious surface -Accessible drain with decent flow in light rain	-Road drain at corner of Institute Road and Boynton Street	1A
Sidewalk	-Isolated Sidewalk Drain -Accessible drains/catch basins with decent flow in light rain -Flat	-Sidewalk catch Basin at the Bottom of the Steps beside Fuller Labs -Near Kaven Hall 111b	1-
Green Roof	-Isolated Green Roof drain -Accessible drain with decent flow in light rain	-East Hall Green Roof Effluent (Mechanical Room)	3C
Grey Roof	-Isolated Grey Roof drain -Accessible drain with decent flow in light rain	-East Hall Grey Roof Effluent (Mechanical Room)	3C
Grassy Hill	-Steep slope ~15-30% grassy area -Maximum pervious surface -Area free of heavy tree cover or man made structures	-Grassy hill adjacent to skull tomb (Corner of Institute rd. and Boynton st.)	2-

1) **<u>Surface Type:</u>** Parking Lot

.

a) Location: Boynton Street Lot WPI Campus, Parking lot catch basin

b) Purpose: The chosen parking lot drain in the Boynton St. parking lot of the WPI campus was identified as a sampling location due the the high amount of shallow concentrated flow entering the drain originating from the Southern side of the parking lot. The drain was also receiving a fair amount of sheet flow from the adjacent Eastern area of the parking lot.

In terms of project objectives, this sampling location allows for the team to analyze contaminants in stormwater originating from heavily use parking lots. The high amount of flow running into the drain and the limited surface types the stormwater came in contact with made this an ideal place to sample as the contaminants we found were representative of one type of surface.

c) Pictures:

↑ *Above: Up close Boynton st. Lot catch basin*

← *Left: Boynton st. Lot catch basin*

2) **Surface Type:** Light Traffic Road

.

a) Location: Private WPI way adjacent to Boynton Street Parking Lot Road drain

b) Purpose: The road drain located on the WPI private way adjacent to the Boynton St. Parking lot was determined to be a suitable sampling location due to the high amount of concentrated shallow flow entering the drain emanating from the lightly used private way stretching up towards the WPI campus and Boynton Hall.

While not completely isolated from other types of surfaces, this sampling location provides an accessible point for sampling and fairly concentrated road-based stormwater flow and should be representative of contaminants found originating from such surface.

c) Pictures:

↑ *Above: Up close view of road drain*

← *Left: Road Drain on WPI private way*

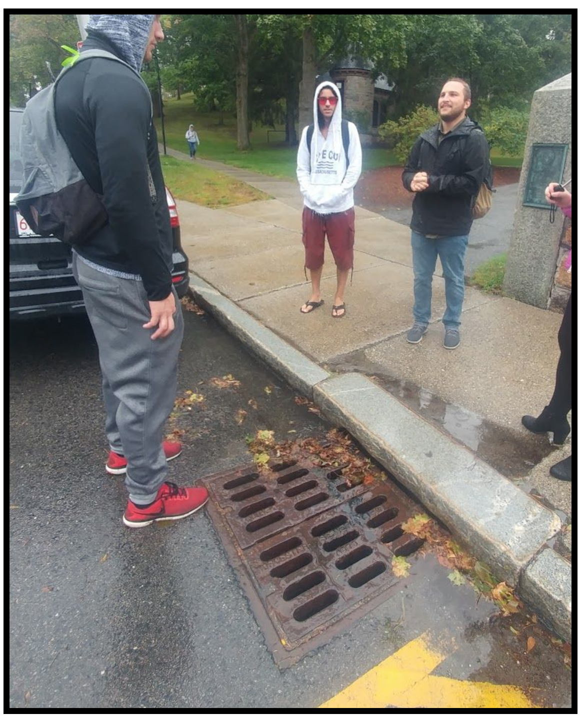
3) **Surface Type:** Heavy Traffic Road, Sampling Method 1A

d) Location: Road drain at corner of Institute Road and Boynton Street

e) Purpose: The chosen road drain at the corner of Institute rd. and Boynton st. was identified as a sampling location due to the high amount of flow entering the catch basin originating from the Eastern-bound portion of Institute rd. and the limited flow to the drain over other surface types.

This sampling location allows for assessment of contaminants found in stormwater originating from a heavily trafficked road due to the concentrated flow off of one surface type. The high amount of flow in a light rain storm and accessibility of the location (adjacent to a no parking space on the street) made this an ideal place to sample from.

f) Pictures:



Above: Road Drain at corner of Institute Rd. and Boynton St.

Above: Close up of Institute rd./Boynton St. Drain

4) **Surface Type:** Walkway

a) Location: Sidewalk catch Basin at the Bottom of the Steps beside Fuller Labs near Kaven Hall 111b

b) Purpose: The chosen sidewalk catch basin was chosen as a sampling Location as the flow running into the drain originates from the surrounding sidewalk area. The flow into this sidewalk drain is not high as the area that contributes to the flow is much smaller than that of a road or parking lot.

In terms of project objectives, this sampling location allows for the isolation of contaminants in stormwater originating from a sidewalk in comparison to the other surfaces tested.

c) Pictures:

Above: Sidewalk Drain outside Kaven Hall at the bottom of the steps beside Fuller labs

5) **Surface Type:** Green Roof

a) Location: East Hall Green Roof Effluent (Mechanical Room)

b) Purpose: The purpose of this site is to analyze the effectiveness of impurity removal.

c) Pictures:

Above:Green roof monitoring site inside East Hall

6) **Surface Type:** Grey Roof

a) Location: East Hall Grey Roof Effluent (Mechanical Room)

b) Purpose: The purpose of this site is to determine the pollutant loading contributed by rooftop runoff.

c) Pictures:

7) **<u>Surface Type</u>**: Grassy Hill

a) Location: Grassy hill adjacent to skull tomb

b) Purpose: The grassy hill adjacent to Skull Tomb and Boynton Hall is the steepest hill on campus with the largest percentage of pervious surface area. Flow is difficult to detect on the hill and sampling from this location requires a unique method.

This sampling location allows for the team to analyze contaminants in stormwater originating from a majority pervious surface in comparison to the impervious surfaces also sampled.

c) Pictures:

Above: Grassy Hill near Skull Tomb
Slope (5-15%)

8) **<u>Surface Type:</u>** Discharge Water Body

a) Location: Salisbury Pond

b) Purpose: Stormwater runoff from all other sampling sites drain into Salisbury Pond. Sampling this location will allow the team to compare water quality and quantity from the different sites to the water quality and quantity that reaches the ecosystem.

c) Pictures:

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1) United States, EPA, Science and Ecosystem Support Division, and Timothy Simpson. "Field Sampling Quality Control." *Operating Procedure,* 2017
2) United States, EPA, Office of Water, and Office of Wastewater Enforcement and Compliance. "NPDES Storm Water Sampling Guidance Document." *NPDES Storm Water Sampling Guidance Document,* 1992
3) Nitsch Engineering, Field Sampling Protocol Guide, 2018

Appendix D: Nitsch Engineering Sampling Protocol

Nitsch Engineering

FIELD SAMPLING PROTOCOL

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SEPTEMBER 5, 2018

Building better communities with you.

FIELD SAMPLING PROTOCOL

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I. PURPOSE AND OBJECTIVES

The Nitsch Engineering Field Sampling Protocol document's purpose is to ensure that field sampling activities are performed consistently by sampling crews. The procedures in this document are to ensure the safety of the sampling crews and the quality of the sample. Adhering to these procedures will ensure that all samples are up to the quality that Nitsch Engineering require. This document was modeled after the United States Environmental Protection Agency's Field Sampling Quality Control, dated April 26, 2017.

The object of this sampling protocol is to obtain representative samples and maintain their integrity to ensure quality results.

II. FIELD SAMPLING SAFETY

To ensure safety in the field, sampling crews should follow the Standard Health and Safety Practices (i.e.EPA Handbook for Sampling and Sample Preservation of Water and Wastewater, OSHA Regulations, Standards and Policies, etc.).

Remember the following items while in the field.

1) Remember, you are responsible for your own safety.
2) Do not rely on others to provide for your safety.
3) Never work in conditions that you feel are unsafe.
4) Use the buddy system
5) Makes sure someone knows where you are
6) Wear appropriate personal protective equipment (PPE) and high visibility clothing
7) Use traffic signs, cones, flashers, etc. when appropriate
8) Work in off peak traffic hours if possible
9) Stay alert
10) Find safety if weather becomes extreme

III. SUPPLIES

Ensure that you have all supplies before going out into the field. Here is a typical list.

1) 1-Liter Sampling Bottles (Amber Preferred)
    - Sampling bottles should be cleaned
    - If bottle is being reused it is important to use distilled water when cleaning. The bottle should be rinsed with distilled water at least three times. \
2) Ice Chest
3) Ice
4) Rain Gauge
5) Powderless disposable Latex or Nitrile Gloves or equal

6) Thermometer
7) Water Proof Labels
8) Notebook or Tablet
9) Sharpie
10) Appropriate Personal Protection Equipment
11) Measuring Tape
12) Distilled water

IV. SAMPLING

1) Prior to Sampling

   1. Ensure all proper equipment is ready
   2. Team has communicated about what the goal is, type of samples needed
   3. All equipment has full battery
   4. Review weather report

2) Arrival in the field

   1. Familiarize yourself with area and ensure you have a safe area
   2. Set up material and supplies
   3. Take temperature of water and record weather.
   4. Record amount of rain in rain gauge.

3) Sampling

   1. Put on clean gloves (new gloves should be used for each location.)
   2. Rinse sample container with distilled water three times.
   3. Fill clean sample containers as much as possible and put top on tight
   4. Label sample with date, time, sample ID, and initials. (see Attachment A: Sample Sheet)
   5. Place sample in ice chest

4) Storage and Transport

   To ensure that the sample are preserved and not contaminated, tightly sealed samples should be placed in an ice chest with a sealed back of ice. Excess water in ice chest from melting ice should be drained and ice should be as needed. It is essential that the sample be moved from the ice chest to a fridge as soon as possible. The labels should be kept dry and not smudged during storage and transportation.

V. Attachment A: Sample Sheet

Sample ID	Date	Time	Weather	Location	Temperature	Tests					Notes
						Conductance (µS)	pH	TSS	Anions	Cations	
Example	11/2/2016	8:35 AM	Sunny 52°F	Library	10°C	X	X	X	X	X	Water was clear with little turbitiy.

VI. References

United States, EPA, Science and Ecosystem Support Division, and Timothy Simpson. "Field Sampling Quality Control." *Operating Procedure*, 2017.

United States, EPA, Office of Water, and Office of Wastewater Enforcement and Compliance. "NPDES Storm Water Sampling Guidance Document." *NPDES Storm Water Sampling Guidance Document*, 1992.

Appendix E: Total Phosphorus Procedure

Total Phosphorous (TP)

1) Clean glassware (100ml beakers, 100ml volumetric flasks, 25ml volumetric flasks) = soak in acid bath overnight, rinse 3 times with tap water, rinse 3 times with DI water.
2) Label 100 mL beakers with blank, standards and samples IDs
3) Make standards
    a. Take out the labeled bottle (large, brownish) of standard from the refrigerator
    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 e-pure tap, then use a spray bottle to fill flask to the line
    f. Add parafilm to the flasks
    g. Invert flasks 5 times each
4) Pour blank, standards, samples into 25 mL vol. flask
    a. Rinse before filling = add a little, swirl, dump out (do twice)
    b. Use disposable, plastic pipette if over line
    c. Pour into corresponding beaker, rinse flask with spray bottle twice
5) Digest samples = about 1 mL of standards and samples will be left in the beakers.
    a. Add 5ml of nitric acid and 1ml of sulfuric acid to each beaker
    b. Heat on hot plate until ~1ml left or start fuming
    c. Add drops of H_2O_2 if too much organics in the sample (cloudy and colored)
6) Turn on spectrophotometer (don't need to wait hours before using)
7) Make sure the wavelength is set to **400 nm** (change by pressing Manual Program) Single Wavelength
8) Filter samples (don't have to for all samples, depends on how cloudy/sediment amount)
    a. #4 filter paper, Whatman
    b. Funnels
9) Get 3 solutions
    a. Phenolphthalein: 1,000 mL, white/clear bottle, clear solution
    b. Molybdovanadate: 1,000 mL, white/clear bottle, yellow solution
    c. NaOH: 6.25N, white bottle, clear solution
10) Get supplies for each solution
    a. (2) Disposable dropper, 100 mL (small) beaker
    b. 1 mL – pipette and tip (1-5 mL, large tips in drawer);
11) Get DI water (in squirt bottle), paper towels, gloves, "my" cell from the water lab, large waste beaker
12) Transfer **blank** solution from beaker into cell; rinse with DI water to get all of sample
13) Add 1 drop of Phenolphthalein
14) Add NaOH with dropper until sample turns pink
15) Add E-pure water to the line on the cell with squirt bottle
16) Add/pipette 1 mL of Molybdovanadate

17) On the spec. press timer, set to 3 minutes
18) Place the cell in the machine (kimwipe first), with the white line mark facing outwards, when the timer hits zero
19) Press Zero
20) Rinse cell into 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 hazardous waste bottle for Total phosphorous

Standard solution preparation:

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

Appendix F: Ammonia Procedure

Ammonia (NH_3)

1) Filter samples
    a. Centrifuge tube
    b. Syringes and 0.45um syringe filter
2) Turn on spectrophotometer (don't need to wait hours before using)
3) Make sure the wavelength is set to **425** nm (change by pressing Manual Program)
4) Make standards
    a. Get Nitrogen-Ammonium Standard Solution 100 mg/L as NH3-N from chem. refrigerator
    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 e-pure tap, then use a spray bottle to fill flask to the line
    f. Add parafilm to the flasks
    g. Invert flasks 5 times each
5) Get 3 solutions from sprinkler room.
    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 (1-5 mL, large tips in drawer);
    b. 25ml UV-vis cell
    c. Rubber stopper
7) Add E-pure water to 25 mL line of cell; for samples, pour from bottle (shake first), use disposable dropper for each one if filled over the line
8) Add 3 drops of 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 spec. press timer, set to 1 minute
12) Place the cell in the machine, with the white line mark facing outwards.
13) Start the timer. When the timer hits zero, press Zero
14) Rinse cell with DI water into waste beaker
15) Repeat steps 7-14 for the rest of the samples and standards, except press Read
16) Dispose of waste into Nessler Reagent hazardous waste bottle

Standard solution preparation

Target conc., ppm	Target volume, ml	Added volume of stock solution 100ppm, ml
0.1	100	0.1
0.3		0.3
0.5		0.5
1.0		1
3.0		3
5.0		5

Appendix G: Total Suspended Solids Procedure

Standard Operating Procedure for:

Total Suspended Solids

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1 Identification of the test method

Determination of Total Suspended Solids

2 Applicable matrix or matrices:

This method is suitable for the determination of solids in potable and surface waters and wastewaters with total suspended solids (TSS) of up to 20,000 mg/L.

3 Detection Limit

The desired detection limit for this method is 0.5 mg/L for a 1-L sample.

4 Scope of the test method

This standard operating procedure provides laboratory personnel with guidance on the procedure for determining TSS. This method is limited to the determination of TSS in water samples collected from natural bodies of water containing TSS of < 20,000 mg/L.

5 Summary of test method

The procedure described here follows Standard Methods (2005), 2540D and EPA (1983) Method 160.2 (Residue, non-filterable). A well-mixed, measured volume of a water sample is filtered through a pre-weighed glass fiber filter. The filter is heated to constant mass at 104 ± 1° C and then weighed. The mass increase divided by the water volume filtered is equal to the TSS in mg/L.

6 Definitions

6.1 Analytical batch: The set of samples processed at the same time

6.2 Laboratory reagent blank (LRB): An aliquot of deionized water treated as a sample in all aspects, except that it is not taken to the sampling site. The purpose is to determine if the analytes or interferences are present in the laboratory environment, the reagents, or the apparatus.

6.3 Laboratory duplicate (LD): Two aliquots of the same environmental sample treated identically throughout a laboratory analytical procedure. Analysis of laboratory duplicates indicates precision associated with laboratory procedures but not with sample collection, preservation or storage procedures.

6.4 Method detection limit (MDL) -- The lowest level at which an analyte can be detected with 99 percent confidence that the analyte concentration is greater than zero.

7 Interferences

It is recognized that TSS measurements may include both positive errors (occluded water and waters of crystallization) and negative errors (decomposition and volatilization of minerals such as carbonates, as well as loss of solids that are small enough to pass through the filter). See SM, 2540 A.2, B.1.b, and D.1.b for further discussion of interferences for this method.

8 Health and safety

8.1 The analysis involves handling of freshwater samples that may contain live microorganisms and therefore pose some threat of infection. Laboratory personnel who are routinely exposed to such water samples are encouraged to protect themselves from water borne illnesses by wearing clean disposable gloves and washing their hands frequently.

8.2 This analytical procedure uses a vacuum pump for the filtration steps. There is a risk of implosion under some circumstances. The analyst should ensure that the receiving flask is free from cracks or other imperfections.

9 Personnel qualifications

Laboratory and field personnel shall have a working knowledge of this analytical procedure and will have received training from an associate knowledgeable of the proper sample analysis procedures. Prior to the first batch of sample analyses, the analyst will complete a demonstration of capability exercise as described below in the Quality control section.

10 Equipment and supplies

10.1 Filters, Glass microfiber: 47 mm diameter, 1.5 μm nominal pore size, such as Whatman 934-AH (catalog number: 1827 047) or equivalent

10.2 Filtration apparatus

a. Filter pump
b. A 1-L or 4-L receiving flask
c. Filter funnel manifold, 3 positions
d. Magnetic filter funnels 300 mL
e. Vacuum tubing, ¼" inside diameter

10.3 Drying oven adjusted to 104 ± 1°C. Aluminum weighing dishes (or

10.4 equivalent).

10.5 Analytical balance capable of reading to 0.1 mg.

11 Reagents and standards

11.1 Deionized water (DI): water that has been passed through a purification system (e.g., the Barnstead/Thermolyne system in 476 Temple).

11.2 There are no standards available for this method.

12 Sample collection, preservation, shipment and storage

12.1 See the SOP for water sample collection procedures (SOP: 1040R01 Water Sampling.doc).

12.2 Bottles are sealed and placed on ice in a cooler for transport to the laboratory. The samples are placed in a refrigerator in the laboratory. The maximum holding time is seven days (SM, 2005) but analysis should begin as soon as possible upon delivery at the laboratory.

13 Quality control

13.1 Record the start and end temperatures for this analysis in the instrument log book.

13.2 Method detection limit: Initial demonstration of capability (for any new laboratory assistant) and quarterly thereafter;

a. Carry ten filters through the procedure, filtering 1 liter of deionized water for each.
b. Calculate the standard deviation of the results. The method detection limit is three times the standard deviation. The detection limit should be less than or equal to 0.5 mg/L

13.3 Precision: Initial demonstration of capability (for any new laboratory assistant) and quarterly thereafter;

a. Collect 5 L of sample from the same site under conditions as close to identical as practical. Ideally, the site should be chosen to have TSS ≥ 10 mg/L.
b. Carry out ten analyses using 300 mL samples for each.
c. Calculate the average and standard deviation of the values.
d. The standard deviation should be less than or equal to 20% of the average value. If it is not, evaluate the procedures to identify sources of error.

13.4 Laboratory Duplicate (LD) reproducibility: Carry out with each analytical batch of filters.

a. Carry out two replicates on the same sample, using a sample volume sufficient to provide at least 5 mg solid (ideally, TSS > 10 mg/L).
b. The relative percent difference (RPD) between the two TSS values should be ≤ 20% of their average value.
c. Use equation 1 to calculate RPD:

Equation 1: $$RPD\ (\%) = \frac{(A - B)}{(A + B)/2} \times 100\%$$

Where: A = mass of first aliquot (mg), and
B = mass of duplicate aliquot (mg)

d. Analyze one set of duplicates for every 10 samples analyzed.

13.5 Blank (LRB): At least one blank should be measured with each analytical batch of filters.

a. For the blank measurement, filter 1L deionized water.
b. The TSS value for the blank should be less than 0.5 mg/L. If it is not, evaluate the procedure and correct sources of error.
c. Analyze one blank for every 10 samples analyzed.

14 Calibration and standardization

There are no calibration or standardization procedures for this method.

15 Procedure

15.1 Balance operation:

a. The analyst should review the latest revision of the SOP for balance operation (SOP: 1010R01 Balance.doc) prior to using a balance for this method.

b. The balance should be level, clean and calibrated prior to use.

c. Perform a balance check prior to each batch of analyses:

1. Select a test weight (or combination of test weights) and place on the balance pan.
2. Record values on the bench sheet (see below) and in the balance instrument log book.

15.2 Preparation of filters:

a. Place filter disks onto the filtration apparatus. Apply vacuum and rinse each with three successive 20-mL volumes of deionized water. Draw air through the filters until it appears that all water has been drawn off.

b. Place filters (in individual labeled aluminum evaporating dishes) in an oven set to 104 ± 1ºC.

c. Heat filters for a minimum of 1 hour to ensure that filters are dry.

d. Remove filters from the oven and place them into a desiccator until they have cooled to balance temperature.

e. Weigh each filter, recording all measurements to 0.1 mg precision.

f. Record the mass of the filter on the bench sheet as the Filter Tare Mass in mg.

g. Store filters in a desiccator until use.

15.3 Selection of sample volume

a. The ideal mass increase for the TSS measurement is between 2 and 200 mg (minimum 1.0 mg). The volume of water sample needed to produce this mass change depends on the TSS value.

b. For water collected under base-flow conditions, the recommended starting volume is 300 mL. However, if the suspended solids collected in the filter are either too high or too low, or if the filtration becomes slow due to clogging (total filtration time > 10 minutes), the volume should be adjusted as indicated below.

1. If the mass of the captured suspended solids is less than 1.0 mg, repeat the analysis using a larger sample volume, up to 2 L.
2. If the filtration becomes slow because of clogging, estimate the filtration volume at which the filtration volume decreased and repeat the procedure with a fresh filter, using a volume less than that needed to significantly reduce filtration rate.
3. Based on experience the analyst may adjust sample volume. If filtration of 500 mL produces little observable solids on the filter, the analyst may filter more of the water sample.

4. If experience has shown that samples from a site normally have very high levels of suspended solids and/or frequently cause clogging, the analyst may reduce the sample volume, as long as the mass of solid collected falls in the range of 2 to 200 mg.

c. For highly turbid samples or samples with expected high amounts of TSS:
   1. Place a magnetic stir bar into the sample bottle.
   2. Place the bottle onto a magnetic stirring unit.
   3. Stir at sufficient speed to create a vortex.
   4. Use a 20 mL volumetric pipette to remove sample from the bottle; choose a point that is mid-depth and midway between the bottle wall and the vortex to obtain a homogenous sample.
   5. Place the measured sample onto the filter and continue suction.
   6. Continue steps 15.3.d.4 – 5 until the volume added starts to slow the filtration rate.
   7. Record the volume (in L) on the bench sheet.
   8. Rinse the filter pad with three 10 mL volumes of DI.

15.4 Procedures for TSS

a. Set up the filtration apparatus, insert a filter, and apply vacuum.
b. Wet the filter with a small volume of deionized water to seat it.
c. Shake the sample vigorously and then measure out the predetermined sample volume using a graduated cylinder. Record the volume filtered in liters on the bench sheet.
d. Rinse the graduated cylinder and filter with three 20 mL volumes of DI, allowing complete drainage between washings.
e. Continue suction for three minutes after filtration is complete.
f. Carefully transfer the filter to an aluminum weighing dish, and place filter on a cookie sheet or similar device.
g. Place filters on sheet into an oven set to 104 ± 1°C and dry for a minimum of one hour.
h. Remove filters from oven and transfer them to a desiccator to cool to room temperature.
i. Weigh one sample filter to the nearest 0.1mg. On the bench sheet record the sample ID and the mass (Mass 1) in the "Weight check" section.
j. Repeat steps 15.4.g. – i. Record the mass as "Mass 2" in the Weight check section of the bench sheet. 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.
k. If the mass of the filter increases by more than 0.5 mg, repeat steps 15.4.g. – i. until the filter mass increase is less 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.
l. Record the Oven Dry Mass (in mg) on the bench sheet.
m. Calculate TSS as described below.
n. Dump remaining sample down the drain, remove label, and rinse with tap water to remove any solids from the bottle. Wash bottles according to the Bottle Prep non-Metals SOP 0150R01.

16 Data acquisition, calculations, and reporting

16.1 For each sample analyzed, including quality control samples, record the volume filtered and oven dry mass in the appropriate places on the bench sheet (see below). Calculate TSS using equation 2.

Equation 2. $$\text{TSS (mg/L)} = \frac{(A - B)}{V}$$

Where: A = mass of filter + dried residue (mg),
B = mass of filter (tare weight) (mg), and
V = volume of sample filtered (L)

16.2 Results should be reported to 0.1 mg/L precision.

16.3 If multiple bottles were used to collect a composite sample across a stream channel, analyze each bottle separately and calculate the average of the values for the final TSS concentration. If flow and discharge have been calculated for each subsection then calculate a flow-weighted average using the TSS concentrations for each aliquot.

17 Computer hardware and software

17.1 Word: This document and attached bench sheet are prepared using Microsoft Word. The Word document file name for this SOP is: 2010R01 TSS.doc

17.2 Excel: Quality control charts are created using Excel.

18 Method performance

18.1 The desired performance criteria for this measurement are:

a. Detection limit: 0.5 mg/L
b. Precision: ± 20% RPD
a. Minimum Quantification Interval: 0.1 mg/L

18.2 Below are values of reproducibility at different TSS values for the TSS process given in Standard Methods 2540 D (each for ten replicates by two different analysts; water volume not specified):

TSS mass (mg/L)	Standard deviation	Coefficient of Variation (%)
15	5.2	33
242	24	10
1707	13	0.8

Both Standard Methods 2540 D and EPA 160.2 indicate that replicates should agree within 5% of their average (e.g., a percent difference between the two values of 10%). The data noted here show that reproducibility is much poorer for samples with low TSS.

19 Pollution prevention

All wastes from these procedures shall be collected and disposed of according to existing waste policies

20 Data assessment and acceptable criteria for quality control measures

20.1 The analyst should review all data for correctness (e.g., calculations).

20.2 Precision values are calculated for pairs of duplicate analyses.

20.3 Record the precision values as a percent on the bench sheet.

20.4 The desired precision is ± 20% RPD.

20.5 The desired detection limit is 0.5 mg/L

20.6 The completed bench sheet is reviewed by the analyst's supervisor

21 Corrective actions for out-of-control or unacceptable data

21.1 Quality control charts will be created for charting precision and blank values.

21.2 The results for precision and blank data are compared to the acceptable values for this analysis; ± 20% and 0.5 mg/L, respectively.

21.3 If a precision value exceeds 20% RPD then the analyst should write in the comments section of the bench sheet: "These data are associated with an out-of-control duplicate analysis. The UCL = 20%." Note: "UCL" is the Upper Control Limit (i.e., 20%).

21.4 If a blank value exceeds 0.5 mg/L then the analyst should write in the comments section of the bench sheet: "These data are associated with a blank value that exceeds the detection limit of 0.5 mg/L."

21.5 The samples cannot be reanalyzed because the sample volume will be depleted after the initial analysis.

21.6 If data are unacceptable for any reason, the analyst should review their analytical technique prior to conducting this analysis again.

22 Waste management

The wastes generated in this method are not hazardous. They can be discarded in the following manner: the water, both filtrate and raw sample, can be discarded in the laboratory sink and filter papers can be discarded with the paper trash.

23 References

23.1 Standard Methods for the Examination of Water and Waste Water. Method 2540 D, APHA, 21st Edition, 2005.

23.2 "Residue, Non-Filterable – Method 160.2 (Gravimetric, Dried at 103 – 105°C)." EPA Methods for Chemical Analysis of Water and Wastes. EPA publication 600/4-79/020. March 1983.

23.3 Water Sample Collection. 2006. OEWRI SOP. Document name: 1040R01 Water Sampling.doc

23.4 Operation of Analytical Balances. 2006. OEWRI SOP. Document name: 1010R01 Balance.doc

24 Tables, diagrams, flowcharts and validation data

24.1 There are no tables, diagrams, flowcharts or validation data for this method.

24.2 See page 10 for the bench sheet. The analyst should make a copy of this form for each analytical batch of samples to be analyzed.

Analyst: ______________________

Date analyzed: _________________

Data reviewed by:	

Balance check: Selected mass: _________ Measured mass: _________

Sample Identification	Date Collected	Weigh Pan Label	Filter Tare Mass (mg) (B)	Volume Filtered (L) (V)	Oven Dry Mass (mg) (A)	Total Suspended Solids (mg/L) [(A - B) / V]

Weight check: Select one sample for weight check. If, after the second weighing, the mass change is ≤ 0.5 mg or the change in mass is ≤ 4 % of the previous value, then do not repeat the oven drying cycle. Continue with drying cycle and weight check until mass change is acceptable.

Sample: ___________ Mass 1 (mg): ______ Mass 2 (mg): ______ Mass 3 (mg): ______

Comments: ____

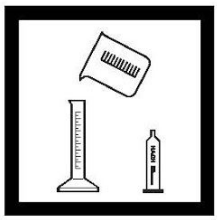
____

Appendix H: Alkalinity Procedure

Method 8203

ALKALINITY (10 to 4000 mg/L as $CaCO_3$)

Phenolphthalein and Total Method



1. Select the sample volume and Sulfuric Acid (H_2SO_4) Titration Cartridge corresponding to the expected alkalinity concentration as mg/L calcium carbonate ($CaCO_3$) from *Table 1*.

Note: *See Sampling and Storage following these steps.*

2. Insert a clean delivery tube into the titration cartridge. Attach the cartridge to the titrator body. See *General Description, Step-by-Step* for assembly instructions, if necessary.

3. Turn the delivery knob to eject a few drops of titrant. Reset the counter to zero and wipe the tip.

Note: *For added convenience use the TitraStir® Stir Plate. See General Description, Step 3 in Step-by-Step.*

4. Use a graduated cylinder or pipet to measure the sample volume from *Table 1*. Transfer the sample into a clean 250-mL Erlenmeyer flask. Dilute to about the 100-mL mark with deionized water, if necessary.

Table 1

Range (mg/L as $CaCO_3$)	Sample Volume (mL)	Titration Cartridge (H_2SO_4)	Catalog Number	Digit Multiplier
10-40	100	0.1600	14388-01	0.1
40-160	25	0.1600	14388-01	0.4
100-400	100	1.600	14389-01	1.0
200-800	50	1.600	14389-01	2.0
500-2000	20	1.600	14389-01	5.0
1000-4000	10	1.600	14389-01	10.0

ALKALINITY, continued

9. Continue the titration with sulfuric acid to a light greenish blue-gray (pH 5.1), a light violet-gray (pH 4.8), or a light pink (pH 4.5) color, as required by the sample composition; see *Table 2*. Record the number of digits required.

Note: *A solution of one Bromcresol Green-Methyl Red Powder Pillow and one pillow of the appropriate pH buffer in 50 mL of deionized water is recommended as a comparison for judging the proper end point color. If the pH 3.7 end point is used, use a Bromphenol Blue Powder Pillow instead of a Bromcresol Green-Methyl Red and titrate to a green end point.*

Total Digits Required x Digit Multiplier
= mg/L as $CaCO_3$ Total (T or M) Alkalinity

10. Calculate:

Total Digits Required x Digit Multiplier = mg/L as CaCO3 Total (T or M) Alkalinity

Note: *Carbonate, bicarbonate and hydroxide concentrations may be expressed individually using the relationships shown in Table 3.*

Note: *meq/L Alkalinity = mg/L as* $CaCO_3 \div 50$.

Table 2

Sample Composition	End Point
Alkalinity about 30 mg/L	pH 4.9
Alkalinity about 150 mg/L	pH 4.6
Alkalinity about 500 mg/L	pH 4.3
Silicates or Phosphates present	pH 4.5
Industrial waste or complex system	pH 4.5

Sampling and Storage

Collect samples in clean plastic or glass bottles. Fill completely and cap tightly. Avoid excessive agitation or prolonged exposure to air. Samples should be analyzed as soon as possible after collection but can be stored at least 24 hours by cooling to 4 °C (39 °F) or below. Warm to room temperature before analyzing.

Alkalinity Relationship Table

Total alkalinity primarily includes hydroxide, carbonate and bicarbonate alkalinities. The concentration of these alkalinities in a sample may be determined when the phenolphthalein and total alkalinities are known (see *Table 3*).

Table 3 Alkalinity Relationship

Row	Result of Titration	Hydroxide Alkalinity is equal to:	Carbonate Alkalinity is equal to:	Bicarbonate Alkalinity is equal to:
1	Phenolphthalein Alkalinity = 0	0	0	Total Alkalinity
2	Phenolphthalein Alkalinity equal to Total Alkalinity	Total Alkalinity	0	0
3	Phenolphthalein Alkalinity less than one half of Total Alkalinity	0	2 times the Phenolphthalein Alkalinity	Total Alkalinity minus two times Phenolphthalein Alkalinity
4	Phenolphthalein Alkalinity equal to one half of Total Alkalinity	0	Total Alkalinity	0
5	Phenolphthalein Alkalinity greater than one half of Total Alkalinity	2 times the Phenolphthalein minus Total Alkalinity	2 times the difference between Total and Phenolphthalein Alkalinity	0

To use the table follow these steps:

a. Does the phenolphthalein alkalinity equal zero? If yes, use Row 1.

b. Does the phenolphthalein alkalinity equal total alkalinity? If yes, use Row 2.

c. Multiply the phenolphthalein alkalinity by 2.

d. Select Row 3, 4, or 5 based on comparing the result of *step c* with the total alkalinity.

e. Perform the required calculations in the appropriate row, if any.

f. Check your results. The sum of the three alkalinity types will equal the total alkalinity.

For example:
A sample has 170 mg/L as $CaCO_3$ phenolphthalein alkalinity and 250 mg/L as $CaCO_3$ total alkalinity. What is the concentration of hydroxide, carbonate and bicarbonate alkalinities?

The phenolphthalein alkalinity does not equal 0 (it is 170 mg/L), see *step a*.

The phenolphthalein alkalinity does not equal total alkalinity (170 mg/L vs. 250 mg/L), see *step b*.

The phenolphthalein alkalinity multiplied by 2 = 340 mg/L, see *step c*.

Because 340 mg/L is greater than 250 mg/L, select Row 5, see *step d*.

The hydroxide alkalinity is equal to: (see *step e*).

340 – 250 = 90 mg/L hydroxide alkalinity

The carbonate alkalinity is equal to:

250 – 170 = 80
80 x 2 = 160 mg/L carbonate alkalinity

The bicarbonate alkalinity equals 0 mg/L.

Check: (see *step f*).

90 mg/L hydroxide alkalinity + 160 mg/L carbonate alkalinity + 0 mg/L bicarbonate alkalinity = 250 mg/L

The above answer is correct; the sum of each type equals the total alkalinity.

Accuracy Check

Standard Additions Method
This accuracy check should be performed when interferences are suspected or to verify analytical technique.

1. Snap the neck off an Alkalinity Standard Solution Voluette® Ampule, 0.500 N.
2. Use a TenSette® Pipet to add 0.1 mL of standard to the sample titrated in Steps 6 or 9. Resume titration back to the same end point. Record the number of digits needed.
3. Repeat, using two more additions of 0.1 mL. Titrate to the end point after each addition.
4. Each 0.1 mL addition of standard should require 25 additional digits of 1.600 N titrant or 250 digits of 0.1600 N titrant. If these uniform increases do not occur, refer to *Appendix A, Accuracy Check and Standard Additions.*

Interferences

- Highly colored or turbid samples may mask the color change at the end point. Use a pH meter for these samples.
- Chlorine may interfere with the indicators. Add one drop of 0.1 N Sodium Thiosulfate to eliminate this interference.

Summary of Method

The sample is titrated with sulfuric acid to a colorimetric end point corresponding to a specific pH. Phenolphthalein alkalinity is determined by titration to a pH of 8.3, as evidenced by the color change of phenolphthalein indicator, and indicates the total hydroxide and one half the carbonate present. M (methyl orange) or T (total) alkalinity is determined by titration to a pH between 3.7 and 5.1, and includes all carbonate, bicarbonate and hydroxide.

REQUIRED REAGENTS

(varies with sample characteristics)

Description	Unit	Cat. No
Alkalinity Reagent Set (about 100 tests)		22719-00
Includes: (1) 942-99, (1) 943-99, (1) 14388-01, (1) 14389-01		
Bromcresol Green-Methyl Red Powder Pillows	100/pkg	943-99
Phenolphthalein Powder Pillows	100/pkg	942-99
Sulfuric Acid Titration Cartridge, 1.600 N	each	14389-01
Sulfuric Acid Titration Cartridge, 0.1600 N	each	14388-01
Water, deionized	4 L	272-56

REQUIRED APPARATUS

Digital Titrator	each	16900-01
Flask, Erlenmeyer, 250-mL	each	505-46
Select one or more based on sample concentration:		
Cylinder, graduated, 10-mL	each	508-38
Cylinder, graduated, 25-mL	each	508-40
Cylinder, graduated, 50-mL	each	508-41
Cylinder, graduated, 100-mL	each	508-42

OPTIONAL REAGENTS

Alkalinity Standard Solution Voluette® Ampules, 0.500 N Na_2CO_3, 10-mL	16/pkg	14278-10
Bromcresol Green-Methyl Red Indicator Solution	100 mL MDB	23292-32
Bromphenol Blue Indicator Solution	100 mL MDB	14552-32
Bromphenol Blue Powder Pillows	100/pkg	14550-99
Buffer Powder Pillows, pH 3.7	25/pkg	14551-68
Buffer Powder Pillows, pH 4.5	25/pkg	895-68
Buffer Powder Pillows, pH 4.8	25/pkg	896-68
Buffer Powder Pillows, pH 5.1	25/pkg	897-68
Buffer Powder Pillows, pH 8.3	25/pkg	898-68
Methyl Purple Indicator Solution	100 mL MDB	21934-32
Phenolphthalein Indicator Solution, 5 g/L	100 mL MDB*	162-32
Sodium Thiosulfate Standard Solution, 0.1 N	100 mL MDB	323-32

* Contact Hach for larger sizes.

OPTIONAL APPARATUS

Description	Unit	Cat. No
Bottle, wash, poly, 500-mL	each	620-11
Clamp, 2-prong extension, 38-mm	each	21145-00
Clamp Holder	each	326-00
Demineralizer Assembly, 473-mL	each	21846-00
Delivery Tubes, with 180° hook	5/pkg	17205-00
Delivery Tubes, 90° with hook for TitraStir® Stir Plate	5/pkg	41578-00
Pipet, TenSette® 0.1 to 1.0 mL	each	19700-01
Pipet Tips for 19700-01 TenSette® Pipet	50/pkg	21856-96
Pipet, volumetric, Class A, 10-mL	each	14515-38
Pipet, volumetric, Class A, 20-mL	each	14515-20
Pipet, volumetric, Class A, 25-mL	each	14515-40
Pipet, volumetric, Class A, 50-mL	each	14515-41
Pipet, volumetric, Class A, 100-mL	each	14515-42
Pipet Filler, safety bulb	each	14651-00
*sens***ion**™*1* Basic Portable pH Meter with electrode	each	51700-10
Support Ring Stand	each	563-00
TitraStir® Stir Plate, 115 Vac	each	19400-00
TitraStir® Stir Plate, 230 Vac	each	19400-10
Voluette® Ampule Breaker Kit	each	21968-00

Appendix I: Ion Chromatography System Procedure

Anions

A. Instrument warm up and column cleansing

1. Name and password is on the computer
2. Turn on IC machine an hour or two before use
3. Make sure there is enough DI water in large/tall 1.9 L bottle
4. Open Chromeleon
5. File→Browser→Panels → Control
6. Click Pump settings
   a. Make sure effluent level matches. Change volume if effluent bottle is refilled.
   b. Open waste valve (bottom left, see diagram on inside of unit door), turn 3-4 half rounds
   c. Click Prime and let the pump prime for a minute (flowrate should change between 0.25ml/min and 3ml/min)
   d. Turn pump off
   e. Close waste valve
   f. Turn pump on
   g. Pressure should rise to around 2,200 psi (< 2,500 psi)
7. Click the cube on ICS detector setting to turn it on
8. Click EG settings
   a. Check the KOH solution is >5% (inform lab manager if not)
   b. Turn on CR-TC and effluent generator.
9. µS rise first and then drop. Wait until it's below 1.0 before starting (could start preparing samples while waiting)

B. Build Sequence Files

1. File → New → Sequence (using Wizard) → Next → My Computer (CE11_1 clock) → Next → Number of vials (2 blanks+standards+samples+3blanks) → Next → Next →
   Chose method file:
   Chose quantification method:
   → Next → Name sequence → Finish, Done
2. Name samples in sequence
3. Change "type" for each line: Blanks = unknowns; standards = standards; samples = unknowns
4. Make sure correct method
5. Program→ Copy "shutdown" method → paste "shutdown" into top area → apply to last sample (blank)[this blank will run for 1 min and then machine will shut down]
6. Save file

C. Prepare samples

1. Get vials, caps, marker, tool (black cylinder), plastic tray
2. Label vials
3. rinse vials a few times before filling
4. use tray when filling (fill to top of tray, doesn't need to be exact)

5. use tool to put on caps ("hole" end first and the other end to further down)
6. Carousel release/align, then setup the autosampler in this order:
    a. 2 blanks
    b. Standards = 100, 200, 400, 800, 1200, 3000ppb, 5000 ppb.
    c. Samples
    d. 3 blanks (2 blanks for wash and one for auto shutdown)

<u>D. Start analysis</u>

1. Batch → Start → Add Sequence file → Ready check (no red; checking for enough effluent volume for analysis and good communication. if bad communication occurs, need to restart the instrument) → Start ("loadposition" should change to "inject" onc the µS drops to 0, if not go to step *)
2. Right-click plot → axis decoration, time for each sample

Don't touch power switch on back!!

*stop the run and close the software, restart the computer → open the software → open the sequence file → replace the first "blank" row with a new one → save file →go to step "Start analysis"

<u>E. Quantification</u>

1. Double click on the sample on the sequence file to bring out the result spectrum.
2. Click QNT editor in tool bar.
3. Highlight the table in Peak Table tab→right click and select auto-generate peak table→OK
4. Name the elements for each peak and insert the conc. for each std.
5. Go through the calibration Curves and check for the off std. → delete the std by right clicking if the std is off → save to method
6. Check intergradation for samples
7. Save the result for sample
    a. Go back to sequence table→select all the stds and samples
    b. Right click →batch report→name the file and save destination

<u>Quantification without running standards (use existing standard sequence)</u>

1. Double click on the sample on the sequence file to bring out the result spectrum.
2. Click QNT editor in tool bar.
3. "General" tab →Global calibration settings: change from "total" to "fixed"→"Calibration" tab→ add most recent standard sequence → save

Appendix J: Inductively Coupled Plasma Mass Spectrometry Procedure

Procedure for ICP-MS

- Check Ar gas is >1000 psi, the vacuum is <1e-8 torr, rinse solution is > 500 ml.
- Sample requirement
  - filter samples through 0.45μm filter if particles expected in the sample
  - Dissolved solids should be less than 0.2% (2000ppm)
  - Acid: no more than 2% of HNO_3
  - Only **aqueous solution** can be used
  - Consult the lab manager if you have any concerns.

ICP-MS instrument preparation

1) turn on the chiller "PolyScience" and wait for the temperature to drop to 18 °C.
2) setup tubings
   a) put sample tube and waste tube on the loop of pump
   b) secure with the clamps
   c) lift the clip for the acid rinse tubing.
3) check probe initialization
   a) go to "Syngistix" tab – select "control" tab- select "autosampler" tab on the left panel
   b) click initialize if not initialized -click "go to Standby"-manually put sample probe into DI tube.
4) ignite plasma
   a) make sure the temp on the chiller is 18 °C.
   b) go to "Syngistix" tab – "Control" tab- "ICP-MS"on the left panel- click button to ignite plasma. The pump will start once the plasma is on.
   c) Wait 30min for instrument warm up
5) Daily Performance check
   a) "Syngistix" – "SmartTune"
   b) change "SmartTune Express" to "SmartTune Manual"
   c) put sample probe in Set-Up Solution, wait solution to enter spray chamber
   d) right click "STD performance check" - select"quick optimize". If it passes the performance check, it's ready to run test. If not, then
      i) if Ce++/Ce fails, use fresh the set up solution.
      ii) If CeO/Ce fails, right click "[STD/KED]Nebulizer gas flow"-select quick optimize
      iii) Inform the lab manager, if you can't get it to pass.
6) Put sample probe into its holder. Select "control"-"autosampler"-"go to rinse"

Test samples with ICP-MS

1) Click "Method" tab – click the blue "S" logo - select "open"-select the appropriate method
2) put blank solution, standard solutions and samples in autosampler; location for blank and standard solutions can be find in method file ("Method"-"Sampling")
3) make new sample file
   a) go to "Sample"-"Batch"
   b) input sample location in "A/S loc."
   c) input Batch ID, Sample ID
   d) select "Run Blank, Stds. and Sample" for Measurement Action for first sample, and select "Run sample" for the rest.
   e) select the right method file for the method column.(right click the cell to open the file list)

f) if dilution is used for sample prep, input dilution information in "Aliquot Volume" and "Diluted to Volume"
g) save sample file.

4) analyze sample
   a) Click "Batch Index" on the right-top corner of the sequence table to select all.
   b) click "Build Run List"
   c) double check the sequence to make sure everything is correct
   d) click "Analyze Batch"
5) monitor data
   a) click on "Reporter" to check test results
6) save results
   a) go to "reporter", click on "Export All..." at the bottom.
   b) Save results to "Report Output Shortcut"

Shut down ICP-MS

1) clean system
   a) rinse system with acid for 5min ("control"- "autosampler" – "go to rinse")
   b) rinse system with DI for 3min ("control"- "autosampler" – "go to Standby"-manually place probe in DI water)
   c) put the sampling probe back to its holder, and wait for a minute to drain out the solution in the tubing.
2) Shut down the system
   a) plasma: "Control"-"ICP-MS"- click button to turn off Plasma
   b) loose sample tube and waste tube from the loop; push down the clip for acid rinse tubing.
   c) Wait for 3min, then shut down the chiller

To edit method

Click "Method" tab – click the blue "S" logo - select "open"-select the method you want to edit.

1) to edit elements to analyze
   a. timing tab: add/delete element
   b. calibration tab: add standard concentrations to new elements and select the unit by right clicking.
   c. QC tab: QC standards tab-add QC standard concentrations to the new element
   d. save
2) to edit standard solutions
   a. calibration tab: edit standards
   b. sampling tab: edit sample name for the standard
   c. QC tab: QC standards-edit the QC standard name and concentrations if needed
      Autosampler- edit location for the QC standard if needed
   d. save
3) To edit delay times
   a. Sampling tab: edit the timings for flush delay if needed to ensure enough time for the sample to get into the chamber.
   b. save

Appendix K: Field Sampling Naming Convention

Format:

"Locational Key : Collection Key - Duplicate Key"

Locational Key:

AOI#1- Kaven Parking Lot
AOI#2- Light Access Road
AOI#3- Heavy Road (Institute Road)
AOI#4- Kaven Walkway
AOI#5- Grass Hill to Skull Tomb
AOI#6- Salisbury Pond
AOI#7- Green Roof East Hall
AOI#8- Grey Roof East Hall
FB#1- Field Blank

Collection Key:
Sample Collection Convention- A collection includes one 1L bottle, one DO bottle, and one 250 mL bottle.

S1- Designates the first full round of sampling at a particular site (roughly first flush)
Sn- Designates the nth round of full sample collection throughout a storm

Periodic Collection Convention- A collection including one 60mL bottle taken between or after a sample collection.

P1- Designates the first periodic sample at a particular site
Pn- Designates the nth periodic sample at a particular site

Duplicate Key:
Duplicate Collection Convention- A repetition of either sample or periodic collection resulting in 2x the defined quantity of runoff.

"Location Key" : "Collection Key" - DUP

EXAMPLE:

AOI#4: S2-Dup→ represents the first round of sample collection at the Kaven Walk site and is the second set of sample taken. Therefore, there will be two 1L bottles, two DO bottle, and two 250 mL bottle collected, in total, during this moment in the storm.

Appendix L: Sampling Data

Date	Time	Location	Specific Conductivity [%]	Water Temperature (In field) [C]	pH	DO	Runoff Channel Depth [ft]	Length of Channel (ft)	Width of Channel [ft]	Dye trace time [s]	Flow rate [ft3/s]	DO (Lab) [mg/L]	Temp (In lab for DO) [C]	Alkalinity [meq/L]
10/27/18	8:40 AM	AOI 1	-	6.5	6.42	9.50	0.08	10.00	0.70	8.67	0.0646	10.50	16.70	0.0640
10/27/18	9:06 AM	AOI 3	-	5.20	6.55	9.24	0.04	10.00	0.90	7.20	0.0521	11.20	12.60	0.1382
10/27/18	8:53 AM	AOI 2	-	5.20	6.41	10.63	0.04	10.00	2.5	6.71	0.1490	-	-	0.0551
10/27/18	9:35 AM	AOI 4	-	5.70	6.85	9.45	0.02	5.10	1.40	6.41	0.0223	-	-	0.0796
10/27/18	9:14 AM	AOI 5	-	4.80	6.08	11.62	0.02	10.00	0.50	27.52	0.0036	-	-	0.1579
10/27/18	8:25 AM	AOI 6	-	-	6.11	6.30	-	-	-	-	-	0.96	11.10	0.1242
10/27/18	3:00 PM	AOI 7	-	-	5.89	-	-	-	-	-	-	0.10	13.10	-
10/27/18	2:54 PM	AOI 8	-	-	5.95	-	-	-	-	-	-	0.00	12.90	-
10/29/18	8:36 AM	AOI 7	-	11.70	-	-	-	-	-	-	-	10.13	13.80	0.1102
10/29/18	8:27 AM	AOI 8	-	11.80	-	-	-	-	-	-	-	10.70	14.30	0.0545
11/2/18	11:15 AM	AOI 7	-	21.80	5.80		-	-	-	-	-	9.57		0.1367
11/2/18	11:07 AM	AOI 8	-	20.80	5.90		-	-	-	-	-	8.45		0.0690
11/3/2018	6:50 AM	AOI 1 S1	-	-	5.56	-	0.04	10.00	0.90	6.08	0.0622	8.89	19.70	0.1301
11/3/2018	7:02 AM	AOI 2 S1	-	-	5.44	-	0.04	10.00	4.00	5.21	0.3228	11.22	17.20	0.0346
11/3/2018	7:10 AM	AOI 3 S1	-	-	5.45	-	0.02	10.00	1.50	5.60	0.0557	9.86	16.10	0.1074
11/3/2018	7:35 AM	AOI 4 S1	-	-	5.52	-	0.01	5.10	0.20	25.04	0.0004	9.70	15.50	0.2375
11/3/2018	7:18 AM	AOI 5 S1	-	-	5.55	-	0.01	10.00	1.00	23.03	0.0045	9.70	15.50	0.1051
11/3/2018	7:18 AM	AOI 5 S1 DUP	-	-	5.46	-	0.01	10.00	1.00	25.43	0.0041	10.01	15.40	0.1584
11/3/2018	7:43 AM	AOI 6 S1	-	-	6.20	-	-	-	-	-	-	5.58	15.10	0.1506
11/3/2018	8:20 AM	AOI 1 P1	-	17.1	5.49	-	-	-	-	-	-	-	-	-
11/3/2018	8:24 AM	AOI 2 P1	-	18.3	5.40	-	-	-	-	-	-	-	-	-
11/3/2018	8:27 AM	AOI 3 P1	-	18.4	4.82	-	-	-	-	-	-	-	-	-
11/3/2018	8:38 AM	AOI 4 P1	-	18.1	5.27	-	-	-	-	-	-	-	-	-
11/3/2018	8:30 AM	AOI 5 P1	-	17.7	5.51	-	-	-	-	-	-	-	-	-
11/3/2018	8:32 AM	AOI 5 P1 DUP	-	18.0	5.53	-	-	-	-	-	-	-	-	-
11/3/2018	8:43 AM	AOI 6 P1	-	18.3	4.71	-	-	-	-	-	-	-	-	-
11/3/2018	9:13 AM	AOI 1 S2	98.40	18.10	5.55	-	0.04	10.00	1.00	5.11	0.0823	8.45	19.10	0.0288
11/3/2018	9:28 AM	AOI 2 S2	91.10	14.60	5.17	-	0.04	10.00	4.10	5.31	0.3243	11.66	18.80	0.0438
11/3/2018	9:34 AM	AOI 3 S2	91.00	14.60	5.13	-	0.02	10.00	1.00	7.58	0.0274	10.02	18.00	0.0850
11/3/2018	9:17 AM	AOI 4 S2	77.60	18.60	5.27	-	0.01	5.10	1.50	6.14	0.0065	11.61	17.10	0.2040
11/3/2018	9:43 AM	AOI 5 S2	91.40	13.00	5.65	-	0.02	10.00	1.00	37.55	0.0055	9.67	16.50	0.1060
11/3/2018	9:47 AM	AOI 5 S2 DUP	91.30	13.10	5.58	-	0.02	10.00	1.00	40.43	0.0051	9.54	16.20	0.1060
11/3/2018	10:04 AM	AOI 6 S2	63.00	12.80	4.98	-	-	-	-	-	-	5.29	15.80	0.1896
11/3/2018	10:25 AM	AOI 1 P2	-	15.30	4.75	-	-	-	-	-	-	-	-	-
11/3/2018	10:32 AM	AOI 2 P2	-	14.90	5.28	-	-	-	-	-	-	-	-	-
11/3/2018	10:35 AM	AOI 3 P2	-	15.20	5.22	-	-	-	-	-	-	-	-	-
11/3/2018	10:44 AM	AOI 4 P2	-	18.50	5.39	-	-	-	-	-	-	-	-	-
11/3/2018	10:38 AM	AOI 5 P2	-	16.70	5.89	-	-	-	-	-	-	-	-	-
11/3/2018	10:38 AM	AOI 5 P2 DUP	-	16.40	5.87	-	-	-	-	-	-	-	-	-
11/3/2018	10:44 AM	AOI 6 P2	-	16.90	5.11	-	-	-	-	-	-	-	-	-
11/3/2018	11:00 AM	FIELD BLANK	89.20	25.10	5.28	7.38	-	-	-	-	-			0.0040
11/13/2018	6:04 AM	AOI 1 S1	73.30	19.60	5.74	-	0.04	10.00	0.80	10.50	0.0318	11.50		0.0298
11/13/2018	6:14 AM	AOI 2 S1	77.30	11.10	5.79	-	0.01	10.00	3.50	5.60	0.0652	11.68		0.0585
11/13/2018	6:25 AM	AOI 2 S1 DUP	87.50	7.00	5.25	-	0.01	10.00	3.50	5.32	0.0685	12.68		0.0826
11/13/2018	-	AOI 3 S1	-	-	-	-	-	-	-	-	-	-	-	-
11/13/2018	6:43 AM	AOI 4 S1	78.20	6.20	5.13	-	0.01	5.10	1.66	7.58	0.0116	13.78		0.1213
11/13/2018	6:34 AM	AOI 5 S1	78.20	6.10	5.26	-	0.02	10.00	1.10	11.80	0.0146	13.58		0.1960
11/13/2018	6:55 AM	AOI 6 S1	36.70	17.10	5.13	-	-	-	-	-	-	8.11		0.1956
11/13/2018	7:44 AM	AOI 7 S1	70.80	14.80	5.44	-	-	-	-	-	0.0018	12.82		0.1498
11/13/2018	-	AOI 7 S1 DUP.L												
11/13/2018	7:27 AM	AOI 8 S1	73.10	15.10	5.67	-	-	-	-	-	0.0417	11.47		0.0589
11/13/2018	8:00 AM	AOI 1 P1	-	-	-	-	-	-	-	-	-	-		-
11/13/2018	8:05 AM	AOI 2 P1	-	-	-	-	-	-	-	-	-	-		-
11/13/2018	8:10 AM	AOI 2 P1 DUP	-	-	-	-	-	-	-	-	-	-		-
11/13/2018	8:15 AM	AOI 3 P1	-	-	-	-	-	-	-	-	-	-		-
11/13/2018	8:20 AM	AOI 4 P1	-	-	-	-	-	-	-	-	-	-		-
11/13/2018	8:25 AM	AOI 5 P1	-	-	-	-	-	-	-	-	-	-		-
11/13/2018	8:30 AM	AOI 6 P1	-	-	-	-	-	-	-	-	-	-		-
11/13/2018	8:30 AM	AOI 7 P1	-	-	-	-	-	-	-	-	-	-		-
11/13/2018	-	AOI 7 P1 DUP.L	-	-	-	-	-	-	-	-	-	-		-
11/13/2018	8:35 AM	AOI 8 P1	-	-	-	-	-	-	-	-	-	-		-
11/13/2018	10:24 AM	AOI 1 S2	64.50	13.80	5.83	-	0.06	10.00	0.67	10.67	0.0391	12.59		0.1642
11/13/2018	10:32 AM	AOI 2 S2	70.40	9.50	6.13	-	0.02	10.00	3.00	4.73	0.1323	12.60		0.0579
11/13/2018	10:42 AM	AOI 2 S2 DUP	73.20	6.80	5.92	-	0.02	10.00	3.00	4.58	0.1365	12.52		0.0302
11/13/2018	-	AOI 3 S2	-	-	-	-	-	-	-	-	-	-		-
11/13/2018	10:18 AM	AOI 4 S2	74.10	16.00	5.92	-	0.02	5.10	0.50	5.22	0.0102	12.54		0.1405
11/13/2018	10:39 AM	AOI 5 S2	73.10	7.10	5.90	-	0.02	10.00	1.00	11.87	0.0176	13.59		0.1312
11/13/2018	11:20 AM	AOI 6 S2	-	11.20	5.56	-	-	-	-	-	-	6.38		0.1726
11/13/2018	10:58 AM	AOI 7 S2	62.10	11.00	5.99	-	-	-	-	-	0.0064	11.93		0.1290
11/13/2018	10:58 AM	AOI 7 S2 DUP.L												
11/13/2018	11:08 AM	AOI 8 S2	56.50	13.00	6.16	-	-	-	-	-	0.0076	10.70		0.0452
11/13/2018	11:50 AM	AOI 1 P2	-	-	-	-	-	-	-	-	-	-		-
11/13/2018	11:55 AM	AOI 2 P2	-	-	-	-	-	-	-	-	-	-		-
11/13/2018	12:00 PM	AOI 2 P2 DUP	-	-	-	-	-	-	-	-	-	-		-
11/13/2018	-	AOI 3 P2	-	-	-	-	-	-	-	-	-	-		-
11/13/2018	12:05 PM	AOI 4 P2	-	-	-	-	-	-	-	-	-	-		-
11/13/2018	12:10 PM	AOI 5 P2	-	-	-	-	-	-	-	-	-	-		-
11/13/2018	12:15 PM	AOI 6 P2	-	-	-	-	-	-	-	-	-	-		-
11/13/2018	12:20 PM	AOI 7 P2	-	-	-	-	-	-	-	-	-	-		-
11/13/2018	-	AOI 7 P3 DUP.L												
11/13/2018	12:25 PM	AOI 8 P2	-	-	-	-	-	-	-	-	-	-		-

Date	Time	Location	Total Suspended Solids [mg]	Mn 55 [mg/L]	Fe 57 Helium KED [mg/L]	Cu 63 [mg/L]	Pb 208 [mg/L]	Na 23 Helium KED [mg/L]	Mg 24 Helium KED [mg/L]	Ca 43 Helium KED [mg/L]	NH3 [mg/L]	Total Phosphorous [mg/L]	Anions [mg/L]								
													Phosphate	Nitrate	Nitrite	Sulfate	Bromide	Chloride	Flouride	Total	Total Nitrogen
10/27/18	8:40 AM	AOI 1	0.0041	-	-	-	-	1.6471	0.4844	0.4708	0.0672	0.2974	0.0300	0.1075	0.0421	0.7513	0.0000	1.7462	0.0197	3.2236	0.0925
10/27/18	9:06 AM	AOI 3	0.0152	-	-	-	-	5.1354	0.9399	0.6870	0.3036	1.7379	1.3414	0.0000	0.0215	1.3209	0.0253	10.4552	0.0000	15.9827	0.2566
10/27/18	8:53 AM	AOI 2	0.0123	-	-	-	-	2.3221	0.5296	0.3941	0.0345	0.6087	0.4142	0.1493	0.0752	0.6130	0.0000	5.3287	0.0107	8.1301	0.0850
10/27/18	9:35 AM	AOI 4	0.3594	-	-	-	-	3.5218	0.5839	0.9416	0.0056	0.0697	0.0506	0.0645	0.0405	0.6454	0.0000	1.2866	0.0152	2.5212	0.0315
10/27/18	9:14 AM	AOI 5	0.3678	-	-	-	-	36.2820	1.7584	1.0706	0.1149	4.1450	1.4200	0.6543	0.1407	7.6293	0.0102	63.5543	0.0563	78.9616	0.2852
10/27/18	8:25 AM	AOI 6	0.0168	-	-	-	-	153.6160	6.0793	7.4493	0.0039	0.3299	-	0.5313	0.0000	23.0998	0.1033	0.0000	0.1213	25.6772	0.1232
10/27/18	3:00 PM	AOI 7	-	-	-	-	-	0.8957	1.5058	1.1648	0.0120	0.1301	0.0610	0.0573	0.0000	5.5304	0.0000	0.9252	0.0529	6.9491	0.0228
10/27/18	2:54 PM	AOI 8	-	-	-	-	-	0.6043	0.2270	0.2790	-0.0269	0.0558	-	0.2421	0.0194	0.6110	0.0000	0.3974	0.0078	2.1522	0.0384
10/29/18	8:36 AM	AOI 7	-	0.0016	0.0658	0.0137	0.0006	0.5952	1.3193	1.0010	0.0920	0.1256	0.0549	0.0592	0.0000	5.5662	0.0000	0.9482	0.0790	7.0237	0.0892
10/29/18	8:27 AM	AOI 8	-	0.0036	0.0018	0.0066	0.0000	0.5060	0.0837	0.1855	0.1493	0.0064	-	0.2405	0.0232	0.5928	0.0000	0.3779	0.0071	2.1191	0.1843
11/2/18	11:15 AM	AOI 7	-	0.0024	0.0788	0.0177	0.0018	0.9552	1.1499	0.9669	0.1810	0.2724	0.0888	0.0347	0.0000	5.7494	0.0000	1.8115	0.0825	8.0692	0.1569
11/2/18	11:07 AM	AOI 8	-	0.0049	0.0034	0.0086	0.0001	1.6017	0.2037	0.2233	-0.0145	0.0202	-	0.3527	0.0295	1.0214	0.0000	2.4611	0.0127	5.1542	0.0767
11/3/2018	6:50 AM	AOI 1 S1	0.0048	0.0045	0.0021	0.0006	0.0001	0.1872	0.0463	0.0392	0.0176	0.0935	0.0009	0.0179	0.0000	0.2106	0.0000	0.1194	0.0051	0.4167	0.0186
11/3/2018	7:02 AM	AOI 2 S1	0.0172	0.0063	0.0154	0.0033	0.0001	2.5819	0.1360	0.0827	0.0625	0.1852	0.0887	0.0140	0.0000	0.3880	0.0000	4.1641	0.0163	4.9020	0.0547
11/3/2018	7:10 AM	AOI 3 S1	0.0644	0.0017	0.0396	0.0013	0.0008	0.7130	0.3608	0.2102	0.1058	0.3732	0.2358	0.0056	0.0000	0.4088	0.0000	0.7463	0.0197	1.9220	0.0884
11/3/2018	7:35 AM	AOI 4 S1	0.2893	0.0031	0.0037	0.0008	0.0001	1.1178	0.4152	1.0153	0.0096	0.5062	0.0132	0.0105	0.0000	0.2121	0.0000	0.3639	0.0094	0.6724	0.0103
11/3/2018	7:18 AM	AOI 5 S1	0.2340	0.0032	0.1690	0.0026	0.0020	1.2718	0.2955	0.1463	0.1908	0.9188	0.4443	0.0068	0.0000	0.7608	0.0000	1.2675	0.0614	3.4812	0.1587
11/3/2018	7:18 AM	AOI 5 S1 DUP	0.2150	0.0039	0.2011	0.0023	0.0022	1.3114	0.3171	0.1548	0.2036	1.0289	0.4520	0.0060	0.0000	0.8425	0.0000	1.2860	0.0338	3.5741	0.1691
11/3/2018	7:43 AM	AOI 6 S1	0.0126	0.1046	0.2181	0.0055	0.0010	13.3799	1.9515	1.6776	0.1556	0.2678	0.0427	0.3027	0.0000	5.0301	0.0152	33.7971	0.0276	4.0341	0.1965
11/3/2018	8:20 AM	AOI 1 P1	-	0.0021	0.0052	0.0018	0.0000	0.3349	0.0826	0.0686	-	-	0.0055	0.0423	0.0000	0.1665	0.0000	0.4386	0.0058	0.8151	-
11/3/2018	8:24 AM	AOI 2 P1	-	0.0116	0.0357	0.0055	0.0003	5.6259	0.2466	0.1517	-	-	0.1129	0.0227	0.0000	0.7939	0.0000	8.4341	0.0439	9.7185	-
11/3/2018	8:27 AM	AOI 3 P1	-	0.0169	0.0075	0.0019	0.0002	1.1916	0.3958	0.2617	-	-	0.2078	0.0127	0.0203	0.4710	0.0000	0.9376	0.0064	2.1752	-
11/3/2018	8:38 AM	AOI 4 P1	-	0.0004	0.0044	0.0017	0.0001	1.5533	0.3974	0.9142	-	-	0.0065	0.0386	0.0000	0.3236	0.0000	0.8267	0.0102	1.3514	-
11/3/2018	8:30 AM	AOI 5 P1	-	0.0063	0.1913	0.0035	0.0022	2.4002	0.3638	0.2030	-	-	0.5661	0.0478	0.0138	1.1309	0.0000	3.1656	0.0383	6.3265	-
11/3/2018	8:32 AM	AOI 5 P1 DUP	-	0.0042	0.1910	0.0034	0.0023	1.7776	0.3612	0.2021	-	-	0.5444	0.0220	0.0221	1.1230	0.0000	1.9236	0.0818	4.9669	-
11/3/2018	8:43 AM	AOI 6 P1	-	0.1146	0.2681	0.0048	0.0012	14.0668	2.1730	1.8351	-	-	0.0333	0.3636	0.0000	5.3754	0.0168	35.9468	0.0338	43.0852	-
11/3/2018	9:13 AM	AOI 1 S2	0.0688	0.0022	0.0053	0.0010	0.0000	0.2978	0.1480	0.0900	0.0062	0.2448	0.0000	0.0311	0.0039	0.2958	0.0000	0.2700	0.0090	0.7254	0.0133
11/3/2018	9:28 AM	AOI 2 S2	0.0108	0.0123	0.0050	0.0029	0.0001	0.7150	0.1487	0.1312	0.2271	0.2678	0.2151	0.0062	0.0286	0.5928	0.0000	1.1266	0.0000	2.4999	0.1972
11/3/2018	9:34 AM	AOI 3 S2	0.0152	0.0093	0.0057	0.0016	0.0001	1.0516	0.3269	0.2335	0.2367	0.2265	0.1982	0.0063	0.0195	0.3848	0.0000	0.8076	0.0101	1.9019	0.2023
11/3/2018	9:17 AM	AOI 4 S2	0.0566	0.0008	0.0058	0.0012	0.0001	1.1700	0.3135	0.6786	0.0078	0.2861	0.0183	0.0156	0.0000	0.2900	0.0000	0.3689	0.0099	0.7943	0.0099
11/3/2018	9:43 AM	AOI 5 S2	0.1302	0.0036	0.1682	0.0029	0.0028	1.8378	0.3360	0.1711	0.2621	1.0518	0.6161	0.0038	0.0000	1.1914	0.0000	1.7613	0.0866	4.9444	0.2167
11/3/2018	9:47 AM	AOI 5 S2 DUP	0.1167	0.0030	0.1480	0.0027	0.0023	1.8492	0.3271	0.1658	0.2653	1.2811	0.6199	0.0063	0.0209	1.2032	0.0000	1.7657	0.0312	4.9966	0.2263
11/3/2018	10:04 AM	AOI 6 S2	0.0104	0.1818	0.3934	0.0030	0.0010	14.9757	2.6527	2.1755	0.1588	0.2265	0.0213	0.4057	0.0000	6.4176	0.0018	40.4877	0.0355	48.8206	0.2224
11/3/2018	10:25 AM	AOI 1 P2		0.0063	0.0102	0.0015	0.0003	0.3670	0.2367	0.1861	-	-	0.0639	0.0497	0.0161	0.3759	0.0000	5.4524	0.0133	6.3101	-
11/3/2018	10:32 AM	AOI 2 P2		0.0213	0.0391	0.0148	0.0008	2.1861	0.4223	0.2475	-	-	0.8696	0.0113	0.0000	1.2965	0.0000	4.2054	0.0000	7.2167	-
11/3/2018	10:35 AM	AOI 3 P2		0.0261	0.0109	0.0016	0.0002	1.1857	0.5315	0.3311	-	-	0.3293	0.0109	0.0200	0.4890	0.0000	0.8820	0.0130	2.5070	-
11/3/2018	10:44 AM	AOI 4 P2	-	0.0014	0.0078	0.0005	0.0001	1.2416	0.5105	1.1774	-	-	0.0218	0.0129	0.0045	0.4611	0.0000	0.6020	0.0109	1.2130	-
11/3/2018	10:38 AM	AOI 5 P2	-	0.0043	0.2481	0.0052	0.0042	3.6550	0.5659	0.2962	-	-	0.6438	0.0243	0.0000	2.0514	0.0000	4.2076	0.0824	8.4218	-
11/3/2018	10:38 AM	AOI 5 P2 DUP	-	0.0047	0.2273	0.0043	0.0034	3.6294	0.6064	0.3230	-	-	0.6726	0.0059	0.0000	1.9983	0.0000	0.0786	0.0868	8.2442	-
11/3/2018	10:44 AM	AOI 6 P2	-	0.1703	0.3858	0.0030	0.0013	15.9107	2.8768	2.3420	-	-	0.0184	0.4332	0.0000	6.8081	0.0182	43.4252	0.0351	52.2615	-
11/3/2018	11:00 AM	FIELD BLANK	2.00	-	-	-	-	-	-	-	-0.0208	-	-	-	-	-	-	-	-	-	-
11/13/2018	6:04 AM	AOI 1 S1	0.0034	0.0022	0.0024	0.0004	0.0001	0.1179	0.0542	0.0387	-0.0196	0.0642	0.0012	0.0229	0.0046	0.0722	0.0000	0.2453	0.0032	0.4408	-0.0095
11/13/2018	6:14 AM	AOI 2 S1	0.0108	0.0033	0.0049	0.0010	0.0001	0.3075	0.0918	0.0876	-0.0081	0.4130	0.0342	0.0208	0.0046	0.1263	0.0000	0.4137	0.0025	0.7543	-0.0006
11/13/2018	6:25 AM	AOI 2 S1 DUP	0.0092	0.0015	0.0146	0.0008	0.0001	0.3009	0.1037	0.1419	-0.0196	1.3860	0.0242	0.0222	0.0050	0.2386	0.0000	0.3966	0.0021	0.8262	-0.0096
11/13/2018	-	AOI 3 S1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11/13/2018	6:43 AM	AOI 4 S1	0.9496	0.0001	0.0068	0.0004	0.0000	0.7873	0.2744	0.5714	-0.0244	0.1698	0.0316	0.0079	0.0000	0.1809	0.0000	0.3001	0.0064	0.6190	-0.0183
11/13/2018	6:34 AM	AOI 5 S1	0.0564	0.0023	0.2093	0.0020	0.0015	1.1515	0.3055	0.1394	0.0831	2.1983	0.3243	0.0071	0.0000	0.5451	0.0000	1.3562	0.0295	2.9558	0.0700
11/13/2018	6:55 AM	AOI 6 S1	0.0174	0.0948	0.1274	0.0035	0.0003	35.2992	4.0528	3.6159	0.0880	0.4084	0.0547	0.4791	0.0000	12.6288	0.0512	85.0901	0.0377	100.0970	0.1806
11/13/2018	7:44 AM	AOI 7 S1	0.0216	0.0004	0.0463	0.0086	0.0012	0.2939	0.6357	0.5810	0.0505	0.2708	0.0859	0.0187	0.0000	1.2458	0.0000	0.4699	0.0750	2.1367	0.0458
11/13/2018	-	AOI 7 S1 DUP.L	0.0212	-	-	-	-	-	-	-	-	-	0.0847	0.0191	0.0000	1.2418	0.0000	0.4582	0.0739	2.1182	-
11/13/2018	7:27 AM	AOI 8 S1	0.0814	0.0017	0.0013	0.0029	0.0000	0.1892	0.0469	0.1487	-0.0114	0.0551	0.0009	0.0781	0.0109	0.2652	0.0000	0.2436	0.0037	0.8971	0.0116
11/13/2018	8:00 AM	AOI 1 P1	-	0.0237	0.0106	0.0013	0.0000	0.9343	0.2228	0.1765	-	-	0.0288	0.0513	0.0093	0.5013	0.0012	1.4474	0.0120	2.3076	-
11/13/2018	8:05 AM	AOI 2 P1	-	0.0054	0.0079	0.0017	0.0001	1.3960	0.1278	0.1116	-	-	0.0000	0.0394	0.0080	0.4254	0.0000	1.5026	0.0040	2.1331	-
11/13/2018	8:10 AM	AOI 2 P1 DUP	-	0.0049	0.0103	0.0019	0.0001	1.0367	0.1414	0.0811	-	-	0.0287	0.0413	0.0032	0.4109	0.0019	0.9711	0.0046	1.6700	-
11/13/2018	8:15 AM	AOI 3 P1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11/13/2018	8:20 AM	AOI 4 P1	-	0.0292	0.0066	0.0022	0.0001	2.6131	0.6966	1.5341	-	-	0.0061	0.0181	0.0039	0.6374	0.0033	2.2096	0.0108	2.9730	-
11/13/2018	8:25 AM	AOI 5 P1	-	0.0025	0.2163	0.0026	0.0018	2.0566	0.3458	0.1694	-	-	0.3044	0.0381	0.0064	0.8178	0.0010	2.1023	0.0292	4.0733	-
11/13/2018	8:30 AM	AOI 6 P1	-	0.2810	1.1512	0.0040	0.0021	12.8552	2.3199	1.9090	-	-	0.1214	0.2800	0.0000	9.3690	0.0148	29.0837	0.0409	40.1203	-
11/13/2018	8:30 AM	AOI 7 P1	-	0.0024	0.0394	0.0054	0.0001	0.4071	0.6288	0.5806	-	-	0.0860	0.0220	0.0039	1.2452	0.0000	0.4006	0.0717	2.0913	-
11/13/2018	-	AOI 7 P1 DUP.L	-	-	-	-	-	-	-	-	-	-	0.0857	0.0214	0.0000	1.2280	0.0000	0.3986	0.0723	2.0562	-
11/13/2018	8:35 AM	AOI 8 P1	-	0.0013	0.0007	0.0021	0.0000	0.2306	0.0335	0.1192	-	-	0.0000	0.0784	0.0138	0.3754	0.0000	0.1493	0.0042	0.9218	-
11/13/2018	10:24 AM	AOI 1 S2	0.0036	0.0034	0.0093	0.0004	0.0000	0.2275	0.0832	0.0595	-0.0163	0.0459	0.0169	0.0249	0.0052	0.0959	0.0000	0.4016	0.0054	0.6823	-0.0062
11/13/2018	10:32 AM	AOI 2 S2	0.0376	0.0028	0.0055	0.0008	0.0001	0.5094	0.0988	0.0822	-0.0261	0.1973	0.0334	0.0205	0.0065	0.1465	0.0000	0.7352	0.0042	1.1005	-0.0149
11/13/2018	10:42 AM	AOI 2 S2 DUP	0.0024	0.0042	0.0065	0.0011	0.0001	0.6085	0.0922	0.0752	-0.0261	0.1469	0.0303	0.0196	0.0053	0.1669	0.0000	0.8913	0.0046	1.2601	-0.0154
11/13/2018	-	AOI 3 S2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11/13/2018	10:18 AM	AOI 4 S2	0.3692	0.0003	0.0076	0.0010	0.0001	1.0615	0.3400	0.8103	0.0244	0.1331	0.0079	0.0174	0.0000	0.2450	0.0000	0.5963	0.0076	0.9505	0.0241
11/13/2018	10:39 AM	AOI 5 S2	0.6700	0.0020	0.1954	0.0014	0.0013	0.8806	0.2935	0.1409	0.0570	2.0422	0.2216	0.0106	0.0000	0.3284	0.0000	0.6333	0.0268	1.7144	0.0493
11/13/2018	11:20 AM	AOI 6 S2	0.0186	0.0793	0.1117	0.0045	0.0005	41.2289	4.0208	3.5252	0.0603	0.1744	0.0155	0.4815	0.0000	10.8287	0.0586	85.1111	0.0406	98.2189	0.1584
11/13/2018	10:58 AM	AOI 7 S2	0.0036	0.0007	0.0329	0.0044	0.0002	0.2727	0.5718	0.5184	0.0277	0.2019	0.0906	0.0181	0.0000	0.8879	0.0000	0.2653	0.0731	1.5841	0.0269
11/13/2018	10:58 AM	AOI 7 S2 DUP.L	0.0036	-	-	-	-	-	-	-	-	-	0.0896	0.0174	0.0000	0.8831	0.0000	0.2568	0.0740	1.5655	-
11/13/2018	11:08 AM	AOI 8 S2	0.0016	0.0006	0.0022	0.0009	0.0000	0.0835	0.0245	0.1024	0.0114	0.0413	-	0.0416	0.0068	0.1300	0.0020	0.0795	0.0044	0.4227	0.0209
11/13/2018	11:50 AM	AOI 1 P2	-	0.0237	0.0106	0.0013	0.0000	0.9343	0.2228	0.1765	-	-	0.0150	0.0268	0.0127	0.2383	0.0000	0.5660	0.0120	1.0228	-
11/13/2018	11:55 AM	AOI 2 P2	-	0.0054	0.0079	0.0017	0.0001	1.3960	0.1278	0.1116	-	-	0.0518	0.0170	0.0098	0.6948	0.0000	6.5481	0.0190	7.5279	-
11/13/2018	12:00 PM	AOI 2 P2 DUP	-	0.0049	0.0103	0.0019	0.0001	1.0367	0.1414	0.0811	-	-	0.0451	0.0319	0.0079	0.4064	0.0000	2.5140	0.0130	3.2391	-
11/13/2018	-	AOI 3 P2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11/13/2018	12:05 PM	AOI 4 P2	-	0.0005	0.0304	0.0014	0.0005	1.7807	0.5557	1.3907	-	-	0.0208	0.0088	0.0000	0.4371	0.0000	1.6651	0.0156	2.2205	-
11/13/2018	12:10 PM	AOI 5 P2	-	0.0039	0.2908	0.0027	0.0027	1.7297	0.3379	0.1578	-	-	0.2662	0.0249	0.0000	0.7287	0.0000	1.7137	0.0323	3.4006	-
11/13/2018	12:15 PM	AOI 6 P2	-	0.3121	0.5809	0.0045	0.0010	13.1407	2.8244	2.2493	-	-	0.1469	0.3028	0.0000	8.8314	0.0165	34.2953	0.0426	44.9767	-
11/13/2018	12:20 PM	AOI 7 P2	-	0.0019	0.0407	0.0060	0.0003	0.3835	0.5721	0.5043	-	-	0.0883	0.0273	0.0000	1.0486	0.0000	0.2975	0.0806	1.8181	-
11/13/2018	-	AOI 7 P3 DUP.L	-								0.0000	-	0.0879	0.0253	0.0000	0.9778	0.0000	0.3033	0.0872	1.7496	-
11/13/2018	12:25 PM	AOI 8 P2	-	0.0064	0.0555	0.0019	0.0001	0.2557	0.0397	0.1469	-	-	-	0.0820	0.0115	0.2894	0.0000	0.4247	0.0086	1.1239	-

Appendix M: Downstream Design Summary

Sheet Flow (**SF**) Shallow Concentrated Flow (**SCF**) Channel Flow (**CF**)

Catchment	**Existing Downstream Analysis NOAA Database Standard (1/2/10/25 yr. storm ~5.92"/day)**					
	Length (ft)	**Slope (ft/ft)**	**Velocity (ft/s)**	**Tc (min)**	**Capacity (cfs)**	**Description**
1	50	0.01	0.90	0.9	-	SF, A-B Smooth Surface n=0.11
	300	0.03	3.34	1.5	-	SCF, B-C Paved Kv= 20.3 fps
	220	0.06	4.97	0.7	-	SCF, C-D Paved Kv= 20.3 fps
	320	0.01	2.03	2.6	-	SCF, D-E Paved Kv= 20.3 fps
	260	0.10	6.29	0.7	-	SCF, E-F Paved Kv= 20.3 fps
	610	0.04	4.06	2.5	-	SCF, F-G Paved Kv= 20.3 fps
2	50	0.01	0.90	0.9	-	SF, 2A-2B Smooth surfaces n= 0.011
	460	0.08	5.74	1.3	-	SCF, 2B-2C Paved Kv= 20.3 fps
	300	0.03	3.34	1.5	-	SCF, 2C-2D Paved Kv= 20.3 fps
	330	0.02	3.14	1.7	-	SCF, 2D-2E Paved Kv= 20.3 fps
	80	0.01	2.03	0.7	-	SCF, 2E-2F Paved Kv= 20.3 fps
	670	0.10	2.03	5.5	-	SCF, 2F-2G Paved Kv= 20.3 fps
	170	0.01	2.03	1.4		SCF, 2G-2H Paved Kv= 20.3 fps

Catchment	Existing Downstream Analysis NOAA Database Standard (1/2/10/25 yr. storm ~5.92”/day)					
	Length (ft)	**Slope (ft/ft)**	**Velocity (ft/s)**	**Tc (min)**	**Capacity (cfs)**	**Description**
3	50	0.04	0.19	4.3	-	SF, 3A-3B Grass: Short n= 0.150
	200	0.07	5.41	0.6	-	SCF, 3B-3C Paved Kv= 20.3 fps
	600	0.07	5.38	1.9	8.07	CF, 3C-3D Area= 1.5 sf Perim= 20.0' r= 0.07' Asphalt, smooth n= 0.013
4	50	0.24	0.04	2.1	-	SF, 4A-4B Grass: Short n= 0.150
	100	0.24	7.89	0.2	-	SCF, 4B-4C Unpaved Kv= 16.1 fps
	380	0.06	4.89	1.3	-	SCF, 4C-4D Paved Kv= 20.3 fps
	190	0.01	2.03	1.6	-	SCF, 4D-4E Paved Kv= 20.3 fps
5	50	0.04	1.56	0.5	-	SF, 5A-5B Smooth surfaces n= 0.011
	190	0.10	5.09	0.6	-	SCF, 5B-5C Unpaved Kv= 16.1 fps
	290	0.04	4.06	1.2	-	SCF, 5C-5D Paved Kv= 20.3 fps
6	50	0.01	0.11	7.5	-	SF, 6A-6B Grass: Short n= 0.150
	510	0.06	3.94	2.2	-	SCF, 6B-6C Unpaved Kv= 16.1 fps

Appendix N: Project Proposal

Quantifying the Pollutant Removal Effectiveness of BMP Practices in Urban Watersheds

Worcester Polytechnic Institute
Major Qualifying Project Proposal

October 11, 2016

Lucas Acaba, Virginia Adams,
Stephen Balcewicz, Keeghan O'Leary, Kim Stanway

Advisors: Professor Paul Mathisen and Professor Harold Walker

Sponsored by: Nitsch Engineering

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DESIGN PIECE

WPI's Major Qualifying Project (MQP) for the Civil and Environmental Engineering department requires a design component. This is part of a senior capstone and is necessary for graduation. American Society of Civil Engineers (ASCE) defines a design component as solving an open ended, ill-defined problem with iterative analysis and synthesis. The design process involves defining the problem in order to analyze the current system to synthesize a new system, all while keeping various constraints in mind (American Society of Civil Engineers, 2018). We will keep in mind engineering standards and practices throughout the project. We will also take into account real life problems, including cost, policies, functionality, human/student impact, and other aspects that could constrain the design. It is important to create a design that will better the area while also being feasible.

For our project's design component, we plan to design a Best Management Practice for an area of interest on campus. The final best management practice design will help reduce and manage the nutrient and stormwater runoff in a selected area of interest. This design will help manage the stormwater in the area and reduce nutrient runoff, while following the requirements established by ASCE and considering the social, economic, and environmental impacts.

<u>Social</u>

Our BMP will be designed for implementation on WPI's campus. We will need to consider the specifics of this site, such as the way the campus operates and who it serves. The design will need to accommodate the students, meaning there will most likely be a lot of foot traffic in the area. It will need to work around this, making as little an impact on their lives as possible. Additionally, the design will need to take campus policies into consideration. This may mean safety, aesthetics, or future plans for said area.

The design may have the opportunity to improve the campus. It could provide a place to improve aesthetics, increase foot traffic, or provide a place for people to gather. The design will look at mitigating the negative impacts as well as creating a positive impact on the surrounding area.

<u>Economic</u>

Since this a WPI project, the design will need to be affordable and cost effective. We would not want a design that is more expensive to build and maintain than to continue with the current system. We want the design to manage the stormwater runoff in the area of interest in the more efficient and effective manner. Ideally, the new design would save money and improve the area in as many ways as possible.

Environmental

The design will help the surrounding environment, as it is a BMP based design and is aimed to reduce nutrient pollution. During the designing phase, it is important to consider the materials and construction, ensuring no additional and environmental harm will be done. Additionally, the design will need to fit the environment is it in.

LICENSURE

According the National Council of Examiners for Engineering and Surveying (NCEES), professional licensure is necessary to help protect the public by ensuring civil engineers know the best practices available. Licensing can be obtained via the Fundamentals of Engineering exam and then the Professional Engineers exam. This is to be sure the engineers know the standards in the area and will follow the correct engineering practices. The specifics of these practices vary from state to state, which results in the Professional Engineers exam allowing for state specific licensure (NCEES, 2018). Since WPI is located in Massachusetts we will look at the licensure process there.

1.0 INTRODUCTION

Wastewater discharge, both domestic and industrial, is thoroughly treated in sophisticated treatment systems to lower contaminant concentrations to reasonable levels. Stormwater runoff does not receive this level of treatment before being discharged to a local water body. In some stormwater management cases there is no treatment. This is due to the fact that stormwater runoff tends to have significantly lower concentrations of contaminants as compared to wastewater (Environmental Protection Agency, 2018). However, the quantity of contaminants present in stormwater can be very high during major rain events (Environmental Protection Agency, 2018). These contaminants can then have detrimental impacts on local ecosystems by introducing metals and other toxic materials, causing uncontrolled plant growth due to unnaturally high nutrient levels, or limiting plant growth through suspended solid contamination or lowered levels of dissolved oxygen.

The contamination of water bodies from stormwater runoff becomes more concerning as urban areas get further developed. Increased amounts of impervious surfaces provides less opportunities for contaminants to be absorbed by soil and plants, resulting in more runoff reaching the nearby water body (Environmental Protection Agency, 2017). To mitigate this, stormwater management plans consisting of best management practices (BMPs) such as recharge basins or detention ponds. However, urban areas consist of a variety of land uses including open spaces and parks, streets, walkways, parking lots, grey roofs, and green roofs. There is a limitation on research being done on the quality and quantity of stormwater runoff from these differing types of surfaces.

Nitsch Engineering has chosen to sponsor this project in order to gather information on how stormwater quality and quantity differ between surface types. This can be used to determine if full stormwater management plans are accurately designed in certain areas. By determining if the plan is over or under compensating, adjustments can be made to ensure that all runoff is adequately treated at the optimal cost efficiency to developer clients. Specifically, they would like to know how pH, dissolved oxygen, total suspended solids, alkalinity, cations, anions, nitrates, nitrites, phosphate, total phosphorus, and chloride levels vary between grassy areas, walkways, parking lots, streets, grey roofs, and green roofs.

In order to meet this goal, we plan to sample stormwater runoff during rain events at six points on the Worcester Polytechnic Institute campus that fit the different land types in which Nitsch Engineering is interested. These samples will be tested for the listed contaminants and compared relative to each other to determine if contaminant levels vary. This information will then be used to design a stormwater management plan for this section of the campus that factors in the possible different levels of contaminants present in the stormwater runoff from each type of surface.

2.0 BACKGROUND

This section of the report details the importance of managing stormwater runoff, stormwater management techniques, and contaminants of concern in stormwater. It also describes Nitsch Engineering and their motivation for sponsoring this project as well as our plan to study stormwater runoff on the campus of Worcester Polytechnic Institute.

2.1 Stormwater Management

Stormwater Management is a vital component in decreasing our environmental impact. Management of runoff is important to achieve the goal of reducing down gradient flooding and improvement of water quality (Dzurik, 2003; Lepage, 2010). Water quality can be improved through the implementation of Best Management Practices (BMP) by removing contaminants that are gained during contact with a variety of urban surfaces. In fact, nonpoint source (NPS) contamination is the largest contributing factor to the degradation of water quality (Tsihrintzis, Hamid, 1996). Non-point source pollution is the buildup of residual contaminants in between precipitation events that are washed away during each storm. This model is addressed as the buildup- wash off model (Wang, 2011). In particular, urban areas contain a variety of land uses which may introduce different contaminants

The Massachusetts Stormwater Handbook outlines that: no outfall can be release directly untreated to wetlands or waterways, peak discharge must remain the same pre and post-development, recharge to groundwater must remain constant or maximized, and Total Suspended Solids (TSS) must be reduced by 80% (MassDEP, 2008). However, there is no quantification of contaminant concentrations in runoff from specific types of surfaces which is an area of concern since urban areas consist of a variety of different land uses. Figure 1, produced by Tsihrintzis and Hamid 1996, shows the characteristics that dictate the management practices of runoff.

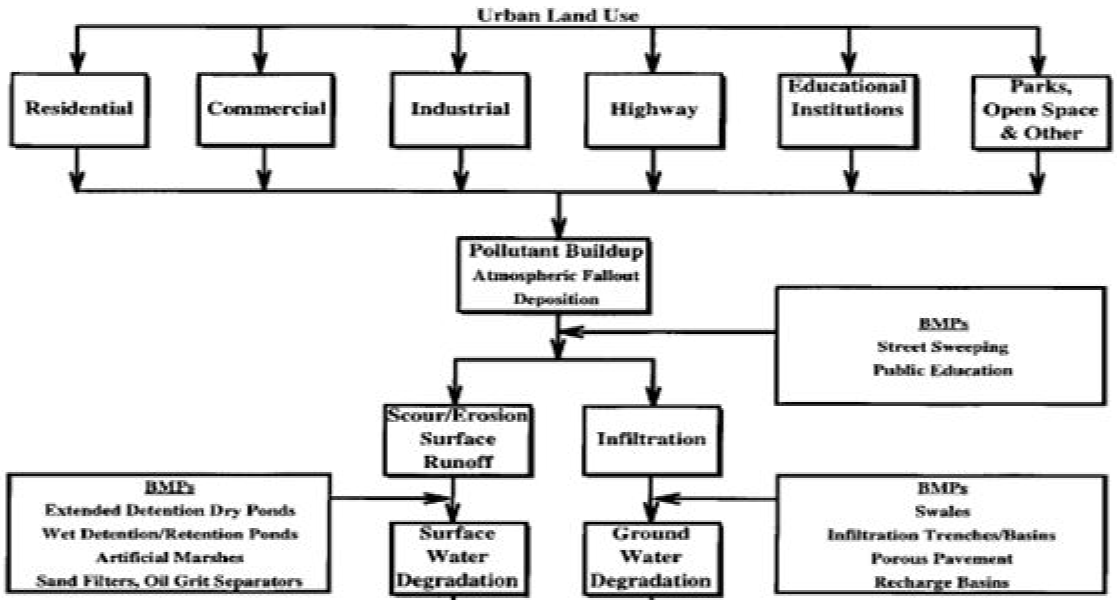


Figure 1: Outlined land uses and the methods for choosing BMP design to mitigate runoff contamination to stormwater. Source: (Tsihrintzis and Hamid 1996)

As outlined by Figure 1, urban land can be used in a variety of different ways which then can dictate the methods of treating NPS pollutants. However, these land-uses defined above are mainly composed of impervious and pervious surfaces. When choosing a BMP design, it would be valuable to know the concentrations of contaminants based on surface relevance. This ensures that the BMP design can maximize pollutant removal. For example, an industrial facility which contains a largely quantity of impervious surfaces may contain a greater number of deep sump catch basins. As outlined by Volume 2, Chapter 2 of the Massachusetts stormwater handbook, this form of BMP is valuable when removing trash, debris, and coarse sediment which may carry oils and grease because of the associated low infiltration rate. However, this form of BMP would lack effectiveness when treating TSS because of its low removal rating (25%) (MassDEP, 2008). Understandably the contaminants that accumulate when in contact with such surfaces must vary based on land use, so must the design. In essence, the determination of constituent contaminations based on surface types will better the design, use and efficiency of BMP when managing stormwater runoff.

In addition to determining the concentrations of runoff contaminants based on land surface, the volumetric loading rate will be necessary to determine the quantity of contaminant that are required to be treated. First flush analysis is important because contaminant concentration will be affected during this period. It was found that the first flush affected the concentration, in descending order, of solids, organics, and nutrients (Kim, Kim and Yur, 2007). The largest contributing factors to the volumetric rate is the slope of the surface and soil composition (in pervious areas).

Through the investigation of contamination composition based on surface type and volumetric flow rates from these areas, it will be possible to significantly improve the management of stormwater by tailoring stormwater management practices to specific areas based on the quantities of contaminants present in its runoff, advancing the protection of water quality. These different contaminants of concern and their possible effects to public health and the environment are investigated in the sections to follow.

2.2 Contaminants of Concern

Nutrients in Stormwater:

One of the major contaminants of concern in stormwater runoff are nutrients, mainly in the form of nitrogen and phosphorous. Nitrogen and phosphorous can enter water bodies through natural processes such as the weathering of rocks, fixation of nitrogen from the atmosphere by leguminous plants, decomposition of organic material, and leaching from surrounding soil (Khwanboonbumpen, 2006). However, the amount of nutrients reaching water bodies is dramatically increased by human contamination in stormwater. This can come from landscape runoff from fertilizers and plant debris, pet and animal waste, detergents from car washing, and vehicle emissions (Environmental Protection Agency, 2018). Industrial discharges and improperly treated wastewater are also major contributors to nutrient pollution (Khwanboonbumpen, 2006). Although wastewater discharges tend to have a significantly higher concentration of nutrients than stormwater runoff, large volumes of stormwater during rain events can lead to water bodies receiving high amounts of nutrients (Environmental Protection Agency, 2018). This problem is further amplified in areas with a high percentage of impervious surfaces since there is no soil or plants to absorb some of the nutrients before the runoff is discharged into a water body or storm drain (Environmental Protection Agency, 2017). The high loading of nutrients can then cause an imbalance in the natural ecosystem of the receiving water body.

The growth of plants in a water body is normally kept in check by limiting growth factors, which are essential nutrients that are lowest in concentration. Phosphorous tends to be the limiting growth factor in freshwater systems while nitrogen is usually limiting in coastal marine ecosystems (Khwanboonbumpen, 2006). Therefore, when excessive amounts of nitrogen or phosphorus enter a water body, it can cause uncontrolled plant growth and begin a process called eutrophication (Environmental Protection Agency, 2018). Eutrophication is, “the process by which a body of water becomes enriched with organic material [that] is formed in the system by primary productivity and may be stimulated to excessive levels by anthropogenic introduction of high concentrations of nutrients” (Khwanboonbumpen, 2006). Eutrophic conditions lead to large, nuisance algal blooms or other excessive plant growth that is unaesthetic and limits the use of the water body (see Figure 2) (Environmental Protection Agency, 2018). Certain algae species can also have public health effects in areas where people swim or fish (Khwanboonbumpen, 2006). When these plants and algal blooms fall to the bottom of water body and decompose, they release more nutrients into the ecosystem and add to sediment oxygen demand (Khwanboonbumpen, 2006). This can continue the eutrophic conditions and eventually deplete dissolved oxygen which is detrimental to plant and animal life.

Figure 2: Eutrophication in the Mississippi River from agricultural runoff.
Source: (Lake Forest College, 2018)

Suspended Solids:
Solids, also referred to as total suspended solids (TSS), are one of the most common forms of contaminants found in urban stormwater. While solids can be contributed from natural sources, such as stream bank erosion, the presence of TSS is greatly increased by various human activities. As water from a rain event flows across impervious and pervious surfaces solids are accumulated and contribute to the pollutant load of stormwater. Major contributors to TSS in stormwater include streets and roads, the erosion of drainage channels, construction sites, and pervious surfaces, and atmospheric deposition of solid particulate matter (Environmental Protection Agency, 2018). The presence of high levels of suspended solids in a water body can negatively impact water quality and cause habitat issues due to increased turbidity levels and sedimentation. Reduction in the ability of light to penetrate the water body resulting from high turbidity levels can negatively impact and limit the growth of photosynthesizing organisms while sedimentation of bottom deposits can alter the habitats of bottom-dwelling organisms (Environmental Protection Agency, 2018). The presence of solids in stormwater can also encourage the accumulation of other pollutants, including metals and nutrients, as the sediment acts as a medium for accumulation and transport of sediment-bound pollutants.

Metals:
Some particular metals of concern in stormwater include copper, lead, zinc, chromium, mercury, nickel, and arsenic. Copper, lead, and zinc are the most prevalent. Heavy metals are primarily

sourced from automobiles, construction, and industrial areas and can have significant impacts on receiving water bodies (Environmental Protection Agency, 2018). Vehicle exhaust residues from diesel and gasoline fuel have been identified as important sources of lead, mercury, zinc, silver, and copper. Automobile brake pads have also been identified as contributors of copper in stormwater. (Lee, 1993). The presence of elevated levels of copper, lead, and zinc in stormwater is of concern as copper is toxic to phytoplankton and can therefore negatively impact aquatic food chains. Lead is highly toxic to humans and aquatic life and serves no biological purpose and the presence of zinc can impact gill function for various fish populations (Brooks Applied Labs, 2016). As communities continue to develop, the presence of heavy metals in stormwater is only becoming more severe and there are already thousands of surface water bodies considered impaired due to heavy metal pollution from stormwater.

2.3 Nitsch Engineering

Nitsch Engineering is an engineering firm that specializes in the providing communities with civil engineering, land surveying, transportation engineering, structural engineering, green infrastructure, planning and GIS services. The company was founded in 1989, and in the twenty nine years that Nitsch has been serving the community, they have worked with a variety of academic clients, developers, corporate and institutional owners, public agencies, architects, and other design professionals on many different development and infrastructure projects. Nitsch has worked in twenty states and five countries. Nitsch boast that 94% of its work comes from return clients meaning that they are trusted and respected in the engineering world. Nitsch is also an accredited woman-owned business and is certified in many different areas (Nitsch Engineering, 2018). The company is committed to its employees and prides itself on Sustainable Business practices, community involvement and charitable contributions. Nitsch has won many awards dating back to 2006 and continue to strive for excellence. Nitsch Engineering has chosen to sponsor this project as they are interested in how stormwater runoff quality and quantity differs from different type's surfaces and land uses. They can then use that information to ensure that their stormwater management practices are designed to adequately address contaminants from each type of area specifically and that they are not over designing in areas where contaminant concentrations are low so they can potentially decrease costs to their clients.

2.4 Worcester Polytechnic Institute

Our site of interest is the Worcester Polytechnic Institute (WPI) campus. Within this site are five points of interest where we intend to focus are sampling. To decide on the specific points we first needed to understand the campus and the current stormwater runoff management.

As for the current stormwater management on campus, there is not much. Based on observations and computer modeling, it is can be seen that the stormwater runs off the impervious surfaces on campus into catch basins. The water flows from the catch basins to storm drains that lead to

Salisbury Pond, taking the pollutants and nutrients from campus and polluting already damaged waters. This can be seen in Figure 3 below.

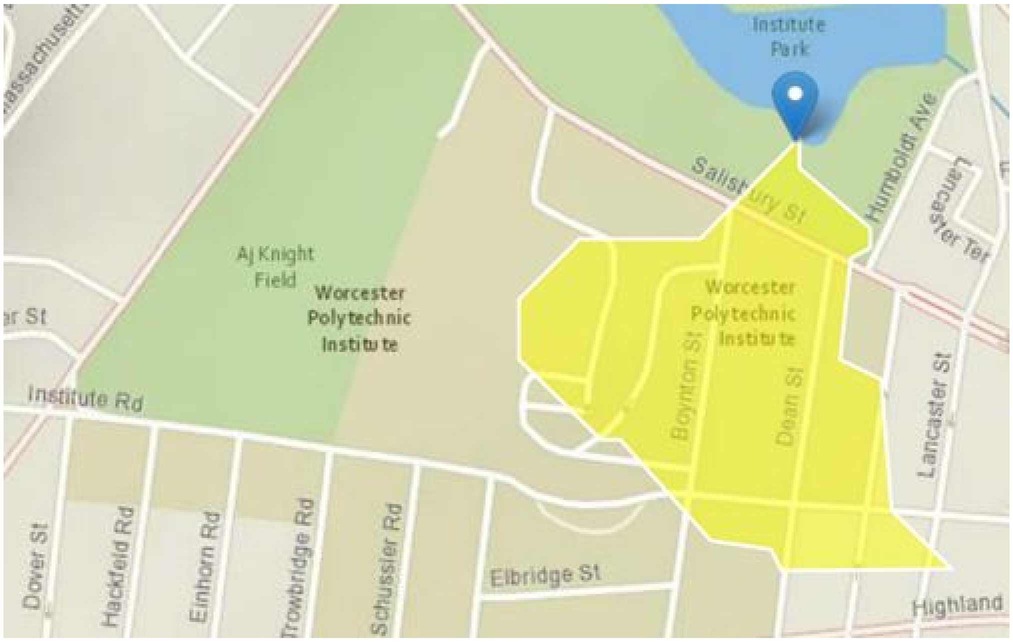


Figure 3: Area of WPI Campus that drains to Institute Pond. Source: Stephen Balcewicz

In order to improve upon this current stormwater runoff situation, the current conditions in stormwater management and related work was examined. In the past, WPI has had other project teams explore this issue. The Water Research Outreach Center (WROC) is a local project center that explores issues related to stormwater. These issues include cost - benefit analyses of best management processes, educating the community on stormwater management, tracking information on stormwater via databasing, and complying with new MS4 regulations (WPI, 2018). The most recent project, *Stormwater Runoff Reduction on the Worcester Polytechnic Institute Campus*, explored stormwater across campus and explored possible BMPs that could help mitigate the impacts of the runoff. The result showed that one area of campus, the grass area by the Skull tomb, contains about 25% of all of the campus drainage (Marsan, et al., 2018). Since the runoff there is so high, we decided to sample on the East side of campus. The locations can be seen on Figure 4 below.

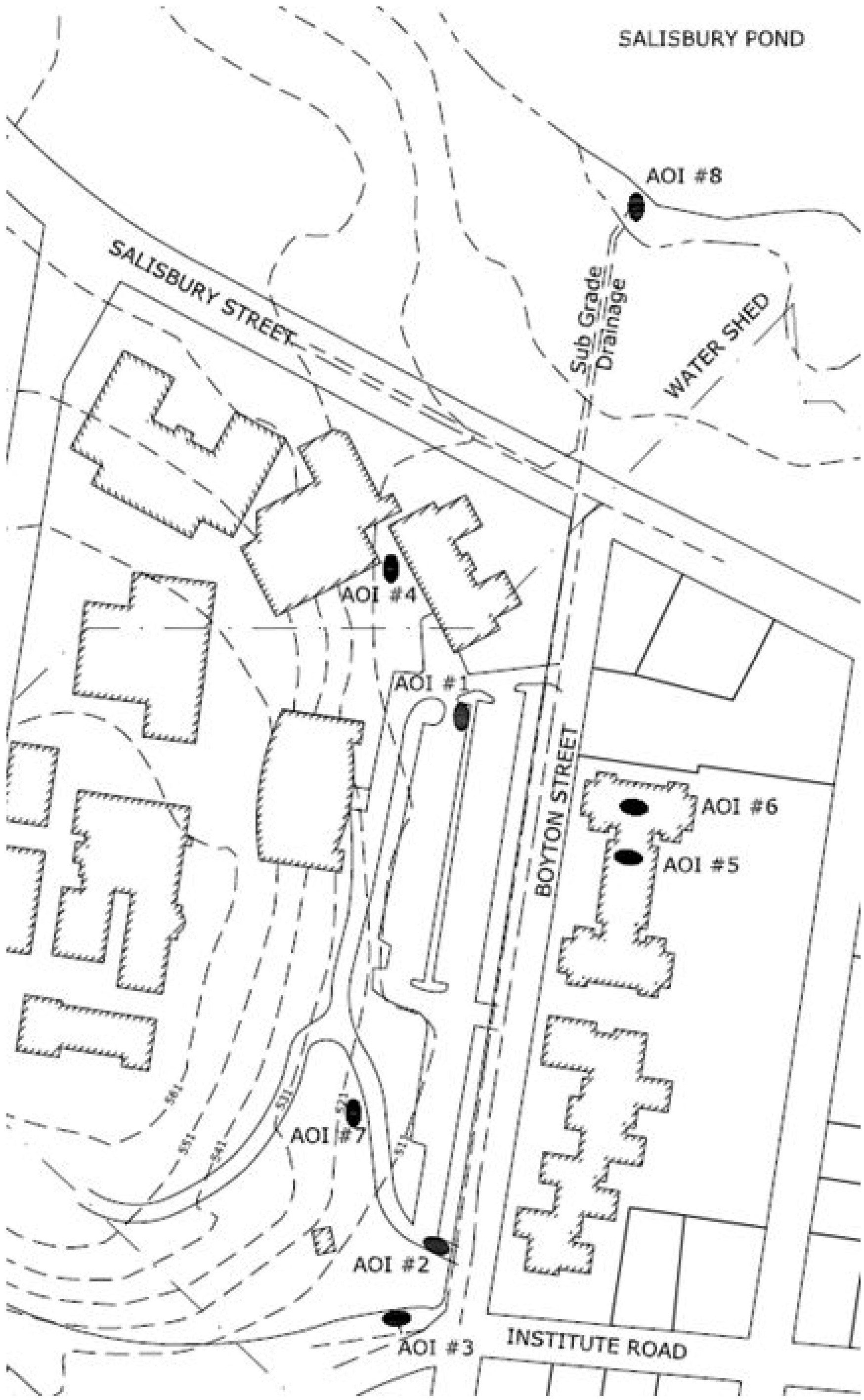


Figure 4: Map of Sampling Points of Interest on the WPI Campus. Derived from OliverGIS, Arcmap, and Streamstats Databases

The areas of interest (AOI) were chosen to meet the criteria set by Nitsch Engineering had given. Therefore, the following types of areas will tested: parking lot (AOI #1), light traffic road (AOI

#2), heavy traffic road (AOI #3), sidewalk (AOI #4), green roof (AOI #5), grey roof (AOI #6), grassy area (AOI #7), and the discharge water body (AOI #8).

3.0 METHODOLOGY

3.1 Project Scope

The scope of our project is to sample and analysis stormwater runoff to gain a better understanding of the current stormwater management situation in order to improve upon it by designing a Best Management Practice (BMP). This project is sponsored by Nitsch Engineering, a consulting firm who wants to look at stormwater runoff from the following surfaces: walkway pavement, parking lot pavement, grassy area, standard roof, and green roof. This will be completed by researching BMPs, analyzing campus for the optimal sampling sites, utilizing our sampling protocol to collect and test samples, analyzing the data to find what is in the stormwater runoff, and then decided on where and how to design our BMP for the WPI campus.

3.2 Objectives

In order to accomplish our goal we will be using the following objectives:

1. Research the effects of nutrient and pollutant loadings in addition to various best management practices use and effectiveness.
2. Map the campus watershed and sample various stormwater catchment areas to test for nitrogen, phosphorus, TSS, and other pollutants.
3. Analyze the results of the samples to see where different contaminants flow and how they might be mitigated.
4. Use the research, sampling, and analysis to design a best management practice to implement on campus.

3.3 Overall Approach

A detailed sampling protocol was developed to allow the team to identify various locations on the WPI campus that are representative of various surface types that typically contribute to urban stormwater runoff and how such stormwater samples were to be collected (see Appendix A). The samples were then to be comparatively analyzed to assess the unique pollutant loading in the stormwater for each location. Samples for each surface type are to be taken during the same rain event within the first hour to provide the most accurate data possible. By assessing and comparing contaminants in stormwater samples for the different surface types selected, the team then can apply the observations on the contaminant levels in stormwater to develop a Best Management Practice for each surface based on its unique contribution to the stormwater contaminants.

3.4 Sample Collection Plan

The purpose of the field sampling protocol guide (see Appendix A) was to provide a set of working directions for sampling crews to perform sampling activities in a safe and consistent manner. The sampling protocol was modeled after both The United States Environmental Protection Agency's Field Sampling Quality Control (dated, April 26, 2017) and The Nitsch Engineering Field Sampling Control Guide (dated, September 5, 2018). See appendix for complete sampling protocol. Stormwater samples to be analyzed for water quality are to be collected using one of three methods, Method 1, 2, or 3. Sampling Method 1 applies to impervious surfaces, Method 2 applies to pervious surfaces, and Method 3 applies to surfaces that require a unique sampling method due to location. Velocity and area calculation Method A is used for surfaces with minimal slope, Method B is used for surfaces with a significant slope, and Method C is used for surfaces that require a unique calculation method due to location.

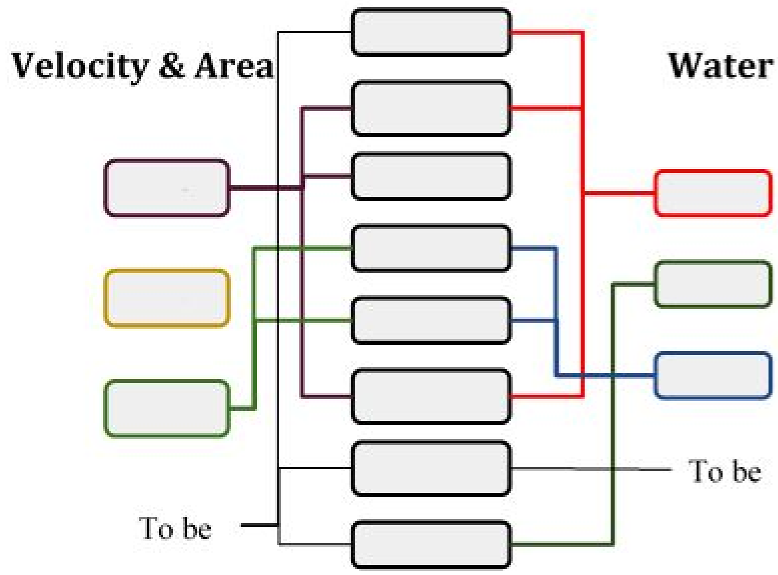


Figure 5: Surfaces and Corresponding Sampling and Calculation Methods

3.5 Surface Selection

The sites to be sampled were chosen based on the requirements of Nitsch Engineering to sample a walkway, grassy area, street, parking lot, grey roof, and green roof. Additional sampling sites of Salisbury Pond and the private WPI road were chosen to collect samples from the water to which the stormwater is drained and also to gather data to assist in a stormwater management plan started by another WPI project team. Table 1 details the criteria for each surface type sampled, the location of the sampling area, and the sampling method applicable for each surface.

Table 1: Summary of Sampled Surfaces

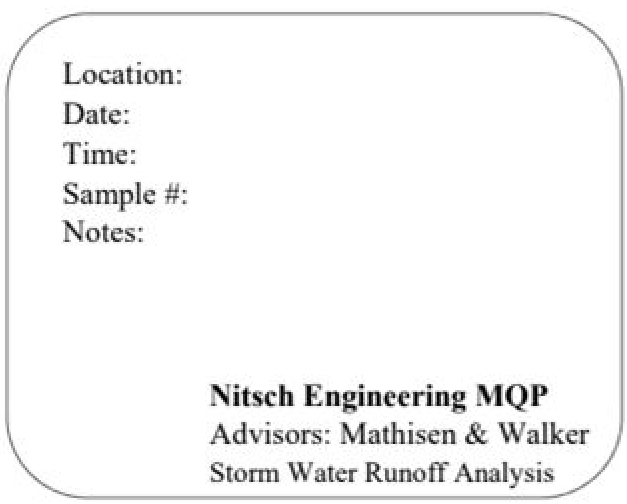
Surface Type	Criteria	Location	Sampling Method
Parking Lot	-Heavily used parking lot -Minimal Pervious Surface -Accessible drains/catch basins with decent flow in light rain	-Boynton Street Lot WPI Campus -Parking lot catch basin	1A
Light Traffic Road	-Lightly trafficked road -Minimal pervious surface -Gradual slope ~5-15% -Accessible drain with decent flow in light rain	-Private WPI way adjacent to Boynton Street Parking Lot -Road drain	1A
Discharge Water Body	-Receiving water body for stormwater from sampling areas	-Salisbury Pond	4-
Heavy Traffic Road	-Heavily trafficked road -Minimal pervious surface -Accessible drain with decent flow in light rain	-Road drain at corner of Institute Road and Boynton Street	1A
Sidewalk	-Isolated Sidewalk Drain -Accessible drains/catch basins with decent flow in light rain -Flat	-Sidewalk catch Basin at the Bottom of the Steps beside Fuller Labs -Near Kaven Hall 111b	1-
Green Roof	-Isolated Green Roof drain -Accessible drain with decent flow in light rain	-East Hall Green Roof Effluent (Mechanical Room)	3C
Grey Roof	-Isolated Grey Roof drain -Accessible drain with decent flow in light rain	-East Hall Grey Roof Effluent (Mechanical Room)	3C

Grassy Hill	-Steep slope ~15-30% grassy area -Maximum pervious surface -Area free of heavy tree cover or man made structures	-Grassy hill adjacent to skull tomb (Corner of Institute rd. and Boynton st.)	2-

When dealing with storm and rain runoff it is important to understand the storm and amount of precipitation that is going to be created. This is especially important when trying to design BMP to counteract runoff. The Environmental Protection Agency (EPA) defines a storm event as any rainfall event in which the rain event has 0.1 inch of rainfall within 72 hours from a previously measurable rainfall event. In order for the storm event to qualify for sampling (QSE) it first has to produce a discharge for one drainage area. And second, the storm is preceded by 48 hours of no discharge to a specific drainage area. (Florez, 2015) For this project a qualifying storm will be any storm that produces a rainfall event that has half an inch of rainfall.

3.6 Labeling

When collecting samples, it is important to label them properly so that quality assurance and quality control (QA/QC) is achieved throughout the sampling process. For every sample a standard label will be printed and filled out before sampling commences. The field characteristic of interest on the label are location, date, time, sample #, and additional notes if necessary. Furthermore, all samples have the name of the project, advisor names and a general description of the sample. This allows for the sample to be identified by external parties when its encountered in the community refrigerator unit in the environmental lab. The filled out label will be secured to the bottle with clear packing tape so that it does not become damaged during sampling conditions. See Figure 5 for the standardized label for this project.


Location:
Date:
Time:
Sample #:
Notes:

Nitsch Engineering MQP
Advisors: Mathisen & Walker
Storm Water Runoff Analysis

Figure 6: Standardized sample label

3.7 Measurements

There are several characteristics that will be measured in the field and in the lab when analyzing stormwater runoff. In the field, the velocity and cross sectional area will be measured to understand the volumetric loading or flow rate of subsequent contaminants. Additionally, the temperature of the sample will be taken, before it reaches the ice chest to conclude if temperature affects contaminant loading. Finally, the dissolved oxygen will be measured and recorded. All records will be documented prior to sampling conclusion.

Following the rain event, the total precipitation will be recorded by the gage located at Worcester Regional Airport. Proceeding field sampling procurement, levels of the pH, nutrients, solids, metals, and organics will be determined using a ICS or ICP MS system or laboratory procedure. The values recorded for every samplable storm, see storm qualification, will be compared by: storm magnitude, duration, and stormless interval prior to rain event will help understand the effects of the microclimate on contaminant concentrations from various urban surfaces.

3.8 Introduction to Lab Procedures

In order to better understand the pollutants and runoff that is to be collected, it will be necessary to complete many different lab procedure and techniques. These procedures are important in order to safely and properly understand what is taking place on the WPI hill when it comes to storm runoff. For this project many of the lab procedures have been taken directly from the Worcester Polytechnic Institute Laboratory Procedures archive. When in the lab, ten different materials will be tested for. Per Nitsch Engineering the ten materials that will be tested for will be pH, Dissolved Oxygen, Total suspended solids, Alkalinity, Cations, Anions, Nitrates, Nitrites, Phosphate, Chloride and Total Phosphorus. For each one of these materials, there is a separate procedure. These procedures can be found in Appendices B - H. Following a rain event and field sampling the runoff water will be taken directly to the Environmental laboratory at Worcester Polytechnic Institute. Here, all of the lab instruments and procedure will be performed. For this project all samples will be tested within the recommended waiting time to ensure a viable sample.

3.9 Sampling List

The runoff composition characteristics, with respect to contaminants, that will be tested are TSS, Alkalinity, Cations, Anions, Nitrates, Nitrites, Phosphates, and Chlorides. Additionally, the pH and Dissolved Oxygen (DO) will be evaluated. In order to conduct the analysis of the large magnitude of impurities 300ml of runoff will be collected per sample. Determining a wide variety of impurities in the runoff samples, from various land surfaces, with help generalize the individual runoff composition of contaminants. Although, the methods of testing such impurities will vary.

As listed in the sampling protocol the pH and DO concentration will be evaluated and recorded in the field at the time of sampling. A pH probe and DO probe will be inserted into the sample and recorded immediately. It is important to test the DO concentration immediately because it is time sensitive due to its diffusion characteristics. By deffeering this analysis there will be an inaccuracy introduced to the reading. The pH analysis is recommended to be completed immediately for convenience, because it consists of a simple probe analysis. See Appendices G & H for full the procedures. The remaining contaminants will be tested in the lab.

The majority of the contaminant list can be processed by an ICS machine. These include: Nitrates, Nitrites, Phosphates, and Chlorides. See Appendix E for the procedure of using the ICS system. The concentration of Cations and Anions will be processed by an ICP MS system, see Appendix F. The Alkalinity[7] will be analyzed using a titration based analysis, see Appendix D. Finally, the TSS concentration will be conducted on the remaining sample. See Appendix C for the full procedure.

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Appendix A:

WPI Nitsch Engineering MQP Field Sampling Protocol

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October 2018

FIELD SAMPLING PROTOCOL

Table of Contents

Acknowledgements

This document was modeled after both The United States Environmental Protection Agency's Field Sampling Quality Control (dated, April 26, 2017) and The Nitsch Engineering Field Sampling Control Guide (dated, September 5, 2018). See appendix for original sampling plans.

Goal and Objective

The purpose of this field sampling protocol guide is to provide a set of working directions for stormwater runoff sampling crews. When performing sampling collection activities it is important to do so in a safe and consistent manner. The procedures and information outlined in this document will provided the intended framework to ensure quality assurance and quality control of the sampling guidelines. By following these procedures and protocols, crews are able to obtain samples that are accurate and to a standard of care which WPI and Nitsch Engineering require. The procurement of precise and accurate data is vital when conducting such analyses.

Field Sampling Safety

Safety in the field is of the utmost importance when field sampling is to occur. Sampling crews should adhere to the Standard Health and Safety Practices (i.e. EPA Handbook for Sampling and Sample Preservation of water and WasteWater, OSHA Regulations, Standards and Policies, etc.).

When Sampling in the field, Crews should remember:

1) You are responsible for your own safety
2) Others are <u>NOT</u> Responsible for your safety
3) If you feel unsafe in the working conditions, you should not work
4) Never sample alone, always be with at least one other crew member
5) Make sure someone knows where you are
6) Wear appropriate field work apparel
7) Stay alert
8) If weather becomes too hazardous, find cover immediately
9) When working in areas were vehicles may be a hazard always use signs, cones and other traffic warning signals
10) When working in traffic, ensure that the local authority and facility staff is notified and on site.
11) When working with potential hazardous samples always wear protective gloves, clothing, etc.
12) When working with storm drains, grate, catch basins, etc. ensure that WPI Facilities are aware and present
13) When in the field use common sense and ensure that you and your crew are safe.

Supplies and Materials

Before going into the field ensure that you have all of the required materials need to samply correctly and safely. The crews typical list of materials should include:

General

1) Field notebook/ or spread sheet
2) Rain Gauge
3) Sharpie/permanent ink writing instrument
4) Appropriate personal protective equipment
5) Traffic cones, signs, flares,etc.
6) Reflective and personal safety apparel
7) Local Authorities
8) Manhole Hook
    a) When opening grate and manhole crews should use a hook to safely open the cover
9) Grade stake
10) Shovel
    a) When Sampling on grassy areas, crews may need to use a shovel in order to dig a hole to capture the runoff

Water Quality

1) Cooler
2) Ice
3) Clear Packing tape
4) Labels
5) Safety Gloves
6) 100mL plastic sampling bottles
    a) Number of bottles need to be based on the number of sampling locations & samples per location.
    b) Ensure that sampling bottles are clean and free of any residue
    c) If the bottles are being reused it is important that the bottles be cleaned with distilled water *only* and then allowed to dry completely
7) 50mL plastic sampling bottles
    a) Number of bottles need to be based on the number of sampling locations & samples per location.
8) Ziplock Sandwich Bag
    a) Number of Ziplock bags need to be based on the quantity of sampling crews
    b) Pre-cut with zipper strip remove
9) Large Zip Lock Bag
    a) Number of Ziplock bags need to be based on the quantity of sampling crews
    b) Pre-cut along 2 edges with zipper strip removed

10) Wood 2x4
    a) Number of wood 2x4 need to be based on the quantity of sampling crews
11) Plastic cup
    a) Number of Plastic cups need to be based on the quantity of grass based sampling locations
12) Sampling pole

Velocity

1) Colored dye
2) Barrel
3) 6 ft. of clear hose
4) 3 sections of sheet metal studding 2’ long
5) Stop Watch
6) Several sand bags or zip lock bags with sand in them
7) Ruler/ Tape measure

Note: velocity measurement materials are base on a crew number basis.

Sampling Procedure

In order to ensure that the results of your field sampling are accurate and consistent results you should follow the procedure below. This procedure is as follows:

1) Prior to Field Sampling
    a) Check the Supplies and Materials list
        i) Ensure that you have all the necessary supplies and materials for the area that you will be sampling. (i.e. if you are sampling in a roadway you want to make sure that you have the necessary traffic supplies such as cones, flares, signs, and scheduled detail where necessary)
        ii) Check each item to ensure cleanliness and functionality
    b) Prepare the field sampling notes sheets
        i) This includes the sampling index sheet, notepads, and ensuring that you have all the correct labels filled out and administered to clean sample bottles.
    c) Ensure crews know the area where they will be sampling and the goal of the sampling that is to occur on that day
        i) Two person crews are recommended
    d) Ensure that all sampling bottles are completely cleaned and dry to ensure *Quality assurance and Quality Control*
    e) If manhole or storm drain covers are required to be opened ensure that the proper authority has been notified and that they will be present at the sampling site.
    f) If the crew will be working in a roadway, ensure that the proper authorities have been informed and will be present at the sampling location
    g) Review the weather report for the sampling day
        i) Ensure that the weather will not be to hazardous as to endanger the field sampling crew

2) Arrival in field and sampling area
    a) Familiarize yourself with the sample area
        i) Ensure that the area is going to obtain the best results
            (1) There is enough runoff to sample
            (2) There is enough flow to measure
        ii) Ensure that the area is safe
    b) Set up all of the supplies and materials that are required in the sampling area
        i) If working in roadway, set up your safety equipment first (i.e. cones, signs, flares, etc.) and that detail has arrived
        ii) If weirs and/or dams are required, set them up and check that they are giving you the desired execution/ flow restriction
        iii) If manhole or storm drain cover need to be opened, open them in a safe and controlled manner under the supervision of the appropriate authority

iv) Ensure that your sampling bottles are correct and ready to go when sampling is to begin

c) Record the weather conditions
   i) Record the weather (i.e. Temperature, Conditions (i.e. Sunny, cloudy))

d) Record the amount or rain in the rain gauge

3) Sampling

a) Water Quality

<u>Method 1 (impervious surfaces)</u>

i) Channel/dams all sheet flow to sampling location as to impede flow velocity minimally
ii) Use a clean bottle and a new, clean pair of gloves
iii) Place 2x4 on the ground, perpendicular to flow at sampling location
iv) Place large zip lock bag strip on ground draped over 2x4, parallel to flow
   (1) This process will promote pooling by restricting flow
   (2) The zip lock bag strip creates a buffer from contaminants at immediate sampling location
v) When pooling occurs, use smaller zip lock bag to collect runoff and transfer to the 100 mL sample bottle.
vi) Fill bottle as much as possible
vii) Record the temperature of the sample
viii) Place bottled sample into cooler for safe keeping until further testing
ix) In a 50 mL sample bottle collect another sample
x) Record the dissolved oxygen concentration
xi) Dispose of sample in safe manner

<u>Method 2 (pervious surface)</u>

i) Locate an area of runoff pooling or flow
ii) With a plastic cup capture runoff
   a) When sampling, do not contact the ground so that unwanted debris is introduced to the sample
iii) Transfer captured runoff to corresponding sample bottle
iv) Fill bottle as much as possible
v) Record the temperature of the sample
vi) Place bottled sample into cooler for safe keeping until further testing
vii) In a 50 mL sample bottle collect another sample
viii) Record the dissolved oxygen concentration
ix) Dispose of sample in safe manor

<u>Method 3 (East Hall Mechanical Room)</u>

i) After testing the flow rate of the system (to flush pipes) Place hose connected to outlet pipe, into the sample bottle
   a) Do not contact the hose to the bottle so that external contaminations are introduced to the sample.

ii) Fill bottle as much as possible

iii) Record the temperature

iv) Place bottled sample into cooler for safe keeping until further testing

v) In a 50 mL sample bottle collect another sample

vi) Record the dissolved oxygen concentration

vii) Dispose of sample in safe manor

b) Velocity & Area

Method A (minimal slope)

i) Channel/dams all sheet flow to sampling location as to impede flow velocity minimally

ii) Place graduated sheet metal stud at the end of the channel, parallel to flow

iii) Record the height of flow through the rectangular stud

iv) Drip dye into the up gradient beginning portion of the stud
   (1) Begin stopwatch once the dye contacts the runoff at the beginning of the channel

v) Record the time it takes the dye to reach the end of the 2 foot section of studding

Method B (significant slope)

i) Locate a channel of flow within the area of interest

ii) Measure the length of channel and record the value
   a) Flow may vary so a larger section is recommended to understand the average

iii) Measure the depth and width of the channel within the area of interest
   a) Several measurements will be necessary due to possible variations in cross- sectional area

iv) Average the areas and record

v) Drip the dye at the upgradient location

vi) Record the time the trace of dye until it reaches the designated end location

Method C (flow meter present)

i) Place hose, connected to outlet pipe, into the graduated barrel

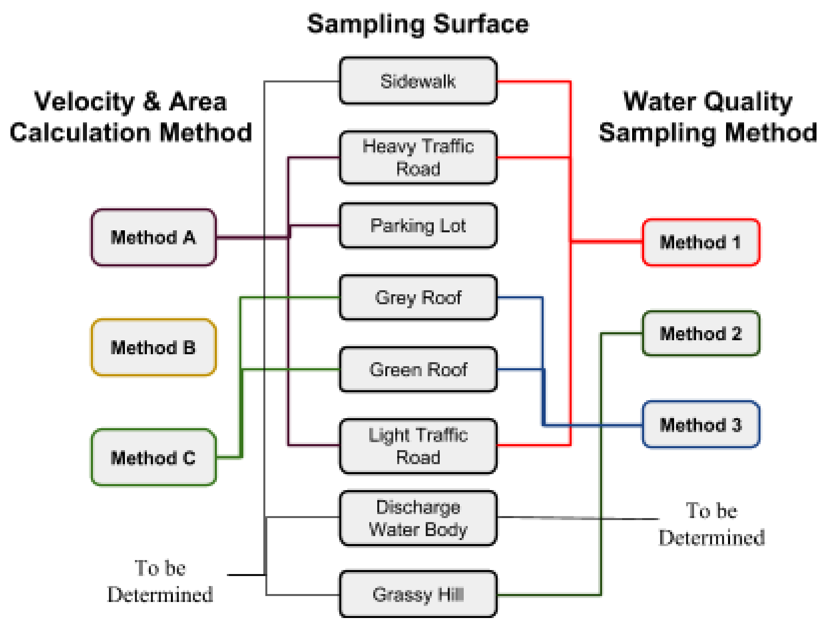
ii) Open control valve and monitor flow

iii) Time the water level as it reaches graduated markings

iv) Record times

4) Storage and Transport

a) In order to keep the samples viable, after sampling the bottle should be tightly and securely sealed. Then they should be placed into a cooler and encased in ice. The ice should be drained and replenished as it begins to melt. The label on the bottle should be cover in clear packing tape to ensure the writing stay visible and dry. As soon as possible, the samples should be moved directly from the cooler to a refrigerator until they are ready for lab testing.



Sampling Index Sheet

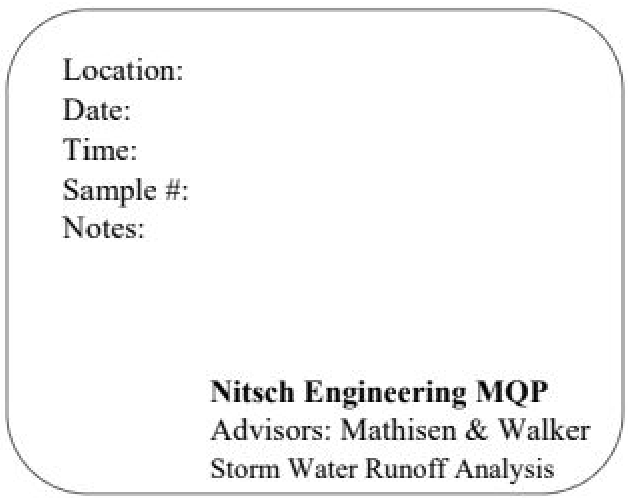
The table below should be partially completed on the the day of field testing. This type of sheet helps the sampling crew to identify many different aspects of the sampling. Further testing will take place to determine the quantity of contaminants.

Table 1: Sampling Index Sheet

Date	Time	Location	Sample #	Sample Location Description	Sample Temp. °F	pH	DO	Runoff Channel Height (in)	Length of Channel (ft)	Dye trace time (s)	Storm Description
10/2/18	5:00 PM	Kaven Lot	1	catch basin in parking lot	-	-	-	-	-	-	Overcast all day, heavy precipitation starts at 5PM, 56°, Precipitation Total>1"
10/2/18	5:15 PM	Institute Road	1	catch basin @ institute-boyton st intersection	-	-	-	-	-	-	
10/2/18	5:30 PM	Kaven Walk	1	8"x 8" surface drain by 111b	-	-	-	-	-	-	
10/2/18	5:45 PM	Fuller-Atwater Kent	1	end of concrete roof channel trough	-	-	-	-	-	-	

Labeling

The figure below shows a recommended format for labeling the samples collected. It is important to record the location of the sample, date, and time to adequately identify where the runoff sample originated. Also, when sampling multiple times across a storm at a consistent location it is recommended to list the sample number so that the order of the collected samples can be understood when analysis commences in the laboratory. Finally, it is suggested to identify the owner, sampler, or organization in addition to its general contents. This will ensure that an outside person/persons who may encounter the sample can understand who the sample belongs to and what its contents are.



Surface Selection and Criteria

Table 2 details the criteria for each surface type sampled, the location of the sampling area, and the sampling method applicable for each surface. The following section outlines how each chosen sampling area fulfills the project objectives and provides visuals of the sampling surface for clarity. All surfaces, barring the Green Roof and Grey Roof, were observed during a light rain storm to determine suitability based on accessible flow for sampling.

Table 2: Summary of Sampled Surfaces

Surface Type	Criteria	Location	Sampling Method
Parking Lot	-Heavily used parking lot -Minimal Pervious Surface -Accessible drains/catch basins with decent flow in light rain	-Boynton Street Lot WPI Campus -Parking lot catch basin	1A
Light Traffic Road	-Lightly trafficked road -Minimal pervious surface -Gradual slope ~5-15% -Accessible drain with decent flow in light rain	-Private WPI way adjacent to Boynton Street Parking Lot -Road drain	1A
Discharge Water Body	-Receiving water body for stormwater from sampling areas	-Salisbury Pond	
Heavy Traffic Road	-Heavily trafficked road -Minimal pervious surface -Accessible drain with decent flow in light rain	-Road drain at corner of Institute Road and Boynton Street	1A
Sidewalk	-Isolated Sidewalk Drain -Accessible drains/catch basins with decent flow in light rain -Flat	-Sidewalk catch Basin at the Bottom of the Steps beside Fuller Labs -Near Kaven Hall 111b	1-
Green Roof	-Isolated Green Roof drain -Accessible drain with decent flow in light rain	-East Hall Green Roof Effluent (Mechanical Room)	3C
Grey Roof	-Isolated Grey Roof drain -Accessible drain with decent flow in light rain	-East Hall Grey Roof Effluent (Mechanical Room)	3C
Grassy Hill	-Steep slope ~15-30% grassy area -Maximum pervious surface -Area free of heavy tree cover or man made structures	-Grassy hill adjacent to skull tomb (Corner of Institute rd. and Boynton st.)	2-

1) **Surface Type:** Parking Lot

.

a) Location: Boynton Street Lot WPI Campus,
Parking lot catch basin

b) Purpose: The chosen parking lot drain in the Boynton St. parking lot of the WPI campus was identified as a sampling location due the the high amount of shallow concentrated flow entering the drain originating from the Southern side of the parking lot. The drain was also receiving a fair amount of sheet flow from the adjacent Eastern area of the parking lot.

In terms of project objectives, this sampling location allows for the team to analyze contaminants in stormwater originating from heavily use parking lots. The high amount of flow running into the drain and the limited surface types the stormwater came in contact with made this an ideal place to sample as the contaminants we found were representative of one type of surface.

c) Pictures:

↑ *Above: Up close Boynton st. Lot catch basin*

← *Left: Boynton st. Lot catch basin*

2) **Surface Type:** Light Traffic Road

.

a) Location: Private WPI way adjacent to Boynton Street Parking Lot Road drain

b) Purpose: The road drain located on the WPI private way adjacent to the Boynton St. Parking lot was determined to be a suitable sampling location due to the high amount of concentrated shallow flow entering the drain emanating from the lightly used private way stretching up towards the WPI campus and Boynton Hall.

While not completely isolated from other types of surfaces, this sampling location provides an accessible point for sampling and fairly concentrated road-based stormwater flow and should be representative of contaminants found originating from such surface.

c) Pictures:

↑ *Above: Up close view of road drain*

← *Left: Road Drain on WPI private way*

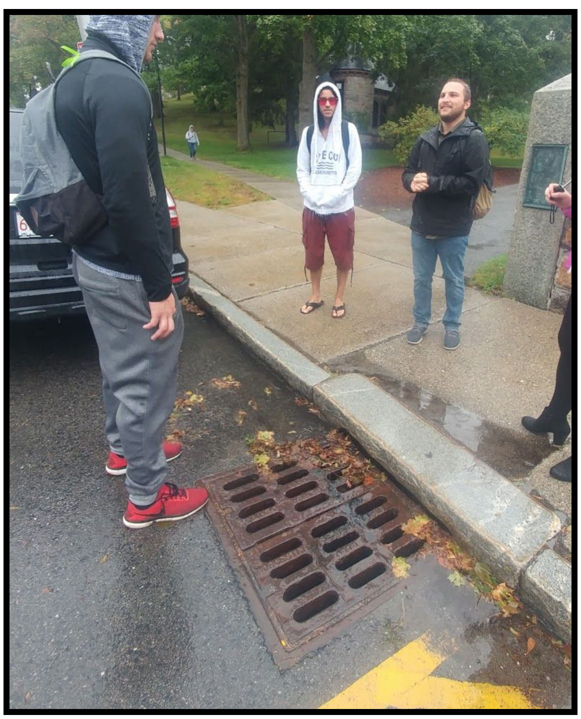
3) **Surface Type:** Heavy Traffic Road, Sampling Method 1A

d) Location: Road drain at corner of Institute Road and Boynton Street

e) Purpose: The chosen road drain at the corner of Institute rd. and Boynton st. was identified as a sampling location due to the high amount of flow entering the catch basin originating from the Eastern-bound portion of Institute rd. and the limited flow to the drain over other surface types.

This sampling location allows for assessment of contaminants found in stormwater originating from a heavily trafficked road due to the concentrated flow off of one surface type. The high amount of flow in a light rain storm and accessibility of the location (adjacent to a no parking space on the street) made this arae an ideal place to sample from.

f) Pictures:



Above: Road Drain at corner of Institute Rd. and Boynton St.

Above: Close up of Institute rd./Boynton St. Road Drain

4) **Surface Type:** Sidewalk

a) Location: Sidewalk catch Basin at the Bottom of the Steps beside Fuller Labs near Kaven Hall 111b

b) Purpose: The chosen sidewalk catch basin was chosen as a sampling Location as the flow running into the drain originates from the surrounding sidewalk area. The flow into this sidewalk drain is not high as the area that contributes to the flow is much smaller than that of a road or parking lot.

In terms of project objectives, this sampling location allows for the isolation of contaminants in stormwater originating from a sidewalk in comparison to the other surfaces tested.

c) Pictures:

Above: Sidewalk Drain outside Kaven Hall at the bottom of the steps beside Fuller labs

5) **Surface Type:** Green Roof

a) Location: East Hall Green Roof Effluent (Mechanical Room)

b) Purpose: The purpose of this site is to analyze the effectiveness of impurity removal.

c) Pictures:

Above:Green roof monitoring site inside East Hall

6) **Surface Type:** Grey Roof

a) Location: East Hall Grey Roof Effluent (Mechanical Room)

b) Purpose:

c) Pictures: to come

7) **Surface Type**: Grassy Hill

a) Location: Grassy hill adjacent to skull tomb

b) Purpose: The grassy hill adjacent to Skull Tomb and Boynton Hall is the steepest hill on campus with the largest percentage of pervious surface area. Flow is difficult to detect on the hill and sampling from this location requires a unique method.

This sampling location allows for the team to analyze contaminants in stormwater originating from a majority pervious surface in comparison to the impervious surfaces also sampled.

c) Pictures:

Above: Grassy Hill near Skull Tomb
Slope (5-15%)

8) **Surface Type:** Discharge Water Body

a) Location: Salisbury Pond

b) Purpose: Stormwater runoff from all other sampling sites drain into Salisbury Pond. Sampling this location will allow the team to compare water quality and quantity from the different sites to the water quality and quantity that reaches the ecosystem.

c) Pictures:

References

1) United States, EPA, Science and Ecosystem Support Division, and Timothy Simpson. “Field Sampling Quality Control.” *Operating Procedure,* 2017
2) United States, EPA, Office of Water, and Office of Wastewater Enforcement and Compliance. “NPDES Storm Water Sampling Guidance Document.” *NPDES Storm Water Sampling Guidance Document,* 1992
3) Nitsch Engineering Field Sampling Protocol Guide

Appendix

Nitsch Engineering

FIELD SAMPLING PROTOCOL

PREPARED BY:

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SEPTEMBER 5, 2018

Building better communities with you.

FIELD SAMPLING PROTOCOL

Table of Contents

I. PURPOSE AND OBJECTIVES

The Nitsch Engineering Field Sampling Protocol document's purpose is to ensure that field sampling activities are performed consistently by sampling crews. The procedures in this document are to ensure the safety of the sampling crews and the quality of the sample. Adhering to these procedures will ensure that all samples are up to the quality that Nitsch Engineering require. This document was modeled after the United States Environmental Protection Agency's Field Sampling Quality Control, dated April 26, 2017.

The object of this sampling protocol is to obtain representative samples and maintain their integrity to ensure quality results.

II. FIELD SAMPLING SAFETY

To ensure safety in the field, sampling crews should follow the Standard Health and Safety Practices (i.e.EPA Handbook for Sampling and Sample Preservation of Water and Wastewater, OSHA Regulations, Standards and Policies, etc.).

Remember the following items while in the field.

1) Remember, you are responsible for your own safety.
2) Do not rely on others to provide for your safety.
3) Never work in conditions that you feel are unsafe.
4) Use the buddy system
5) Makes sure someone knows where you are
6) Wear appropriate personal protective equipment (PPE) and high visibility clothing
7) Use traffic signs, cones, flashers, etc. when appropriate
8) Work in off peak traffic hours if possible
9) Stay alert
10) Find safety if weather becomes extreme

III. SUPPLIES

Ensure that you have all supplies before going out into the field. Here is a typical list.

1) 1-Liter Sampling Bottles (Amber Preferred)
    - Sampling bottles should be cleaned
    - If bottle is being reused it is important to use distilled water when cleaning. The bottle should be rinsed with distilled water at least three times. \
2) Ice Chest
3) Ice
4) Rain Gauge
5) Powderless disposable Latex or Nitrile Gloves or equal

6) Thermometer
7) Water Proof Labels
8) Notebook or Tablet
9) Sharpie
10) Appropriate Personal Protection Equipment
11) Measuring Tape
12) Distilled water

IV. SAMPLING

1) Prior to Sampling

   1. Ensure all proper equipment is ready
   2. Team has communicated about what the goal is, type of samples needed
   3. All equipment has full battery
   4. Review weather report

2) Arrival in the field

   1. Familiarize yourself with area and ensure you have a safe area
   2. Set up material and supplies
   3. Take temperature of water and record weather.
   4. Record amount of rain in rain gauge.

3) Sampling

   1. Put on clean gloves (new gloves should be used for each location.)
   2. Rinse sample container with distilled water three times.
   3. Fill clean sample containers as much as possible and put top on tight
   4. Label sample with date, time, sample ID, and initials. (see Attachment A: Sample Sheet)
   5. Place sample in ice chest

4) Storage and Transport

   To ensure that the sample are preserved and not contaminated, tightly sealed samples should be placed in an ice chest with a sealed back of ice. Excess water in ice chest from melting ice should be drained and ice should be as needed. It is essential that the sample be moved from the ice chest to a fridge as soon as possible. The labels should be kept dry and not smudged during storage and transportation.

V. Attachment A: Sample Sheet

Sample ID	Date	Time	Weather	Location	Temperature	Tests					Notes
						Conductance (µS)	pH	TSS	Anions	Cations	
Example	11/2/2016	8:35 AM	Sunny 52°F	Library	10°C	x	x	x	x	x	Water was clear with little turbitiy.

VI. References

United States, EPA, Science and Ecosystem Support Division, and Timothy Simpson. "Field Sampling Quality Control." *Operating Procedure*, 2017.

United States, EPA, Office of Water, and Office of Wastewater Enforcement and Compliance. "NPDES Storm Water Sampling Guidance Document." *NPDES Storm Water Sampling Guidance Document*, 1992.

Appendix B:

Total Phosphorus (from Worcester Polytechnic Laboratory Procedures):

The analysis for total phosphorous can be completed at any time after the sample is taken. The procedure follows the steps below.

1. Digest the 60 mL sample bottle under the fume hood using sulfuric acid and ____ for an appropriate amount of time (typically overnight)
2. Prepare blank Spectrometer sample
    a. Add one drop of phenolphthalein to a square Spectrometer vial
    b. Titrate with ___ M NaOH
    c. Fill to 25 mL mark with DI water
    d. Add 1 mL of Molybdovanadate to solution and swirl
3. Transfer 25 mL of the digested sample to a volumetric flask
4. Transfer sample to a small beaker and clean volumetric flask with DI water
5. Add one drop of phenolphthalein to sample
6. Titrate with __ M NaOH
7. Transfer solution to Spectrometer vial
8. Add 1 mL of Molybdovanadate to sample and swirl
9. Fill to line with DI water
10. Prepare DR|3000 Spectrometer
    a. Press On
    b. Press Timer
    c. Input 3 minutes
    d. Press Timer to begin
11. Once the Spectrometer is ready, insert the blank vial with the line facing outwards and read the result
    a. Press Abs
    b. Zero

Insert prepared samples and read the result

Appendix C:

Total Suspended Solids (from Worcester Polytechnic Laboratory Procedures):

1. To prepare filters:
    a. Set up _____ pump
    b. Use tweezers to place #___ filter (1.5 µ) in pump
    c. Filter with DI water
    d. Label aluminum pans
    e. Place filters and aluminum pans in oven to dry for a few hours
2. Weigh filter and record result (make sure to record the entire number)
3. Place filter in pump and pump sample through
    a. If there is a lot of TSS, can use 500 mL or 250 mL instead of 1000 mL and multiply the result by the correct factor
4. Dry filters with sample in oven for a few hours
5. Zero aluminum pan
6. Add filter with sample and record entire result
7. Calculate the amount of suspended solids
    a. $m_{filter\ with\ sample} - m_{initial\ filter} = TSS$

Appendix D:

[Need alkalinity procedure]

Appendix E:

[Need ion chromatography procedure]

Appendix F:

[Need ICP MS Procedure]

Appendix G:

pH Procedure

Appendix H:

Dissolved Oxygen Procedure (from Worcester Polytechnic Laboratory Procedures):

1. Clean the DO probe with brown circular material; empty cover and refill with Electrolyte solution
2. To calibrate DO probe (Orian 3star Thermo):
    a. Fill beaker with partway with water and insert probe (it should not be fully submerged)
    b. Place on stir plate
    c. Turn on spec and press calibrate
    d. Let sit for several hours
3. Remove DO probe from calibration solution and insert into 300 mL glass DO bottle
4. Quickly record reading
5. Rinse DO probe with DI water
6. Repeat steps 3 to 5 for each sample