# SUSTAINABLE LANDSCAPE DESIGN: A RAIN GARDEN ON THE WPI CAMPUS

An Interactive Qualifying Project Proposal

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## Abstract

Flooding and water pollution are tremendous problems for the Worcester community. The consequences of these problems can be detrimental to property, the environment, and the overall well-being of the community. Rain gardens are an innovative and logical way to help remedy these issues while bringing life and color to the area. With a community effort, we can use rain gardens to make significant improvements in the way Worcester deals with the issues of storm water runoff.

## Executive Summary

WPI is an institution that is always seeking ways by which they can improve their green performance as well as promote social and environmental sustainability, not only on campus, but also, in the wider Worcester community. One area for improvement is storm water management on campus. Over the years, expansions on the campus have led to the development of many buildings, walkways, and pavements. These impermeable surfaces do not allow rain water to soak into the ground, creating large volumes of storm water runoff. This runoff water enters the sewer system, carrying with it pollutants that it picks up along the way.

The goal of our project is to provide a sustainable method of reducing this storm water runoff and pollutants, by developing designs of a rain garden. A rain gardens is a shallow depression that is designed to capture storm water runoff before it is able to reach the sewer system.

In order to achieve this goal we:-

1) Selected an appropriate location for the rain garden
2) Analyzed the site using surveying equipment and performed soil and water testing
3) Developed three rain garden designs
4) Developed a plan for dissemination
5) Developed an implementation plan

We received suggestions of possible locations for the garden site from Alfredo DiMauro, Assistant VP for Facilities at WPI and narrowed down the possibilities to six locations on campus: the land between the Library and Fuller Labs, the Wind tunnel between Higgins Labs and Alumni Gym, the area of land behind Riley Hall, the area of land outside Atwater Kent, along West Street and the land between Salisbury and Olin Hall. In order to select the best location of the rain garden, we developed a rating rubric to rank the six locations in terms of slope, pooling, area, proximity, light, constructability and visibility. The areas next to Salisbury lab and the Library were ranked the highest. We selected the portion of land next to the Library due to the fact that there is a high concentration of storm water runoff along the access route. Also, there is a high percentage of the student body crossing by this location every day, making the rain garden design visible to a large selection of people.

Once our location was selected we conducted water testing, soil testing, and took measurements of the drainage area and how much land we had to work with. The water testing was performed in order to have a general idea about what pollutants are present in the storm water runoff that would be diverted into the garden. We collected a water sample from the access road beside the Library during a rain event. Our sample was taken to the Microbac Laboratories in Worcester and tested for phosphates and nitrates. The results indicated that no traces of nitrates were found, however the concentration of phosphates in the sample was 4.71 milligrams per liter (mg/L). Though the level of phosphates was high, the use of rain garden will allow the natural phosphorous cycle to take place. Our soil testing indicated the soil that is currently at the site will be chemically suitable for a rain garden following pH adjustment and that no additional actions will need to be taken to change these conditions. The calculated drainage area came up to about 3100 square feet, and the area of land that we had available to build the garden came up to 1100 square feet.

After this we came up with our three final designs. First we thought of a traditional rain garden that is dug down eighteen to twenty four inches. Then we were worried of the utilities that may lay under our site so we made a rain garden on a berm, an elevated landscape. Finally we decided on adding a gray infrastructure with the rain garden. We did this by using permeable concrete and cut the gardens size from around 1000 square feet to around 688 square feet due to the fact the concrete will absorb most of the storm water.

Presented in this report are also plans for the implementation and dissemination of the rain garden on the WPI campus. As part of the WPI mission statement, the advancement of society through the spread of knowledge is an important factor in a complete education. Through the development and showcasing of a rain garden on the WPI campus, we aim to further the growth of the field of green infrastructure throughout WPI and the further Worcester community.

## List of Tables & Figures

**Table of Contents**

# Chapter 1: Introduction

In the city of Worcester, the negative effects of storm water runoff are significant. Urbanization has had a strong impact on the water cycle, and therefore, on other life cycles that are associated with water. The natural landscape has been altered and replaced with a man-made impermeable landscape through the urbanization process. Rainwater is no longer able to soak into the earth as easily in many locations, which leads to flooding, erosion, property damage, and pollution of local bodies of water.

The damaging effects on the environment have increased as a result of the change in the natural landscape, and are further compounded by the improper use of pesticides and fertilizers. Consumers who have inadequate knowledge about the use of these products fail to distribute them correctly and in proper amounts, leading to a significant increase in the toxin levels in local bodies of water. Consequently, unhealthy soil is created, ground and surface water quality is reduced, and the functionality of ecosystems is hindered.

The economic effects related to storm water runoff also have a large impact on the Worcester community. These problems affect the community both on a civic and individual level. Installation of sewer systems and other traditional large-scale grey infrastructure is expensive and time consuming for the city. These solutions are not ideal to accommodate the effects of storm water runoff on a residential basis.

Through this project it is our goal to create three rain garden design suggestions for a parcel of land on the Worcester Polytechnic Institute campus. These models will exhibit how residents can implement ways to recycle gray water, reduce storm water runoff and sewage toxins, and create a landscape that is self-sustaining in an environmentally sound and financially feasible way. Ultimately, we hope not only to remediate some issues of flooding and water pollution on the WPI campus, but also, we hope to educate WPI and the wider Worcester community on the benefits of using green infrastructure in conjunction with grey infrastructure as a remedy for situations where grey infrastructure alone is not sufficient. In order to accomplish the goal of this project in an efficient manner, we will include the following: 1) An overview of green versus grey infrastructure; 2) Information regarding the effects of excessive storm water runoff; 3) An outline of design specifications for rain gardens in general; 4) A detailed outline of how we went about designing a rain garden at WPI; and finally 5) An implementation and dissemination plan for the rain garden at WPI. In the long run, we hope to be proactive in helping Worcester Polytechnic Institute progress towards its goal of being a pioneer in the use of green infrastructure and further the universities strive for sustainability.

# Chapter 2: Green and Gray Infrastructure: The Birth of the Rain Garden

Storm water runoff causes significant problems in Worcester. This chapter will provide an in-depth explanation of the negative effects of storm water runoff that Worcester faces. In order to accurately explain this issue, the following information has been included: 1) A definition and outline of the urban landscape of Worcester and WPI; 2) Information regarding the costly effects of flooding; 3) A definition of water pollution and how storm water runoff contributes to it; 4) An overview of how storm water runoff has affected water pollution in Worcester and in what ways WPI contributes.

## 2.1: WPI: A Pioneer in the Well-Being of the Community

WPI has always prided itself in its ability and drive to develop new ways to reach out to the community for the betterment of society. As stated in the institution’s mission statement, “Knowledge is conveyed through scholarly publication and instruction” (*Board of Trustees*).

Through projects, research, and publications every year, members of the WPI community look to extend the knowledge gained and make an impact on a grander scale. Through this mission statement, WPI professors and students aim to implement research results that will lead to the betterment of the community. Year in and year out, research and project experimentations are carried out in varying fields of engineering, including environmental engineering. A rain garden on the WPI campus would help to provide an example of environmental engineering to the aspiring students on campus. Rain gardens are a perfect example of green infrastructure that can augment that of the gray infrastructure that is currently in place. Rain gardens and porous pavement will help to greatly reduce the pure volume in intake in the drainage systems located around campus. Environmental Engineering is a growing field of interest, one predicted to grow more than 27% through the next 2-3 years (Environmental Engineering). Most students who study Environmental Engineering go on to work in the field of Civil majors, focusing on the industrial aspects of water and wastewater systems (Overview: Environmental Engineering). Creating a sustainable landscape design for the WPI campus would help to both showcase the school's position and benefit the students on the campus itself.

The creation of a rain garden on the WPI campus would also help to increase the beauty of the area, thereby allowing for a better environment for the students on campus to study in. Though seemingly trivial, one very important aspect of a university campus is the visual appeal and layout of the campus itself. According to Pascarella's General Causal Model of Student Development, "…both an institution's formal characteristics (such as size, location, and curriculum) and its environment provide the impetus for student development either successfully or unsuccessfully. This interaction between formal characteristics and the actual campus environment produces a visible and identifiable college climate that provides the structure for developing peer-to-peer relationships and student-faculty interactions, both of which require a high level of student effort and involvement" (The College Environment). Based off of the logic presented by Pascarella, both logistical and visual aspects of the WPI campus are important in providing a nurturing environment for the optimal educational benefits.

WPI aims to create a campus that is visually appealing to the students and as stress-free as possible. This is especially important given the condition of the surrounding community. On ratings given on *College Confidential*, where students and visiting parents can rate a school from one to five stars in several categories, echo the disparity between the atmosphere of the campus, and of the surrounding community. In one review, WPI was described as *"(a) Nice campus, well maintained buildings…well cared for…and clean".* In contrast, the same review gave the area immediately around campus a meager two points, saying *"Worcester is a rather depressed city. I've seen worse, and there does exist a lot of rehab potential that could make the city awesome, but it's far from there yet* (Worcester Polytechnic Institute Visit Report).*"* The physical layout and appearance of a campus are one of the key factors in the general atmosphere and success for the attending students. In Pascarella's study, certain aspects were taken into consideration, such as sizing or number of buildings, layout of campus, organizational setting, and demographics of the student body. In citing Moos' study on the relationship between the development of college students and their growing environment, it is shown that a lack of connection between the student and the environment of learning resulted in lack of achievement, behavior development, and self esteem (Fleming, W. J., et al.). Part of WPI's mission is to create a nurturing environment for the students to learn in and work towards the implementation of research for the betterment of society. In providing such amenities as a well-designed and visual appealing campus, it has been proven through research that students will better suited to achieve their goals. In building a rain garden on the WPI campus, goals of both environmental awareness and campus beautification can be met. The implementation of a rain garden will be just one of the steps that have been taken by facilities and maintenance of the institution in order to provide the optimal learning environment. Also, this rain garden will showcase the ability of WPI to pioneer environmentally safe and driven processes that can work to reduce harmful effects to the surrounding ecosystem. In the next section, we will examine the harmful effects of storm water runoff in the city of Worcester, and what WPI can accomplish to mitigate these issues.

### 2.2: The Effect of Excessive Storm Water in Worcester

#### 2.2.1: The Causes and Effects of Flooding in the Worcester Community

The city of Worcester, Massachusetts suffers greatly from the effects of flooding due to the lack of permeable surfaces within the city. According to a presentation given by Donna Williams at the *Worcester Residential Rain Garden Training Workshop* on June 23 and 24, 2011 a natural landscape allows for 50% of water to be absorbed, 40% to evaporate, and only 10% to serve as runoff; whereas, in a developed area only 15% of the water is absorbed, 30% evaporated, and a hefty 55% leaves as runoff (Williams). Even considering this fact, the city is also not designed to accommodate storm water runoff by other means. The combination of these factors makes it very difficult for the city to deal with large quantities of rain water at any given time.

With this come a lot of problems associated with flooding that are costly to the city and to the individual.  In this section, the main causes and effects of flooding in the Worcester community will be discussed.

#### 2.2.1.1: Impermeable Surfaces in Worcester

Impermeable surfaces within the city play a huge role in flooding issues because they do not allow water to pass through them in the same way the natural landscape does. Impermeable surfaces include anything from paved roads and buildings, to gravel parking lots and driveways (Gamble). As seen in the Google Maps image below in Figure 1, the city of Worcester is a highly developed are that is covered with impermeable surfaces. All the gray portions of the image represent the more developed area of the city, while the green portions represent the forestry. This shows that a large majority of the area of the city is impermeable and that there is not enough green landscape to rationalize it.

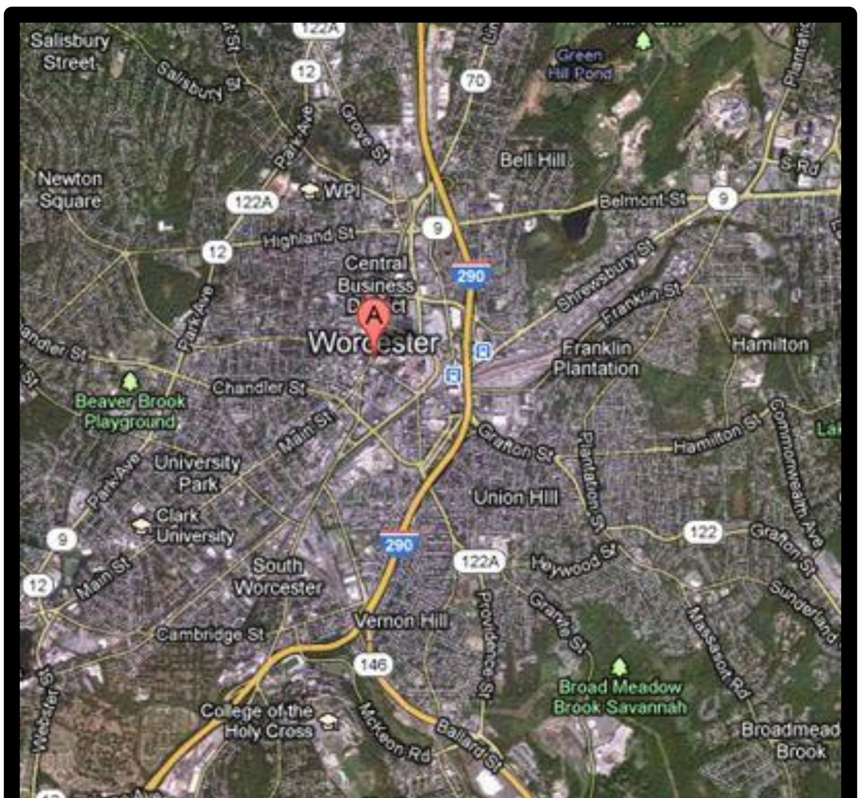



**Figure 1: Google Maps Image of Worcester, MA**

The impermeable surfaces within the city force rain water to wash over them rather than soak into them as a natural landscape would; therefore, the water has nowhere to go but into the city sewer system, low points in the landscape where it can pool, or local bodies of water after it has made its way to that location. Unfortunately, during this process, the water gets in the way of everyday activities and causes difficulties for people who are traveling.  Landscaping plays an enormous role in the severity of these difficulties.

#### 2.2.1.2: Flooding Problems Associated with Impermeable Landscapes

Landscaping plays a tremendous role in determining the intensity of flooding that is experienced.  Locations with similar landscaping and similar weather patterns to those seen in the Worcester area are a good indicator of the kinds of situations Worcester has the potential of encountering in terms of flooding. Many locations have experienced the detrimental consequences of large quantities of storm water that have also been seen in Worcester. According to an article from CBS News, following Hurricane Irene in August 2011, the state of Vermont experienced such severe flooding that “263 roads were closed across the state and at least nine shelters were set up” (Irene, CBS). This becomes hazardous to the community by slowing or eliminating through traffic and eroding land that is not accustomed to such high water exposure. The city of Worcester, being such a developed area in comparison to many parts of Vermont, can experience similar, if not worse, effects from flooding to those seen in Vermont following Hurricane Irene.

#### 2.2.1.3: Cost of Flooding in Worcester

Such situations have been seen in Worcester, as well. The costly effects of flood damage can destroy homes, businesses, and city property. Oral surgeon, Dr. David Kelly, said that his business at 59 Quinsigamond Ave. “got away relatively unscathed during the September 8, [2011] storm, but said that may have been because of upgrades he installed after he suffered a $1 million loss in a September 2008 storm that flooded his building” (Flooding, Telegram.com). Some of the improvements he had to make following the 2008 storm included installing a new sump pump, replacing a backflow preventer, and installing a gas-fired generator to keep the pumps running if there is a loss of power. This figure represents a large sum of money that only one business in Worcester had to spend on reparations and improvements cause by basement flooding following one storm. Although it is not an ideal assumption, if every individual in the city of Worcester, having a population of roughly 182,596 people according to the Worcester City website, experienced basement flooding and made these same changes to remediate the issue, more than $182 billion would be spent on improvements following one storm. On an individual scale, yes, the improvement costs are generally not this astronomical; however, generally homeowners cannot afford to make these necessary improvements to prevent future flooding, and therefore, have to deal with the effects of flooding repeatedly.

Flooding is not only costly in a monetary sense, but is also time consuming to setback with which to deal. Specific to the Worcester Polytechnic Institute campus, an article by Christine Drew from December 13, 2010 stated that “due to the heavy rain [that] weekend and a drain blockage, the library experienced flooding, mainly on the 3rd and 2nd floors on Sunday December 12”. According to the article, Tech Suite 217 and the printing area, both frequently used by students and faculty, was “severely affected”(Drew). The area did not open again until 3pm on Monday, December 13. Reservations for that particular tech suite were moved to other rooms, potentially causing confusion and time conflicts. Although the area was only out of use for a day, students rely on them to be available for use at all times, so even the slightest interruption can cause problems.

### 2.2.2: The Causes and Effects of Water Pollution in the Worcester Community

Water pollution is also a side effect of urbanization, and more specifically, storm water runoff. Pollutants of all kinds can be spread to unwanted locations by means storm water in a variety of ways. Two ways that will be discussed in this section include sewer system overflow and pollutant transfer over impermeable surfaces.

#### 2.2.2.1: Water Pollution Definition

Water pollution is defined by BusinessDictionary.com as "the presence in water of harmful or objectionable material in sufficient quantity to measurably degrade water quality" (BusinessDictionary.com). As defined, reduction of water quality coincides with the reduction of the usability of water by humans, plants, and other organisms that need water to survive; hence, water pollution can be detrimental to a variety of ecosystems and harmful to human life, creating problems on a global and local scale.

#### 2.2.2.2: Causes of Water Pollution in Worcester

The combined sewer system within the city is designed to only handle so much water at a time. In cases where it rains excessively, the system can become overwhelmed and overflow into unwanted locations. Bernice Corpuz of WBZ News Radio reported that "one lasting casualty of [a] storm [in September, 2011] is Lake Quinsigamond [in Worcester]. Sewage overflow dumped into the lake" causing high bacteria levels (Corpuz). Large quantities of water that overwhelmed the combined sewer system within the city left the water in this location unusable. High bacteria levels in bodies of water make the water dangerous for humans and animals, and can influence plant growth near the body of water. This, being a local body of water to the Worcester community, represents one way that water pollution in lakes and rivers can be caused by storm water runoff.

### 2.2.2.3: Storm Water Pollution Background

Storm water pollution is a subtopic of water pollution that is specific to how storm water runoff increases water pollution. According to the EPA, storm water runoff is increased by urbanization; therefore, "urbanization increases the variety and amount of pollutants carried into streams, rivers and lakes" (Urban Areas, EPA). As seen in Table 1 below, there are a variety of different pollutants that can be carried to unwanted locations by storm water runoff.

| Pollutants |
| --- |
| Sediment |
| Oil, grease and toxic chemicals from motor vehicles |
| Pesticides and nutrients from lawns and gardens |
| Viruses, bacteria and nutrients from pet waste and failing septic systems |
| Road salts |
| Heavy metals from roof shingles, motor vehicles and other sources |
| Thermal pollution from dark impervious surfaces (i.e. streets, rooftops, etc.) |

**Table 1: EPA List of Pollutants Carried by Storm Water Runoff (Polluted Runoff)**

All of the sources of pollution that the EPA has listed in the table above are commonly found in the Worcester area. Considering that Worcester is such a developed and urbanized city, it is at great risk for having large quantities of these pollutants being transported by storm water runoff into unwanted locations. This indicates that there is the possibility for a wide range of pollutants to be present in the water runoff that we will be diverting into our garden. In order for us to accurately determine which pollutants we are dealing with, understand how they got there and how to deal with them, some water testing must be conducted.

One other significant source of water pollution is chemicals and nutrients that are left behind on impermeable surfaces and washed into the city sewer system by storm water runoff. Chemicals, debris, excess nutrients, and bacteria can all be brought directly to the sewer systems by storm water. According to the Environmental Protection Agency (EPA), one of the most common and most preventable sources of water pollution is pesticides, fertilizers, and other similar chemicals. The EPA verifies that in 1996 approximately 28.03 million tons of nitrogenous fertilizers were produced, and that these products are directly linked to causing water pollution (Profile, EPA). Along with the use of pesticides and fertilizers, there are situations like gasoline spills at gas stations, oil and other fluid spills from vehicles, and household chemical spills that all get washed away by storm water runoff when left on the ground.

The WPI campus in particular, is located on a hill making it at a slightly higher elevation than much of the surround city. This means that much of the rainwater that lands on campus and anything it drags along runs down the hill to the outskirts of campus and into the surrounding city. The rest of the water either enters the storm drains on campus that bring it to the city and local bodies of water, or soaks into the limited permeable surfaces on campus. This is how pollution on the WPI campus directly affects the surrounding community.

Shown in Figure 2 below, is a map of the WPI campus. The area in yellow represents the main impermeable surfaces on and surrounding campus. As can be seen, the impermeable portion covers a significant portion of the area, much of which cannot be seen in this photo due to tree coverage. When it rains, the water runs over all of these surfaces and into storm drains, some of which flush directly into Salisbury pond; therefore, any pollutants left behind on these surfaces are being brought directly to the city water system and local bodies of water. The WPI campus is highly concentrated with people, vehicles, and wildlife that all play a role in creating pollution of this sort, making WPI a direct contributor to storm water pollution.

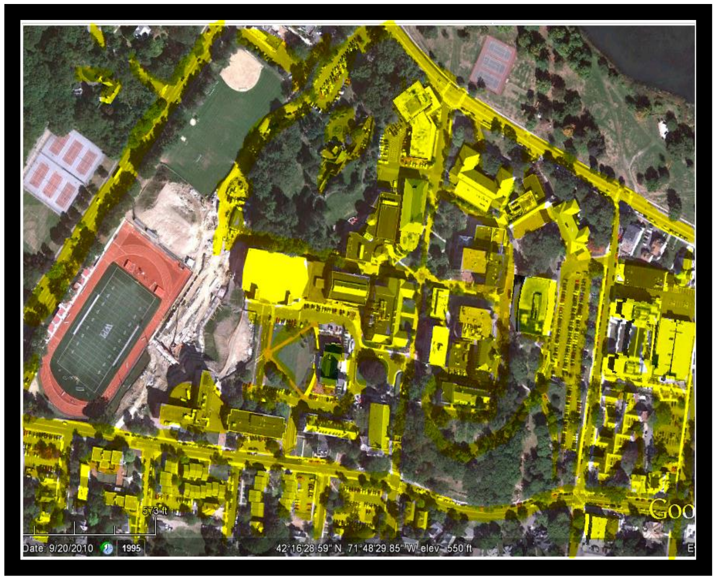


**Figure 2: Arial View of WPI Campus (Impermeable Surfaces in Yellow)**

As in innovative and intellectual representation of the surrounding community, it is not ideal for WPI to be significantly contributing to pollution in the wider Worcester area.

### 2.2.2.4: Cost Effects of Water Pollution in Worcester

Water pollution can be very costly on and individual and civic level. The cost of water filtration within the household is not detrimentally expensive, but is still something that can be avoided.  On a larger scale, cities can face fines in federal water quality regulations are not met, and it is pricey to install proper water treatment centers to accommodate water pollution. For example “the [Upper Blackstone Water Pollution Abatement] District has completed over $170 million in plant improvements to help achieve modern environmental standards, and continues to make plant improvements. These include installation of improved air pollution controls, construction of a modern landfill, modernized laboratory and administration facilities, enhanced site security, and the first two phases of an ongoing plant improvement project to achieve stringent effluent standards using a sustainable biological nutrient removal system. The District’s plant is currently achieving a higher standard of performance than envisioned when it was designed. Our modernized 45 mgd [million gallons per day] facility is exceeding performance expectations without chemical addition while using less energy than the original facility. Performance data for fiscal year 2011 is shown at the 'Performance' tab" (Treatment, UBWPAD). As seen in this example, fixing problems associated with water pollution within the city of Worcester is a huge financial burden to the city. These figures represent the large-scale costs of modernizing the equipment used to treat the city water so that it is up to date with current environmental standards.

### 2.2.3: Conclusion: Relation of Storm Water Runoff Background to Our Project

The harmful effects of storm water runoff are seen frequently on a local scale that affects everyone in the Worcester area. Information regarding these effects is beneficial to our project because it provides a baseline for the kinds of preventable problems within this community that green infrastructure can help alleviate. It is most important to first understand completely the source, process, and outcome of the issue as a whole before any suggestion for remediation is given. Following this information is necessary to deliver the appropriate tools by which to begin comprehending how the problem can be addressed. This is where the comparison of green versus grey infrastructure comes into play in the next chapter.

## 2.3: Green and Gray Infrastructure Approaches to Storm Water Management

In order to combat the issues associated with storm water runoff that were highlighted above, gray and/or green infrastructure techniques can be employed. The term gray infrastructure as defined in the journal article "Gray and green infrastructure", refers to man-made structures that facilitate transportation, provide housing, and offer services such as water, energy, and telecommunications. Examples of gray infrastructure include, but are not limited to, concrete gutters, end-of-pipe treatment, roads, sidewalks, buildings, and sewers (see Figure 3).

**Figure 3: Sewer & Concrete Gutter**

Many urban settings such as Worcester and the WPI campus contain many of these facilities that have overtime become fundamental to society as we know it. These methods of dealing with storm water runoff were effective before when the primary concern was to control the quantity of runoff, by simply moving it away as fast as possible so that it could do no damage as stated by Tyer in his journal article entitled “Stormwater Management: Moving to the Top of the Agenda”. However, with problems such as degraded water quality and combined sewer system overloads, it is clear that damage is indeed being done and something more needs to be done. This has led to the development of green infrastructure, which Wise, in his journal article entitled “Green Infrastructure Rising”, defines as the interconnected network of open spaces and natural spaces that naturally manages storm water, reduces the risk of floods, captures pollution and improves water quality. This may lead one to wonder why modern society has not simply switched completely to green infrastructure methods with all the added benefits that arise as stated in the definition. The reality is that gray infrastructure is the systemized approach that is used to combat storm water runoff. In order to change, we need to first understand why it exists. This is discussed in the next section.

### 2.3.1 History of Gray Infrastructure

Our current reliance on gray infrastructure stems from urbanization. Urbanization as defined by the Darity in his article refers to the conversion of forests and agricultural land to suburban and urban areas, vegetation and topsoil are removed and replaced with buildings roads and other infrastructure and drainage networks are installed. In his article entitled "Infrastructure", Tomazinis noted that early human settlements were simple places where persons within the community were able to live with some level of convenience and enjoy some measure of security against outside threats. Urban infrastructure provided the support facility that made living, gathering, hunting, and producing possible. As society has progressed over time, infrastructure systems and services have continuously evolved in both technology and organization. In his chapter of the book Perspective on Urban Infrastructure, Tarr notes that the evolution was dependent on a wide range of political, technical, financial and demographic factors. He stated that the built environment is slow to change and that public urban infrastructure is even slower. Significant changes to urban systems such as privy vault/cesspool system to sewerage or wells and pumps to waterworks required the support of interest group coalitions on the demand side and technical expertise and financial resources on the supply side. He continues to highlight that these major changes to the systems took several decades. In society as we know it today, in order for a significant shift from sole reliance on gray infrastructure to an integration of both green and gray, as history points out, it will require strong and powerful interest from groups that are aware of the need for green infrastructure.

The current storm water management program in Worcester consists primarily of gray infrastructure. The official governmental website of the City states that the surface sewer or storm water system collects rainfall from city streets and it is sent to the nearest waterway. The combined sewer system collects both sewage and storm water and transports it to the Upper Blackstone plant for treatment before it is released into the Blackstone River. However, during heavy, prolonged rains the amount of storm water entering a combined sewer system can be overwhelming for the pipes and the treatment plant, leading to combined sewer overflows, which pollute rivers and streams to which they flow. In addition the website also states that for the fiscal 2011-2015, the projected capital budget for the city indicates that $ 19,000,000 is budgeted for a sewer reconstruction program, surface drainage and new sewer construction. The imminent failure of portions of the infrastructure currently in place has resulted in the need for the sewer reconstruction program. The surface drainage program seeks to address drainage and street flooding at locations across the city. The installations can range from a single catch basin to the construction of a 60" diameter surface sewer.

These traditional methods of combating storm water runoff pollution are costly and ineffective in some cases as flooding still occurs. The same holds true for WPI. The institution is relying primarily on gray infrastructure methods such as concrete sewers and catch basins to combat storm water runoff. However, green infrastructure techniques can be utilized at WPI and in the surrounding Worcester community as it provides an antidote by intercepting rainfall before it reaches sewers.

**2.3.2 The Green Infrastructure Approach**

With the implementation of green infrastructure methods, in the effort to alleviate storm water runoff problems, there are various pros and cons that arise. Green infrastructure as defined by wise in the previous section refers to the interconnected network of open spaces and natural spaces that naturally manages storm water, reduces the risk of floods, captures pollution and improves water quality. Examples of these include and are not limited to greenways, wetlands, bio swales and rain gardens (see Figure 4).

**Figure 4: Bio Swale & Rain Garden**

The Pros include:

- The capacity to reduce the volume of storm water before it leaves a site
- Reduction of pollutant discharges
- Typically more financially feasible than gray
- Natural landscape provides beauty, wildlife habitat and natural flood prevention (Arsenault et al)
- Physical and psychological health benefits to people residing within them (Tzoulas et al)
- Opportunities to educate the community about storm water

The Cons include:

- Conflicts exist between the need to enhance, protect, and maintain natural areas and the need for new development, especially in terms of funding priorities because new development creates new revenue (Arsenault et al)
- Regular maintenance needed to reap maximum benefits

The Worcester community, which includes the WPI campus, currently uses conventional piping and drainage systems. By constructing and implementing green infrastructure, WPI could reduce runoff levels and reduce the pollutant levels present in this runoff. Although WPI is already making efforts to improve the water quality in the area by keeping pesticide and fertilizer to a minimum, more can be done. A study that was conducted at a housing development at the Somerset Subdivision, Prince George's County, Maryland, compared green infrastructure techniques to gray infrastructure techniques in relation to the resulting runoff volume and pollutant level. Half of the development had been constructed using green infrastructure such as rain gardens and vegetated swales and the other half had been constructed using gray infrastructure methods such as a curb-and-gutter design with detention pond for storm water management. From an environmental standpoint, the green infrastructure section of the development performed better than the gray. The average annual runoff volume for the green section was approximately 20% less than the gray section. The number of runoff-producing rain events in the green section had decreased by 20%. Also when compared to the percentages for gray infrastructure, concentrations of copper were 36% lower, lead 21% lower and zinc 37% lower in the green infrastructure section. Although the green and gray techniques were used independently in this specific case study, similar benefits can be reached by using both approaches to combat the runoff volumes and pollutants at WPI and in the Worcester community.

### 2.3.3: The Financial Feasibility of Green Infrastructure

Instead of only relying on traditional gray infrastructure methods to combat storm water runoff, WPI can use both green and gray to manage the problem. This will be a financially beneficial solution for WPI as the as the savings can be significant. The City of Bellingham in

Washington, needed to implement parking lots. They were able to save about 75 to 80 percent per parking lot project by constructing a rain garden instead of conventional in-ground storage and treatment systems (vaults) in the parking lots. On the City Hall parking lot project, the conventional vault estimate was $ 27,600 and the rain garden cost, $5,600. On the Bloedel Donovan Park parking lot project, the conventional vault estimate was $52,800 and the rain garden cost, $12,800. In each of these parking lot cases, it was necessary to develop a solution to storm water runoff. Instead of relying only on gray infrastructure methods the City considered using rain gardens, which are a green solution. Although WPI already has storm drains in place to deal with storm water problems, flooding still occurs. Instead of possibly implementing even larger drains or catch basins, WPI can have significant savings by using green infrastructure in addition to what is currently present. The same proved to be true for the Episcopal High School (EHS) in Baton Rouge, LA and the Mt Tabor Middle School (MTMS) in Portland, OR. Both institutions were having flooding problems and used green infrastructure techniques to handle the issues instead of replacing their combined sewer pipe and re-piping. In both cases, a cost analysis of green vs. gray infrastructure was done. At EHS, re-piping was going to cost approximately $500,000 and using green techniques came up to approximately $110,000 resulting in savings of approximately $390,000. MHS was able to save approximately $500,000 instead of replacing sections of their combined sewer pipe that would cost more than $1,300,000. WPI and the Worcester community also stand to have similar savings which can be used for other community needs.

WPI is an expanding campus and always seems to have some construction or new development underway, also the student body is growing and the campus is not. Implementing green infrastructure requires funding and hence persons in charge of financing on campus will need to see the benefit of the investment. As Arsenault et al in their journal article highlight, a conflict exists between the need to enhance, protect, and maintain natural areas and the need for new development, especially in terms of funding priorities because new development creates new revenue.

### 2.3.4: Green Infrastructure and the Community

Green infrastructure methods are a more aesthetically pleasing solution to storm water runoff because it contains natural elements such as trees, shrubs, grass, flowers and soil in order to manage storm water runoff. Arsenault et al in their report entitled "Northampton SDAT, Building Economic and Land Use Sustainability" mention that these elements add a natural beauty to any property that they are implemented on. Tzoulas et al in their journal article entitled "Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review", state that this in turn positively impacts the physical and psychological health of persons who dwell in these areas. For example they suggested that "natural features and open spaces in a residential area play an important role in residents' feelings of attachment towards the community, and their interactions with other residents." The converse is also true. Green environments that are not managed can have a negative effect on these residents, increasing the chances of anxiety. Natural spaces that are maintained provide an atmosphere for peace and serenity. The same can be true for the Worcester and WPI community. With green elements present, there will be a stronger sense of community.

Green infrastructure on the WPI campus will promote the awareness of the negative effects storm water runoff in the Worcester area. Once people know about the problem, they will be able to take steps to reduce it. The developed area can serve as a demonstration site for people in the community. If they are able to see it work in real time, they will be more likely to use green infrastructure in their yards or neighborhood. As Wise mentioned in his journal article, these projects "foster community cohesiveness by engaging residents in planning, planting and maintaining highly visible storm water infrastructure that beautifies and adds value to neighborhoods." In addition, Haaren in his journal article entitled "Landscape planning facing the challenge of the development of cultural landscapes" mentions that "the appearance and condition of the future landscape will depend on the societal conditions that are shaping it." Community cohesiveness allows everyone in the group to feel a sense of belonging and encourages a shared vision. This in turn creates the environment necessary to positively impact the future landscape. By undertaking green infrastructure initiatives, WPI and the Worcester community stand to gain from the community cohesiveness that can follow.

Though green infrastructure methods are able to combat the negative effects associated with storm water runoff, it is not feasible to completely replace all existing gray infrastructure with green because this would be extremely costly. However by using both techniques, such as the storm water drains that are already in place and a rain garden problems associated with storm water runoff such as flooding and pollutant levels can be significantly reduced. Our project focuses on developing a rain garden as a method of alleviating problems associated with storm water runoff on the WPI campus.

**2.4: Building a Rain Garden at WPI to Alleviate Storm Water Problems**

In this section we would like to convince the WPI community that the implementation of a rain garden would alleviate storm water problems. In order to do this we will include the following: 1) The reason for WPI's interest in rain gardens; 2) proving that rain gardens significantly reduce storm water runoff volumes; 3) Improving the quality of water in a given area by reducing the level of pollutants through rain gardens; 4) Getting the community on board with these projects to enhance the stewardship of natural resources at WPI and in the surrounding Worcester community; and finally 5) proper site analysis and design techniques need to be undertaken in order to avoid garden failure. Ultimately once all these subjects are touched upon it will be safe to say that WPI will feel secure with implementing a rain garden on it's campus.

WPI has crated the Presidents Task Force on Sustainability, to provide leadership and coordination for WPI's campus-wide efforts directed toward enhancing the long-term sustainability of WPI's activities and in supporting WPI's educational mission with regard to sustainability (WPI). WPI has noticed that this can be done through a rain garden. Since rain gardens a relatively new idea WPI can be seen as a pioneer of such sustainable landscape here at the northeast. Also combining a rain garden with the green roof on top of East Hall will benefit WPI as holding them to one of the more sustainable colleges in the United States, which had been noticed by the Princeton Review for the last two years (WPI).

Rain gardens have the capability to significantly reduce the volume of storm water runoff on the WPI campus. For example; A neighborhood in Burnsville, Minnesota constructed a garden to capture 0.9 inches of rainfall over the tributary impervious area. It reduced runoff volumes by approximately 90 percent (Burnsville Case Study). Each rain garden, regardless of vegetation or soil type, was capable of storing and infiltrating most of the runoff over the 5-year study period. Both rain gardens in sand, as well as the prairie rain garden in clay, retained and infiltrated 100 percent of all precipitation and snowmelt events during water years 2004–07. Evaluation of Turf-Grass and Prairie-Vegetated Rain Gardens in a Clay and Sand Soil, Madison, Wisconsin, Water Years 2004–08. (USGS). The WPI campus has many impermeable surfaces, whether it is building roofs, sidewalks, roads etc. hence by implementing a rain garden it will allow the runoff volumes to be reduced as seen in these case studies.

Another role a rain garden has is the power to improve the quality of water in a given area by reducing the level of pollutants. A case study was conducted in Australia, comparing the effectiveness of using a rain garden to that of conventional concrete piping and drainage systems. By analyzing pollutants for 10 events, the results indicated that gross pollutant load was reduced by 100%, suspended sediment by 68%, total phosphorus by 60% and total nitrogen by 57% (Lloyd, S. & Wong T). The WPI campus currently uses conventional piping and drainage systems. By constructing a rain garden, WPI will be able to improve the quality of water in the Worcester area.

A rain garden on the WPI campus will promote the awareness of the negative effects storm water runoff in the Worcester area. Once people know about the problem, they will be able to take steps to reduce it. Some examples of great steps taken in spreading the word of rain gardens consist of the following. In Kansas City, Missouri, a 10,000 Rain Garden Initiative was implemented to encourage members of the community to take action to manage their storm water runoff. Initially, citizens were confused about what rain gardens were and how they functioned and the need. The campaign was able to dispel some of the confusions. Also the initiative has received national attention and information requests from other communities that are seeking to start similar programs. (Kansas City, MO, Case Study). At North Carolina State University, a rain garden was implemented next to the Syme Residence Hall. The project was done as part of a grant for innovative teaching.  The NC State University Landscape Architecture Department has since received an additional grant to install five more sites adjacent to other campus housing facilities. Students will build these spaces. The resulting process will offer invaluable learning experiences for students seeking professional design careers (Syme Residence Hall Rain Garden Case Study). The garden at WPI can serve as a demonstration site for people in the community. If they are able to see it work in real time, they will be more likely to implement one in their yards or neighborhood such as the citizens of Kansas City did.

Selected plant species should be thoroughly investigated to insure that they work well together. The rain garden for WPI should accommodate for the proper growing conditions of the selected plants. If proper conditions are not followed the garden may fail to perform. A case study was performed on a rain garden that was constructed at the University of Minnesota. Many of the indicated problems could have been avoided if proper site analysis techniques had taken place. There were growth limitations with the plant species selected. The geraniums that were planted along the west edge were not filling in the area as they should and their growth was not as lush as expected. Also, there was a fairly large bare area northeast of the center of the basin where the anemones and chelone come together (University of Minnesota). WPI Grounds and Property Manager Alan Carlsen has many different nurseries including Pleasant View in Paxton, Bigelow Nurseries in Northborough, and Weston Nurseries in Weston were he purchases plants from. These three potential nurseries should allow WPI to avoid problem of growth limitation that the University of Minnesota had.

Since mixed case studies were shared in the previous section of both successful and unsuccessful rain gardens, we will now examine characteristics of a successful garden to give an idea of what we looked for throughout the project.

### 2.5: Characteristics of Successful Rain Gardens

To inform successful characteristics of a rain garden, the following is covered; 1) Information about the location; 2) dimensions; 3) finally ending with soil and plant selection.

Locating a position for a rain garden is just the beginning in creating an effective rain garden. The location takes into account the proximity of the land to a building, sun light, pooling, and the slope it is on. Sitting water may leak into a buildings foundation hence it is important to keep rain gardens away from buildings. Rain gardens may not be located within ten feet of a buildings foundation as well as twenty-five feet to a septic system. (North Carolina Coop Extension) This makes sure no flooding in basements or interruption of septic tanks/wells occurs, as shown below in Figure 5.

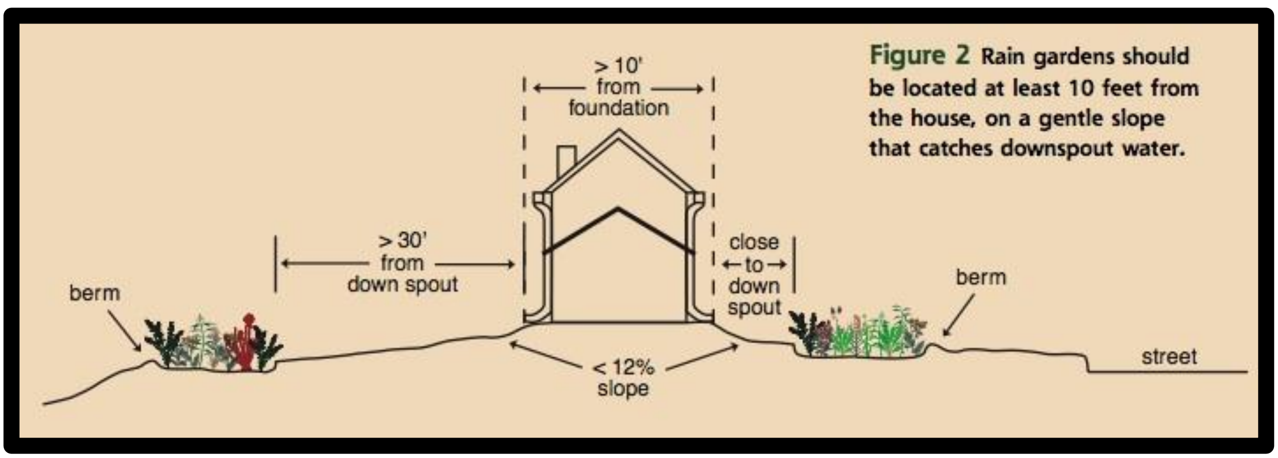



**Figure 5: Placement of a Rain Garden**

Sunlight is essential to any garden and is a key factor for their growth and life. Many native perennials are adaptive to the amount of light of their region, which allows them to also grow in partly shaded areas as well (University of Texas at Austin). A characteristic one looks for in the placement of a rain garden is also a location that pools a lot of storm water. Areas with a high amount of precipitation and low absorption are prime for a rain garden  (Rain Garden Network). Slopes are needed in a rain garden in order to bring run off to the garden naturally.

Donna Williams, commission chair of the Blackstone River Valley Coalition, told us that a slope much greater than 12% is not desired because the force of the water might over power and destroys the garden. In order to determine the slope you must calculate the rise over run and multiply it by 100 to get a percentage.

Once a location is found, proper dimensions of a rain garden are needed to boost performance and aesthetic appeal. In order to calculate the surface area one must divide the rain garden volume pounding by the average depth of water, which is usually around nine inches deep (Wisconsin Department of Natural Resources). If the runoff is too overwhelming for the garden it will slowly erode and get destroyed. Excavate existing fill soils to a depth of 18" below existing pavement surface in order to insert proper soil for a garden. The depth is how far you need to dig to make the base of your rain garden level. A typical rain garden is around twelve inches deep not including the six-inch depression (NPSNJ rain garden manual). Using a well-mixed ratio of sand, compost, and loam for the soil is sought out for in order to have the highest performance in absorption. The shape of a garden gives to the beauty of it as much as the plants. People rather look at a structure with elegant curves then a plain rectangular garden (Dona Williams Interview). Having a rain garden that is aesthetically appealing is a necessity for WPI, in order to spread the word and wonders of a rain garden it must look good to insure that people come back to it.

The appropriate composition of the soil within the rain garden is essential for plant growth and water absorption, which is the main function of a rain garden. An inspection of the soil at a rain garden that was implemented at the University of Minnesota revealed that there was a potential for problems during a large storm runoff event. The silt loam soil layer restricted infiltration to the sand trench. In addition, low infiltration rates were located in the center of the basin (University of Minnesota). An investigation of the soil during site analysis at WPI is necessary to determine the soil composition. If the soil composition will not accommodate easy water infiltration then the soil will need to be adjusted. Filling the excavated area one must follow the 3:1:1 ratio of sand, compost, and loam. For example a 400 square foot garden needs around 9 yards of coarse sand, and 3 yards of both loam and soil compost. Hardwood mulch is used on the surface of the rain garden, which aids in moisture retention and has less of a tendency to float when the rain garden is wet (The Sustainable Landscape).

Plants used in a rain garden are one of the most important factors towards its success. Most ideal plants for a rain garden are native plants as well as perennials. Plants that are native to the rain garden location will survive with the least amount of maintenance and are usually perennials that do not need fertilizers or replanting (New England Wildflower Society). Deciding what section of the garden each plant belongs to is very important if you would like the plants to be able to work together in absorbing storm water. The bottom layer includes plants that like wet conditions. Plants on the side are able to stand wet or dry soil. The top edge of the garden has to be filled by drought-tolerant plants (Seattle Public Utilities). Blooming seasons of plants are of high importance as well. One may want to add plants with many different and long blooming seasons so there will always be life in the garden. The longer the plants thrive and grow the more effective the rain garden is.

Understanding that rain gardens have the potential to augment storm water run off and the effects brought on by it as seen in the Burnsville Case Study is the first step in creating a rain garden. Also finding out the proper characteristics needed for a rain garden to be successful is important as well, so we can have a sort of model to follow as our guide. Our group does not want our garden to end up failing like the one at the University of Minnesota. Since we understand all these things and have looked at a good amount of studies, we are ready to move onto our methods and results section of the report.

# Chapter 3: Rain Garden Site Selection – A Methodology and Analysis of Rain Garden Site at WPI

This chapter will give a detailed explanation of how to construct a rain garden and how our team went about selecting and analyzing the rain garden site on the WPI campus. It is intended that this section give the reader some guidance as to how about selecting a rain garden site and what basic analysis should be done at that location in order to build a successful rain garden. In order to effectively portray this information, we will include the following: 1) An overview of the steps needed to construct a rain garden 2) An explanation of how we went about completing each step for the rain garden at WPI. Ultimately, this section should serve as a detailed and sequential example of how to go about building a rain garden.

## 3.1: Building a Rain Garden

Building a rain garden requires completion of a variety of different steps. As seen in Figure 3.1 below, there are five steps to building a rain garden. These steps include the following: 1) Selecting a site; 2) Water testing; 3) Soil testing; 4) Plant Selection; 5) Construction.

| Building a Rain Garden | |
|---|---|
| **Step 1** | Selecting a Site |
| **Step 2** | Water Testing |
| **Step 3** | Soil Testing |
| **Step 4** | Plant Selection |
| **Step 5** | Construction |

**Figure 2: Steps for Constructing a Rain Garden**

All of these steps can be completed by the individual on both a large or small scale. However, it is important that all steps be completed. Following is a chronology of how we completed each step.

## 3.2: Rain Garden Location & the Relation to Effectiveness

### 3.2.1: The Importance of a Rain Garden's Location

When considering the design and implementation of a rain garden, one must deliberate, first and foremost, on the location of the rain garden. This is relevant to the garden because in order for the rain garden to be successful in mitigating storm water run off and providing a good source of information to the community, utilizing the appropriate location is crucial. Even seemingly minor factors, such as the slope of the land or the permeability of ground surfaces in the surround area, can drastically affect the performance of the rain garden. In the case of the WPI campus, the location for an effective rain garden should also be in a well traveled, visually appealing area so as to garner interest and further support for the push in green infrastructure. In short, the main factors of consideration include:

- Slope
- Lighting
- Pooling of Water
- Amount of Usable Area
- Ease of Construction at the Site
- Proximity of Land to Buildings and Utilities
- Visibility of Location to WPI Student Body

A combination of these varying factors must be taken into consideration in order for the rain garden to be successful and gain the attention of the WPI community.

Rain gardens that maintain the appropriate distance from certain grey infrastructures minimize the potential harmful side effects of the pooling of water. As stated by Sue Ellingson (appliedco), the lowest point of any rain garden should be at least:

- 10 feet from the foundation of a building;
- 15 feet away from any sewage or drainage systems;
- 25 feet away from a drinking water source.

This is due to the basic design functions of a rain garden. They are typically designed to retain water and absorb it over an extended period of time. As it is unwise to have large quantities of water situated in such a location, these guidelines should be considered. Generally, water traveling through the soil will spread out one foot for every two foot of vertical drop. So in theory, if the garden were to be five foot from the foundation of a building, the water would miss a foundation wall ten feet deep. This factor should especially be considered in the situation of an exceptionally deep foundation. Large pools of water located in close proximity can lead to the leaking and flooding of basements, even after a relatively moderate amount of precipitation (appliedco).

Areas in need of storm water collection that are in close proximity to a cautioned area can have water diverted by means of rain collection systems. A problematic area can have a collection system, such as rain barrels, that gather the storm water runoff, which can then be directed to the location of a distant rain garden (Rain Barrel Guide). Rain barrels can hold water in amounts varying from several gallons to several hundred, and will be able to retain water for as long as necessary. In times of drought, large rain barrels can help to supply water to the ran garden. If this is too much water, some could be diverted to another location, while the rest was fed into the garden site by drip irrigation (Construction Storm Water Pollution Prevention Bulletin).

Rain gardens must be located on a downward slope with a source of runoff at the top of the slope and a drain at the bottom in order to be effective. Slopes are needed in rain gardens in order to bring run off to the garden naturally. A flat landscape does not allow storm water to easily reach a nearby rain garden, nor for excessive amounts of water to overflow the garden and prohibit the plant species from drowning.  In some cases, flash flooding on a steep slope may wash away some of the rain garden itself. To combat this, slopes of around 10-15% grade are desired (Donna Williams). This allows for precipitation to flow into the garden, yet not in an overbearing fashion.

Even if a desired location for a rain garden is a bit too steep, there are options for making a location usable. Building a berm at the bottom of a rain garden can help to greatly reduce the runoff past the lower edge of a rain garden if there is a slightly higher slope than suggested. Usually constituted of soil, sand, or gravel, a berm acts as a semi-permeable barrier, retaining water in the rain garden, yet allowing for the passing through of water as well. As shown in Figure 6, one possible way to accommodate slope issues is to dig into the upper portion of the site, and add this material to the lower portion and a berm. This can help to make a more suitable ground layer for the rain garden.

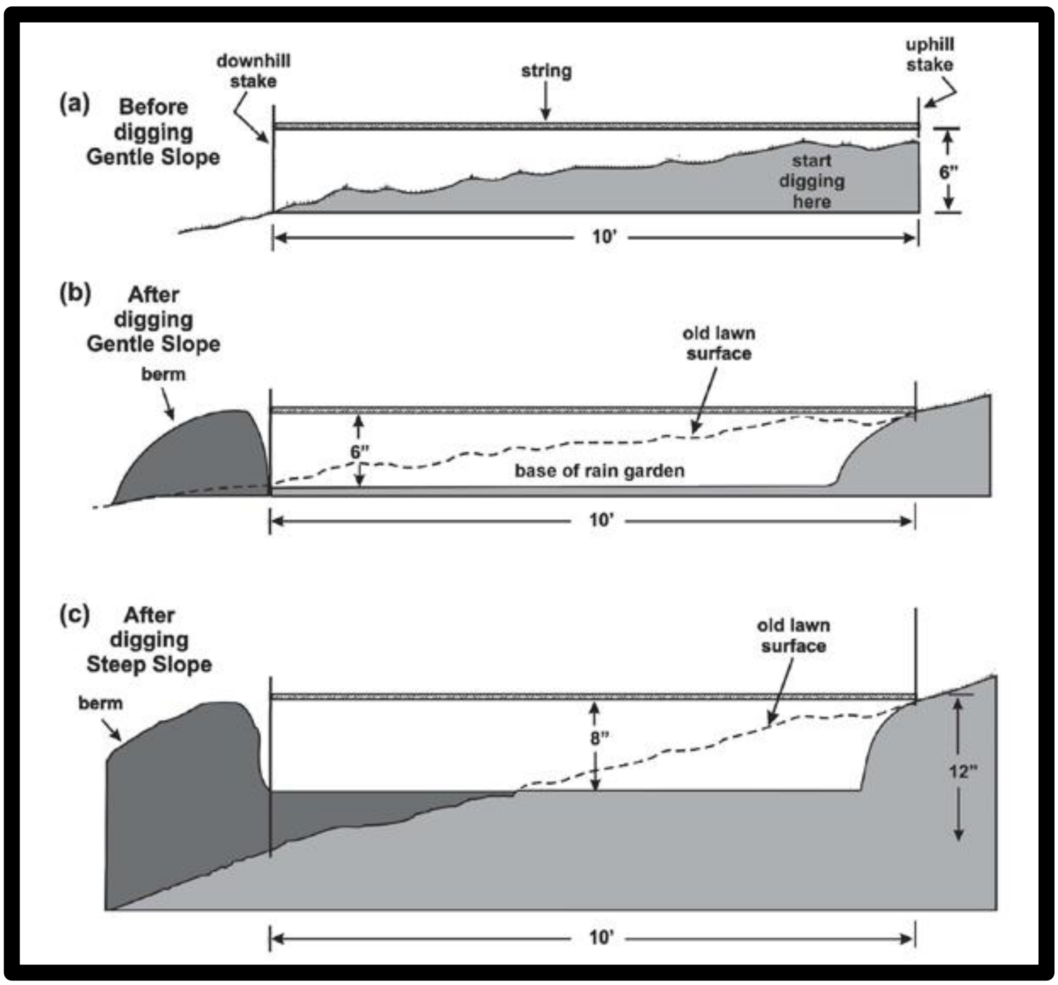



**Figure 6: Berm Use in a Rain Garden**

Not only does the slope need to be considered, but the surface area needs to be taken into consideration. “You want a 3:1 ratio (runoff sq. ft. to garden sq. ft.) if you would like the garden to work to its peak” (American Nurseryman). In the case of the rain garden on the WPI campus, the size of the rain garden would vary based on the selected location, as each site would have a different calculated runoff area. It is important that this number is relatively close because a rain garden receiving too much water will flood, kill the plants, and leave a large body of un-absorbed water – negating the original intention of the garden. In the rain garden at the Worcester Youth Center, the 1000 square- foot rain garden is positioned to collect storm water runoff from a parking lot in excess of 15,000 square feet, leading to the eventually flooding of the youth center basement (Donna Williams). Here at WPI, there are areas of land (such as the access roads and rooftops) that feed into the possible rain garden locations. Many of this area are far smaller than 15,000 square feet. In this case, a rain garden in the range of 3,000 square feet would be exponentially more efficient and beneficial. In a normally proportioned rain garden, an average 1-inch rainstorm would drain out in anywhere between 24 and 26 hours. This also negates infestation, as mosquitoes and other wetland insects take 7-10 days to lay and hatch their eggs by drip irrigation (Construction Storm Water Pollution Prevention Bulletin).

### 3.2.2: Rain Garden Site Analysis: A Method

WPI wanted us to design a rain garden that can be used as a demonstration site for the local communities. Not only did the garden have to serve its purpose in collecting storm water, but it also had to be in an area with high visibility as well. The reason the garden needs to be able to collect storm water is so that it can be educational; the point of a rain garden is to take in the excess grey water, which is what we are trying to spread through this project. Due to this, visibility is important because that is a quick and easy way to get the word out for the garden. If one puts a garden in a highly populated area many people will see it and start talking about this new part of the campus. Again, this interest feeds into the WPI mission by pioneering ways to better the standing system of grey infrastructure, and to the development of further ideas by current WPI students.

We met with Alfredo DiMauro, head of landscaping here at WPI. Due to his experience in landscaping and drainage utilities, we wanted his opinion and preferences on where the best possible locations for a rain garden would be. Mr. DiMauro suggested many locations throughout campus starting at Park Ave heading all the way to Gateway Park. We decided to look into the sites on the hill due to the necessary visibility factor and ended up with the following six options; the land in front of Salisbury Labs, Atwater Kent, the Wind Tunnel, West St entrance, behind Riley by the Little Theatre, and the land between Fuller and the Library.

In order to choose the best location for our specific rain garden, we decided to create our own grading rubric. We had seven different categories: slope, visibility, light, pooling, area, build-ability, and proximity. The idea is to take into account each major factor of selecting a site, and weighing the pros and cons. All given scores were averaged for each category, then added up to achieve a final score. The grading chart and scoring results follow, shown in Table 3.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 7 | 10 | 6 | 10 | 5 | 7 | 5 | 50 |
| **Location** | **Slope** | **Visability** | **Light** | **Pooling** | **Area** | **Build-ability** | **Proximity** | **Total** |
| Library | 6 | 10 | 3 | 8 | 5 | 6 | 5 | 43 |
| AK | 7 | 8 | 4 | 8 | 2 | 4 | 3 | 36 |
| West St | 7 | 10 | 3 | 7 | 0 | 0 | 5 | 32 |
| Salisbury | 7 | 10 | 6 | 4 | 4 | 7 | 5 | 43 |
| Wind tunnel | 1 | 10 | 2 | 8 | 2 | 1 | 1 | 25 |
| Riley | 7 | 7 | 6 | 7 | 4 | 6 | 5 | 42 |

**Figure 3: Grading of Possible Rain Garden Locations**

Each of the categories has a different worth based on importance. For example, visibility and pooling are both worth ten points while area and proximity are worth five points. As part of the motivation behind this garden is to allow for the viewing of the community, visibility is important. The pooling of water, essentially deciding the garden's effectiveness, is also important. The proximity of the garden to nearby selections matters, yet can easily be remedied by simple design changes and a slight movement in the location of the garden. The maximum points a site can get when everything is added up is fifty points (as shown in Table 3).

Once a site was chosen, we then proceeded to find both the slope and the surface area. These are excellent beginning data collections: the area needs to be large enough and of the right slope in order to be effective in any sense. If the area is not sufficient in these categories, it will be much harder to implement an effective rain garden in the area. Finding the slope of the rain garden area can be done in an easy, albeit simple, fashion. First, measure out a horizontal length with a measuring tape. Then, measure the height off the ground that the lower edge of the measuring tape is. Using these two numbers, simply divide the rise (vertical change) over the run (horizontal length), and multiply this number by 100. (University of Wisconsin). Upon measurement and calculation, we found the average slope to be about a 10 to 11 percent grade. However, in order to get a more exact measurement, we borrowed the surveying equipment from Professor Hall of the Civil Engineering Department. Upon completion of measurements, we were able to find a more exact percent slope. The way we found the surface area is by using surveying equipment to find distances and angles. We then plugged that into AutoCAD and were able to then calculate the surface area through the computer. As AutoCAD drawings are automatically drawn to dimension properly, these designs will continued to be used to create appropriately dimensioned models.

### 3.2.3: Rain Garden Site Analysis: Results & Analysis

As seen on Table 3, there was a tie for the best location with the runner up only being one point behind. The two top-rated parcels of land were between the library and Fuller Laboratories, and on the West side of Salisbury Laboratories. Out of these top two we decided to choose the land between the library and Fuller. This land was selected for several main reasons:

- Top-tier visibility right outside of the library;
- On the path of Crimson Key tours;
- Next to Fuller lecture halls, the biggest on campus;
- High quantities of storm water runoff on the access road

The high level of impermeability along this 3,000 square foot –plus access road makes for a perfect location for the rain garden. This is a good sign because with the rain garden we can minimize storm water runoff before it reaches the drain. Though the slope seems very steep throughout the whole hill we found a partially flat area at the top of the hill. A topographical map from campus utilities manager Christopher Salter showed a much more gradual slope at the top of the hill, a notion supported by our surveying results. As shown in Figure 7 below, the elevation lines are much closer to the East (right) of the vertical purple line. The slope in this area reaches values as high as 25 to 30 percent slope, far to high for a feasible rain garden location.

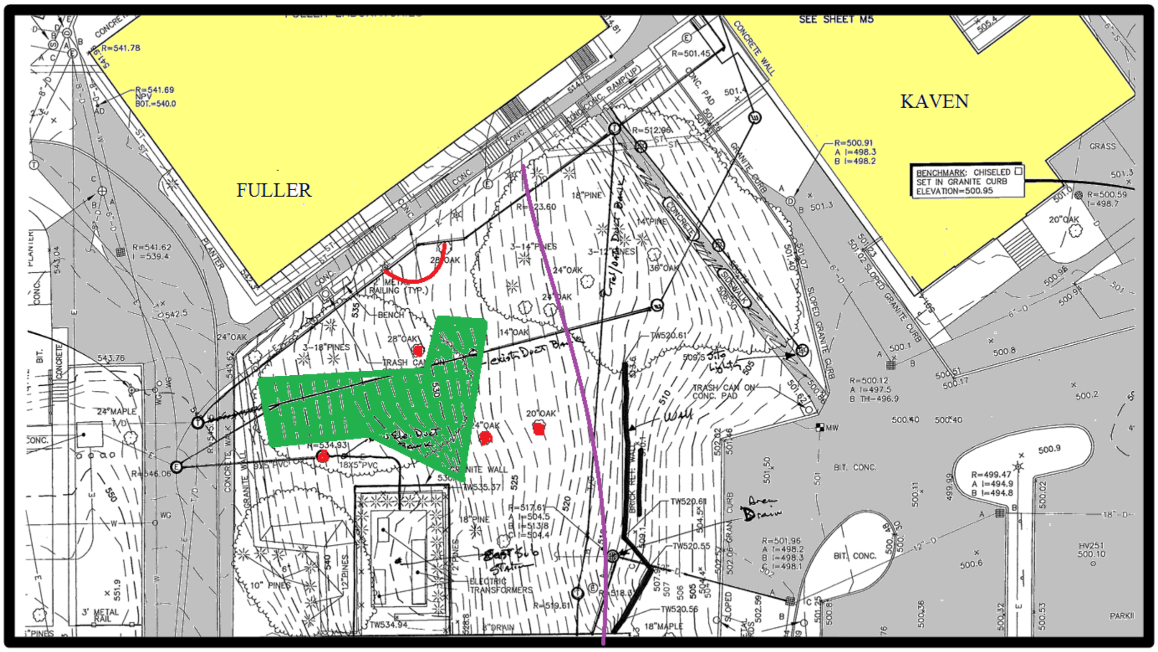



**Figure 7: Topographical Blueprint of Potential Rain Garden Site**

To measure the slope we used the rise (height gain) divided by run (length) and multiply by one hundred formula. Once the area was calculated we ended up with a 10.3 percent grade. A slope of 10.3 percent grade is just what we needed, it is very close to the 12 percent grade recommended by Donna Williams, among others. Once the slope was measured we then tried to figure out the surface area using surveying equipment. We gathered all distances and angles and then plugged them into AutoCAD. Using this software we were able to get precise calculations of the surface area, which ended up being 1036 sq. ft. This amount is ideal because we measured the impermeable area of the road and calculated slightly higher then 3100 sq. ft., which follows the 3:1 ratio mentioned earlier. This number clearly does not have to be exact, but it is best to keep both a watered garden and one that is not drowned by the inundation of excess runoff.

After deliberating on each of the possible locations and impartially grading them, it was determined which site would prove to have the most potential. The site chosen between the Library and Fuller Laboratories is a large, visible area, which could accommodate the large quantities of storm water runoff that make their way down the impermeable roadways above. In analyzing the site, it was proven that a rain garden could easily be built in such a location without a severe site overhaul. This process allows for the further investigation into building a rain garden and the process of creating the actual designs themselves.

### 3.3: Water Pollution on the WPI Campus

Storm water pollution is a significant problem in urban areas throughout the United States. Developed areas are particularly at risk for suffering from water pollution because of the greater population density and greater impermeable surface coverage. This global epidemic directly affects human, animal, and plant species. In Worcester, the local community has suffered greatly from the effects of storm water pollution. The WPI campus in particular, being covered by impermeable surfaces, has to deal with flooding issues very frequently. Storm water runoff floods walkways, roads, and basements of buildings on campus at times. Walkways become impassable, flooding of buildings has led to mold problems, and in the end, the majority of this water is washed directly down the storm drains, much of which goes directly to Salisbury Pond. Through these means, any pollutants left on the surfaces are spread further to other parts of campus and the surrounding community, including Salisbury Pond. It is important to be aware of what these pollutants are, how they affect the environment, and how our project will remedy the issue.

### 3.3.1: Importance of Testing Storm Water

In order to construct a successful rain garden, it is first important to understand the kinds of conditions that are being dealt with in relation to storm water pollution. Testing the storm water runoff that will be diverted to the rain garden for specific contaminants is an essential part in the analysis portion of the whole process. Without proper knowledge of this information, the garden may fail to function properly. Testing the storm water runoff at the site of the rain garden is important because it indicates what pollutants have to be taken into consideration when selecting plants for the garden.

### 3.3.2: How to Test Storm Water

There are many different options when it comes to testing the storm water at the rain garden site depending on budget, time, and needed information. One can easily test the pH of the storm water runoff at home using pH strips. pH strips are a cheap, easy, and quick way to test storm water.

One can also purchase a home testing kit. Home testing kits allow you to test for lead, bacteria, radioactivity, and a large range of other things in a sample of water. The kits range in price from $9.95 to $149.95 depending on what you want to test for (Drinking, DiscoverTesting.com). They can be purchased at DiscoverTesting.com, as well as many other online and home-improvement stores such as Home Depot® or Lowes®.

Professional testing is a more expensive, but more accurate way to test storm water. It also allows testing for contaminants than one cannot test for at home. Locally, water testing can be done through Microbac Laboratories, Inc., in the on-campus laboratories, or labs in other universities.

### 3.3.3: Storm Water Testing at Our Site: A Methodology

It was initially on our list to get in contact with the Facilities Department at WPI to determine what pesticides and fertilizers are currently used on campus, and if there was any record of past use of pesticides and fertilizers. With the help of Alan Carlsen, the grounds manager on campus, it was determined that pesticides and fertilizers were not currently being used on campus and that there was no record of any use in the past. Although this is a great indication that we would not run into many problems with contaminants in the storm water on campus, we felt that is was still necessary for us to test the storm water in order to provide a complete analysis of the conditions with which we were dealing.

For our project we took an approximate 2-cup sample of storm water runoff from the drain in front of Fuller Labs on campus because this is the water that will be diverted into the rain garden. We opted to have the water tested professionally through Microbac Laboratories, Inc. in Worcester. We had the sample tested for nitrate and phosphate concentration and it cost $48.00 in total.

### 3.3.4: Storm Water Testing Results: Our Findings

Our results, shown in Figure 3.1.1 and in the Appendix, indicate that there was no measurable quantity of nitrates in the water sample, and that the concentration of phosphates in the sample was 4.71 milligrams per liter (mg/L). The phosphate level in the sample appears to be well about the reporting limit listed by Microbac Laboratories, Inc. These higher levels of phosphates will be utilized well by the plants in the rain garden rather than going straight into the sewer system on campus where they could cause damage. Due to the great density and mere size of plants we hope to achieve in the garden, a relatively large concentration of phosphates should not be a problem for the garden because the garden will require a lot of these ions to thrive.

| Substance | Concentration |
|---|---|
| **Nitrates** | N/D |
| **Phosphates** | 4.71 mg/L |

**Table 4: Storm Water Testing Results**

**OUTSIDE DRAIN**

**1127184-01 (Stormwater) Sampled: 11/10/2011 14:00; Type: Grab**

| Analyte | Result | Reporting Limit | Units | Prepared | Analyzed | Analyst | Method | Notes |
|---|---|---|---|---|---|---|---|---|
| **WET CHEMISTRY (MASSACHUSETTS DIVISION)** | | | | | | | | |
| Nitrate as N | ND | 0.400 | mg/L | 111111 1455 | 111111 1455 | HCL | SM 4500-NO3-E | |
| **Phosphorus, P** | **4.71** | 0.0100 | mg/L | 111611 1200 | 112211 1200 | HCL | SM18 4500-P B, E | |

**Table 5: Water Testing Results from Microbac Laboratories**

### 3.3.5: Storm Water Pollution Recommendations

Based on our results, it is clear that the level of phosphates in the water is not healthy to be sent straight into the city sewer system, and that it is something that our rain garden can be effective in combating by putting the phosphate ions in the storm water runoff back into the natural phosphorous cycle. In continuation with this, testing on the soil at the site will need to be conducted for further information about what kinds of pollutants the storm water runoff brings into the soil that is already there.

### 3.4: Soil Composition on the WPI Campus

### 3.4.1: Importance of Proper Soil Composition

Soil composition is a crucial factor that must be considered in the design of an effective rain garden. When we say soil, we are referring to the unconsolidated mineral or organic material on the immediate surface of the earth that serves as a natural medium for the growth of land plants (USDA). In order for plants to grow effectively in a rain garden, the soil needs to not only be healthy, but also of the correct type in order to allow proper filtration of the storm water runoff. There are many ways to test soil for physical and chemical properties; all of which will be outlined. In the context of designing a rain garden, if proper soil examination is not accounted for, the garden may fail.

According to the NSTA Natural Resources Conservation Service, there are over 21,000 soil types found in the United States. Each of these types has varying amounts of three main components: silt, sand, and clay. The texture of the soil is determined by the proportion of each material. The loam soil texture contains a roughly even distribution of silt, sand and clay. Sand has the largest particle size with a diameter between 0.05mm and 2mm, silt is intermediate with diameter between 0.05mm and 0.002 mm, and clay has the smallest with a diameter less than 0.002mm (EPS.) As a result of the varying sizes of the particles that make up the soil, various soil textures are suited for different purposes.

The soil in a rain garden needs to allow for adequate storm water filtration and, at the same time, needs to retain nutrients for the plants. Sandy soils have a high water infiltration rate and do not retain nutrients well. Clay - heavy soils drain water slowly and hinder root development for plants. Soil in a rain garden needs to be in the middle of these two extremes. Hence, loamy soil, which has a medium texture, drains soil well, and holds nutrients is ideal for a rain garden. Though this soil type is recommended, amendments can be made in the rain garden design that will compensate for the effects. In locations with sandy soil, gardens can be constructed so that they are smaller and deeper to compensate for the high infiltration rate. Also, locations that have high concentrations of clay soils can be larger and shallower (EPS).

The chemical properties of the soil need to be examined in addition to the physical properties. The minerals and microbes in the soil are responsible for filtering, buffering, degrading, immobilizing and detoxifying organic and inorganic materials (USDA). Healthy soil contains the right balance of these minerals, microbes, and nutrients that allow the soil to perform these functions. By examining the pH level of the soil, the necessary soil quality amendments that may need to be completed in order to improve the growing conditions of plants will be identified (Higgins). This is important because the pH influences the solubility of nutrients, as well as the activity of microorganisms responsible for many of the chemical transformations that take place in the soil. Hence, the pH affects the availability of many plant nutrients. A pH level of 6.0 to 7.0 is ideal for plant growth as most plant nutrients would be available, and usable, at this level (USDA).

### 3.4.2: Soil Testing Methods

In order to assess the condition of the soil at the location of our future rain garden, we performed both on-site and off-site tests as shown in Figure 3.9 below.

**On-site**

- Feel Test
  - Ball Test
  - Ribbon Test
- Percolation Test

**Off-site**

- Professional Testing
  - pH
  - Minerals

**Table 6: Types of On-Site and Off-Site Soil Testing**

The on-site feel test, which constitutes the ball and ribbon test, was done in order to determine the soil texture of the soil at the site. Carrying out these tests were important because the soil texture is closely related to determining the size of the rain garden, as well as, measuring how fast the storm water will infiltrate the rain garden. Approximately three tablespoons of moist soil was placed in the palm and kneaded until pliable, as seen in Figure 8. By merely feeling the soil, grittiness is usually an indication of sand, whereas smoothness an indication of silt and stickiness an indication of clay (MCD).

**Figure 8: Ribbon Test**

After the ball was kneaded, it was then shaped into a ball and squeezed. Soil that breaks with slight pressure indicates a coarse texture (sand or sandy loam). Soil that stays together but changes shape easily indicates sandy loams or silt loams. Soil that resists breaking indicates fine texture, which is highly clay or a clay/loam composition (MCD).

The ball was then placed between the thumb and forefinger. The soil was pushed with the thumb and squeezed upward to form a ribbon. The ribbon was extended over the forefinger until it broke under its own weight. If the ribbon is less than 1” and feels gritty, this indicates a coarse texture (sandy soil). If it does not feel gritty, then a medium texture soil that is high in silt is present. For ribbons between 1” and 2” that feel gritty, medium texture soil is present. If it does not feel gritty then it has a fine texture. Ribbons that are greater than 2” indicate clayey soil which has a fine texture (Dietz, 2011). In order to determine the final soil texture, we followed the flow chart shown in Figure 9.

**Figure 9: Percolation Test**

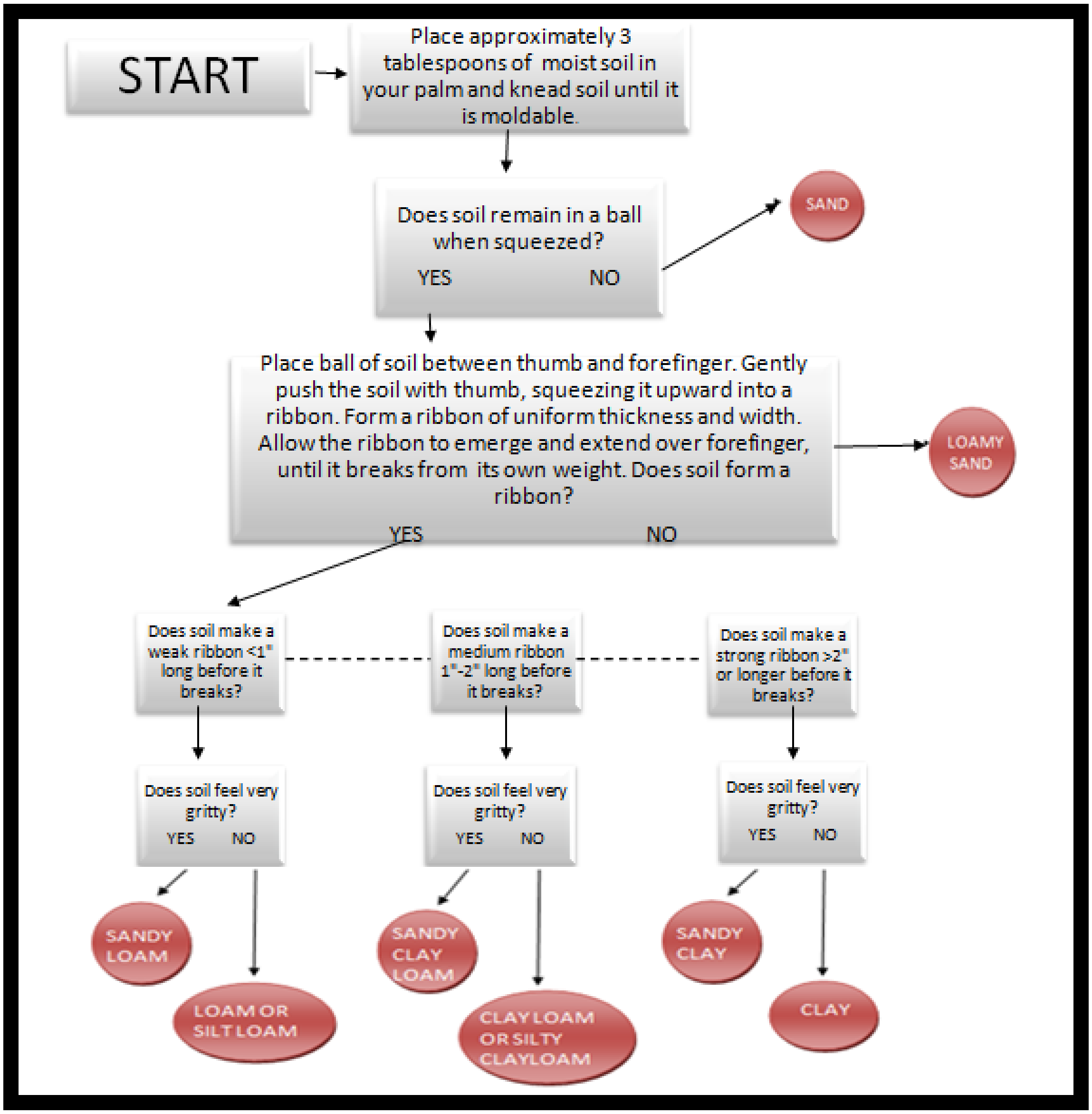



**Figure 10: Soil Texture Feel Test Flow Chart**

A percolation test was conducted to measure the infiltration rate of storm water runoff. A hole approximately 6" deep by 6" wide was dug. The hole was filled with water and we allowed the water to stand until all the water was drained into the ground. The hole was refilled with water, and the depth of water was measured with a tape measure (see Figure 10) after a certain time interval until the hole was empty. If there is still water in the hole after 24 hours, then the site is not suitable (Dietz, 2011). This means that there are further changes that will have to be done in order to improve the infiltration rate.

Our off-site soil testing was done with the University of Massachusetts Amherst Soil and Plant Tissue Testing Laboratory. This test provided us with a chemical analysis of our soil. This was important to ensure that the soil currently present at the site is suitable for our rain garden and will allow plants in the garden to thrive. A soil sample was taken from ten random spots within the area of the future garden location (approximately one-half cup of soil from each). The soil was taken from these areas and was mixed together. The sample was dried overnight and then mailed to the lab for testing. We chose the standard soil test with organic matter. It provides information about the pH, buffer pH, extractable nutrients, extractable heavy metals, percent organic matter and provides recommendations for nutrient and pH adjustments.

### 3.4.3: Soil Test Findings

From the on-site feel test that was conducted, following the flow chart shown in Figure 11, after the soil was kneaded until moldable and shaped into a ball and squeezed, the soil did remain in a ball when it was squeezed. Hence, the sandy soil texture was eliminated. After the ribbon test, where the ball was made into a ribbon, the soil made a medium ribbon that was between 1” and 2” long before it broke. Continuing along the flowchart, the soil did not feel very gritty. In contrast, the soil felt sticky. This narrowed our soil texture category to the regions of clay loam or clay loam with a high silt concentration. This test provided us with a preliminary idea of the type of soil we were handling.

The results of our percolation test reveal that the soil present at the site does not absorb water at a fast enough rate to compensate for the heavy flow of storm water runoff that it will have to undertake. This means that the soil has too high a concentration of clay

The results we received from the off-site chemical testing done through UMass Amherst revealed relatively stable conditions for a rain garden. As seen in Table 4.1 the general soil pH tested at 5.7, nitrogen levels in the sample tested at 0 parts per million (ppm), and phosphate levels were very low.

| Micronutrient | PPM | Soil Range |
|---|---|---|
| **Boron (B)** | 0.5 | 0.1-2.0 |
| **Manganese (Mn)** | 0.7 | 3-20 |
| **Zinc (Zn)** | 3.1 | 0.1-70 |
| **Copper (Cu)** | 2.2 | 0.3-8.0 |
| **Iron (Fe)** | 12.7 | 1.0-40 |
| **Sulfur (S)** | 12.5 | 1.0-40 |

| | |
|---|---|
| **Soil pH** | **5.7** |
| **Buffer pH** | 6.7 |
| **Nitrogen : NO3-N** | 0 ppm |
| **Organic Matter** | 4.3% (Desirable range 4-10%) |

| Nutrient Levels | PPM | Low | Medium | High | Very High |
|---|---|---|---|---|---|
| **Phosphorus (P)** | 4 | XXXXXXX | | | |
| **Potassium (K)** | 95 | XXXXXXXXXXXXXXXXXXXXXXXXX | | | |
| **Calcium (Ca)** | 684 | XXXXXXXXXXXXXXXXXXXXXXX | | | |
| **Magnesium (Mg)** | 173 | XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX | | | |

**Figure 11: Soil Test Results from UMass Soil and Plant Tissue Testing Laboratory**

This indicates that fertilizers have little to no impact on the soil conditions on campus. The pH of the soil is a little low for ideal rain garden conditions. Compensation for this is easily achieved by addition of limestone. The results also indicated that the lead concentration in the soil was low and that the extractable aluminum level was at 61 ppm (parts per million), which is within the acceptable range of ten to 250 ppm for soil. See Appendix B for complete soil testing results.

Our results indicate that the soil that is currently at the site will be chemically suitable for a rain garden following pH adjustment and that no additional actions will need to be taken to change these conditions.

## 3.5: Native and Perennial Plants

### 3.5.1: Native and Perennial Plants: An Introduction

When anyone hears the word garden, plants are the first things that come to mind. The same goes for a rain garden as well, not only are plants the exciting part of the garden but they are also a very important aspect to the gardens success. This is true because the plants are in the depression were water is gathered, and they are the ones that absorb all the storm water which prevent it from entering the sewer system.

Native plants are defined as, "A native (indigenous) species is one that occurs in a particular region, ecosystem, and habitat without direct or indirect human actions". "Native plants are valued for their economic, ecological, genetic, and aesthetic benefits in addition to the growing societal belief in their intrinsic value as living species". "Native plant species provide the keystone elements for ecosystem restoration" (Dorne, Jeanette). Such plants are also ideal for rain gardens because they are use to the condition/soil/weather of their area and grow in those conditions without the help of humans; meaning that these plants are very self-sustaining.

Going a step into native plants we have the native plants that are perennials. "Perennials are considered to be ornamental plants that do not die after one season of growth" (Iannotti, Marie). These plants regrow using the same seed once they "die" in the wintertime. This is great for a rain garden because it creates less need for maintenance, making the garden even more self-sustainable; perennials keep the garden working for a few years before needing to be re planted. In the end the longer the garden lives the longer it is affective.

### 3.5.2: Plant Selection Methods

The way we went about organizing all the native perennial plants found is through a plant guide and also by creating one big table. The different categories on this table include plant name, type, pH, minimum temperature in Celsius, blooming season, and the amount of water use for each plant.

The pH is important because the plants pH must match the soils' because "Placing plants in garden soil that does not match their pH needs can weaken the plants by: making them more susceptible to plant diseases and insect infestations, causing the plant to grow more slowly and have a smaller yield, reducing the amount of nutrients being passed from the soil to your fruit, herbs or vegetables" (How to Garden Advice). Minimum temperature is on the table to figure out if the plants will survive the harsh winter of the northeast. As much as hardiness is a big factor on plant selection so are the blooming seasons; you want the garden to be alive through out the year so selecting plants that bloom all at the same time is a bad choice. Lastly plants with a high water intake are a given in a rain garden because they are meant to absorb as much runoff as possible. This table can be seen below in Table 7.

| | | Plant | Type | PH | Min Temp C | Blooming | Water Use |
|---|---|---|---|---|---|---|---|
| Partial Shade | Lower Water Section | Dwarf Folthergilla | shrub | 5.6-6.5 | -28.8 | Feb-May | high |
| | | Witch Hazel* | tree/shrub | 5.6-7.5 | -39.9 | Sept-Dec | medium |
| | | Rhododendron Canadense* | shrub | <6.8 | -45.5 | Apr-May | high |
| | | Red Twig Dogwood* | shrub | 6.1-6.5 | -39.9 | May-June | medium |
| | Herbaceous | Purple Joe-Pye Weed | herb | ? | ? | July-Sept | medium |
| | | Harlequin blueflag* | herb | 6.1-7.8 | -34.4 | May-Aug | medium |
| | | Cardinal* | herb | 6.1-7.8 | -45 | July-Sept | high, medium |
| | | Interrupted Fern | herb | 6.1-7.8 | -39.9 | June | high |
| | | Greek Valerian* | herb | 6.8-7.2 | -39.9 | April-June | medium |
| | Medium Range-Medium Moisture | N. Maidenhair Fern | Fern | 6.1-7.5 | -39.9 | - | medium |
| | | Eastern Red Columbine | herb | 6.1-7.5 | -39.9 | Feb-July | medium, low |
| | | Fringed Bleedingheart* | herb | 5.6-7.5 | -39.9 | Mar-Oct | medium |
| | | Fringed Bluestar* | herb | ? | ? | Mar-June | medium |
| | | Wild Geranium | herb | <6.8 | -39.9 | Mar-July | medium |
| | | Woodland Phlox | herb | 5.6-7.5 | -39.9 | Mar-May | medium |
| | | Indian Pink* | herb | 6.1-6.5 | -28.8 | Mar-May | medium |
| | | Labrador Violet* | herb | 5.6-7.5 | -39.9 | April-June | medium |
| | | Golden Alexander* | herb | 6.1-7.5 | -34.4 | April-Aug | high, medium |
| Shade | | Dolls Eye | herb | 5.1-6.5 | -34.4 | April-June | needs moist soil |
| | | Purple giant hyssop* | herb | - | -34.4 | June-Sept | - |
| | | Apios Americana* | vine | 5.6-7.5 | -31.6 | May-Sept | medium |
| | | Bluebell bellflower* | herb | 6.6-7.5 | -28.8 | June-Sept | - |
| | | Lanceleaf coreopsis* | herb | ? | ? | April-June | medium |
| | | Roundlobe hepatica* | herb | <6.8 | ? | Mar-April | low, medium |

**Table 7: List of Potential Native Perennial Plants**

Using a plant list of recommended rain garden plants from the New England Wild Flower Society we created the table above. We used the NEWFS as a reference because they also constructed a rain garden, which ended up being very successful for them. Once this table was set up we used common gardening databases, (www.wildflower.org and http://davesgarden.com/#b) to get the information stated above.

One of the key aspects that need to be noticed from this table will have to be the pH. In any garden you want the pH range of the plants to be similar. Through out all these plants the common pH range is 6.1-6.5. Another important aspect to notice is the water use. We only included plants that have medium to high water intake because those are the best for absorbing the standing water that lasts around 24-48 hours (Gardening with Water Quality in Mind). Taking a look at the minimum temperature, it is clear to that all the plants are between -

28 to -45 Celsius, which easily survives the cold temperature of Worcester. After this table was finalized we went through it one more time to pick plants that looked good and marked them with an asterisk next to their name.

"There is healing power in flowers — and in trees, fresh air and fragrant soil. Just strolling through a garden or, for that matter, seeing one out your window, can lower blood pressure, reduce stress and ease pain, studies show" (Painter, Kim). It is crucial for the garden to be aesthetically appealing because if it looks nice then it will keep people within the community interested and attached to it. If people are interested in it then they will spread the word about it, which further helps, our dissemination plan. Kim Painters statement compliments the idea of having something beautiful to look at makes you a happy person all together.

### 3.5.3 Plant Selection Results

In order to get the best combinations of both aesthetically appealing and plants that work well together, we had to look thoroughly through our plant guide in Figure 3.13. We chose plants within a pH level of 6.1 and tried to spread the blooming seasons around. For our designs, we decided to use the following plants;

- Red twig dogwood
- Rhododendron Canadense
- Cardinal Flower
- Harlequin Blueflag
- Golden Alexander
- Fringed Bluestar
- Indian Pink

- Lanceleaf Coreopsis
- Roundlobe Hepatica
- Dolls Eye
- Apios Americana
- Purple Giant Hyssop

The reason we chose these plants is because they all matched up with pH and all have high water intake, but what sold us is that all the different colors look great together when mixed properly.

Now that we have concluded our testing and gathered results for both the soil and water testing, analyzed the site and selected out plants we are ready to go a step further. In the next chapter we will focus on the three aspired designs that we have put together to alleviate storm water run off here at WPI.

## Chapter 4: Designs for a Rain Garden on the WPI Campus

We designed three alternative designs that considered aesthetic appeal, shape, surface area, and drainage methods. It is important to be flexible in the design aspect because it will serve as a model to the broader community and should be appealing to a wide spectrum of people as well as different scenarios that need to be remedied. The three designs include a regular depressed rain garden, a berm, and porous concrete. We will go into detail on each of these designs and in the end we will recommend the first proposed design as the one that should be implemented here at WPI and explain why we thought it was the best one.

### 4.1: Depressed Rain Garden Design

First thing that came to mind for a design was a traditional orthodox rain garden. A traditional garden is “A rain garden, typically 18 to 24 inches of soil is removed and altered with tillage, compost and sand to increase water infiltration” (The Ground Water Foundation). In other words you pick your land, dig down, and insert good absorbent soil along with native plants. Our land between the library and Fuller can accommodate such design, but we have to put a minor change to it. Since most of the run off from the road will not go down the slope naturally we must insert a drain before the sewer drain to divert the water under the sidewalk and towards our garden. This process can be seen in Figure 12.

**Figure 12: Depressed Rain Garden Design. Plants: 1) red twig dogwood 2) rhododendron**


**canadense 3) cardinal flower 4) harlequin blueflag 5) golden alexander 6) fringed bluestar 7) indian pink 8) lanceleaf coreopsis 9) roundlobe- hepatica 10) purple giant hyssop.**

The way we will do such a thing is with a catch basin. “Catch basins have a wide sloping inlet which collects runoff, assuring that even when high volumes of water are being dumped into the system, there is minimal overflow. The inlet opens to a pipe, which is covered with a grating. The grating traps large debris, preventing it from entering the piping. As water floods the catch basin, small particles, which slip through

the grate, settle to the bottom. Drainage pipes are located above the bottom of this vertical pipe, ensuring that the water which flows into the drains is clear of sediment" (wiseGEEK). Our catch basin will work similarly but instead of water being dumped into the sewer the pipe will run under the side walk and out to our rain garden as seen in Figures 12,13, & 15.

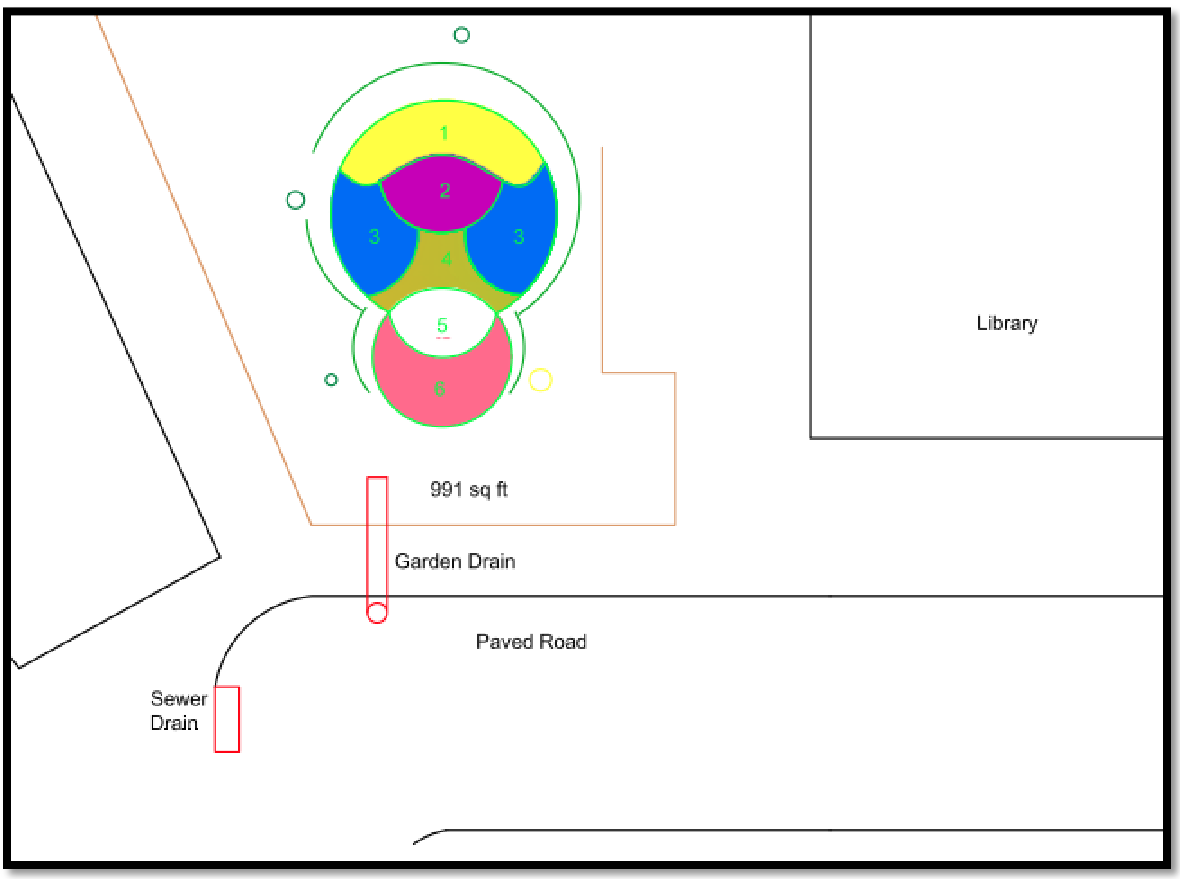
This design is great because it follows the 3:1 (run off area to garden surface area) ratio suggested for rain gardens. This means that the garden has to be 1/3 the size of the impermeable runoff area in order to be able to contain the storm water. We measured the paved road and calculated to be around three thousand square feet. After surveying the land and implementing that into AutoCAD we were able to get the surface area for the garden, which was around ten thousand and thirty six square feet, which follows the 3:1 ratio suggested.

Another thing to notice are the different colors. The colors in each section of the rain garden represent the color of the plants that will be implemented in that section just to give and idea of how it will physically look. Each of the plants selected are all native perennials, which thrive and grow best in shady regions. These perennials can also take in high to medium amounts of water, which is great for when absorbing the sitting water that stays on top of the garden for 24-48 hours, getting ready for the next rainfall.

### 4.2: Berm Rain Garden Design

Utilities underground our site may be an issue and not allow us to dig, our next design will be able to remedy this problem with a berm. A berm is when a landscape is built up. So in a sense we will have to add soil on top of the ground and then dig the depression out. Berms are also needed for regular rain gardens as well. “Rain garden surfaces need to be level and a berm approximately the height of the depth of the garden should be constructed around the bottom 2/3 – 3/4 of the garden. The berm holds water in the garden during rainstorms” (Lake Superior Streams). Our suggested design looks like the following in Figure 13.

**Figure 13: Berm Rain Garden Design. Plants: 1) witch hazel 2) rhododendron canadense 3) fringed blue star 4) white baneberry 5) Apios Americana. The berm will be elevated 18-24”**




**above the ground level.**

Due to the fact that the berm will be elevated about two feet this will allow us to dig into the berm. By doing so we will not penetrate the existing land to implement the rain garden, hence not threatening to penetrate the utilities.

As seen in Figure 13, the surface area is also vey close to the 3:1 ratio that was a part of the first design, which shows to us that this can also be a sufficient garden design. In order to divert the water to the garden the same drain design will be used as in the previous design.

As far as the plant selection goes we added the following different plants such as the Witch Hazel, White Baneberry, and the Apios Americana. Though these plants are a different species they are still all native perennials with a high intake of water that can survive in shady conditions such as our site by the library.

**4.3: Porous Concrete Rain Garden Design**

Our final design is a little out of the box when one thinks rain gardens. Instead of having all the water diverted towards the garden through the drain we will install porous concrete on the side of the road all the way down to the pipe were most of the runoff is located.

Porous concrete like conventional concrete is made from a mixture of cement, coarse aggregates, and water. However, it contains little or no fine aggregates like sand,

which results in a porous open-cell structure that water passes through readily (Concrete Network). Villanova University has also explained and tested porous concrete; “Pervious concrete mix lacks the sand and other fine particles found in regular concrete. This creates a significant amount of void space, which allows water to flow relatively unobstructed through the concrete.” Villanova University has been the top researcher of such concrete and they have a sight on campus that uses it. “The site is designed to capture and infiltrate storms of up to two inches of rainfall.  From these events there is virtually no runoff from the site” (Villanova University).

**Figure 14: Porous Concrete Demonstration**

This concrete put on the side of the road closest to the library were water accumulates will be very affective when tag teaming with a rain garden. Whatever water left from the pavement will enter the catch basin and then be absorbed by a smaller scaled rain garden. This can definitely help reduce storm water run off from entering the pipe by Fuller Labs, and it also can allow for a smaller rain garden at our site. This garden well be around half the size of what we originally planned and we would mostly have it their for demonstration purpose due to the fact that porous concrete consumes a high percentage of storm water.

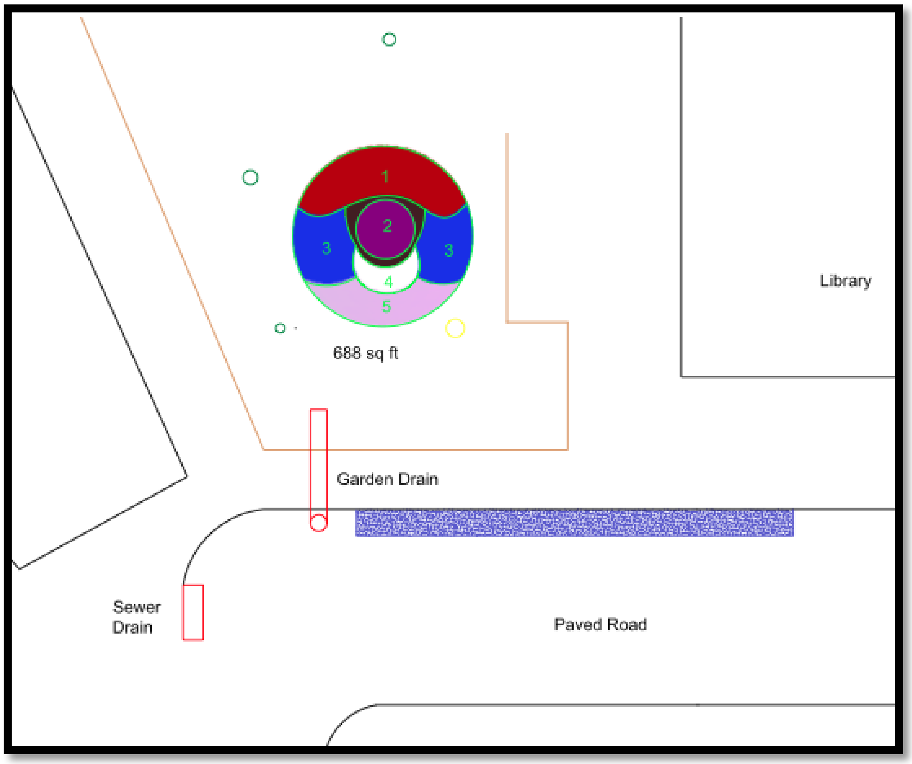



**Figure 15: Porous Concrete Rain Garden Design. Plants: 1) red twig dogwood 2) rhododendron canadense 3) fringed blue star 4) white baneberry 5) apios Americana. The blue rectangle on the road is were the porous concrete will be placed.**

The only negative that has been considered with this design is the fact that it snows a lot here in the North East. The problem with this is that sand is put down after snowstorms. These sand particles would then clog up the wholes in the concrete and possibly not allow the water from passing through it.

### 4.4: Design Results and Decision

Taking into consideration plants, drainage systems and other aspects we feel very content with the three designs produced. We feel that each of these designs can be used in our location and are looking forward to seeing one of them being implemented in the future. We emailed Chris Salters, part of the facilities team at WPI, and he said digging down two feet will be fine and it won't disturb any of the schools utilities. This tells us that the berm design is not the only option available and that our sponsor can consider all of them while making her decision of what rain garden shed like to implement.

We mostly recommend the first proposed rain garden design seen in Figure 12 due to the fact that there should be no problem with utilities and that we are not 100% positive the porous concrete will be able to do it's job in the New England snow storms. It also follows the 3:1 ratio mentioned earlier so we feel it will be able to remedy the problem just fine.

Another reason we chose the first design is because it is the most common type of rain garden. The community and homeowners can implement this garden with a lot more ease due to its simplicity. Building a berm or adding porous concrete is a little to advanced for a regular family to look into and create on their property on their free time.

### 4.5: Conclusion

Now that the regular rain garden design, berm design, and porous concrete design have been presented we hope that the idea for each is clear. If looking into the implementation plan is sought after that can be found in Appendix D. Since these designs are complete we are now ready to move on to the dissemination plan, which will allow us to spread the word about our rain garden to the community.

## Chapter 5: Dissemination of the WPI Campus Rain Garden

The construction of a rain garden on the WPI campus is desired, in part, in order to reach out to the community and show an example of the potential benefits and relative ease of such a sustainable landscape design. The greater Worcester community sees constant issues with the negative effects of storm water runoff. Streets are constantly flooding due to the failure and clogging of street drainage systems. High quantities of impermeable surfaces, such as concrete and asphalt, limit the areas that can naturally and properly absorb the rainwater. This has lead to the general degradation of the ideas of runoff management throughout the city. However, the creation of a rain garden that can be easily displayed to the surrounding community and can act as a teaching tool would help to greatly increase the awareness of the local issues. An understanding of why sustainable landscapes are needed, how they work, and what exactly that does for the environment are vital steps that can all be achieved through such a process. Having such knowledge is the first step that would allow individuals and organizations to work towards projects like rain gardens, in the hopes of doing their small part to protect the environment.

### 5.1: Campus Involvement

The dissemination of the construction of a rain garden on the WPI campus can be achieved in means both before and after the building of the rain garden. The involvement of on-campus organizations, even before the construction of the rain garden, can help to bring a greater sense of awareness to the WPI community. In meeting with the heads of Camp Reach, great interest was shown in basing an educational project around the rain garden. Though not given an official agreement, Camp Reach has given a verbal commitment to offer some sort of partnership in the rain garden to act as an educational boon for the high school girls that are part of the program. WPI’s Green Team has shown interest in the project and has helped to offer several valuable resources to the continuation of this project. The head of the Green Team, Liz Tomaszewski, offered contact information on a group of students working on the implementation of a similar project at Clark University. In both cases, a better understanding of rain gardens can be taken from something as simple as an information stand, or a presentation given to the team members on our findings. Similar to our final presentation, this would give background on the effects of storm water runoff both in the general community, and at WPI itself. They would then learn about such aspects of the design as site and plant location, and why these are important steps to the overall picture. The AutoCAD designs and visualizations of our design would serve as a closing of the gap between concept and actuality. Members of groups such as the Green Team and Camp Reach are constantly looking into environmental projects to further their pursuits. We believe that sharing the concept of our rain garden on WPI would be beneficial, and perhaps inspirational, to both groups.

**5.2: Information Stand**

One idea for the dissemination of a rain garden built on the WPI campus would be to position a plaque or stand at the location of the garden itself, found in Appendix E. This stand, similar to the information signs posted in zoos and National parks, would explain what a rain garden is and how it works. Also, a diagram will be presented, representing the rain garden and giving some information about each plant present and how they can limit the storm water runoff. This will help to give a sense of purpose to the garden. If passersby merely see a garden on a hill and take it as a visual addition, then the basis of the project is flawed. However, if these people see a garden with a description and diagrams of the resulting minimization of storm water runoff, then this garden can hopefully drive home the point of sustainability. There are several possible designs for rain gardens – as such, there will be several different proposed sign designs to reflect that notion. Placing this plaque next to the sidewalk, were campus' tours passes by, the tour guides will be able to throw out a pitch about the rain garden and by doing so spreading the word outside of the WPI and even the Worcester community.

### 5.3: Conclusion

Groups of the WPI campus that work to learn about sustainability and the environment can use the construction or design of the rain garden on campus as an at-hand example of the implementation of green infrastructure and its form and function. Along with the Green team and members of Camp Reach, organizations such as the President's Task Force on Sustainability and the Frontiers program are always looking for ways to get involved in programs on campus and learn more in the field of sustainability and the environment. Frontiers, starting on July 8th this upcoming summer, will be holding a program on advances in biochemistry and environmental engineering this year. Frontiers is a program that could work to build off the ideas in the rain garden design towards their own sustainable landscape designs.

## Chapter 6: Constructing the Rain Garden – What Comes Next?

The information provided in the previous chapters is intended to provide the reader with a better understanding of the issues regarding storm water runoff in Worcester, an in-depth explanation of how green infrastructure can be used in conjunction with gray infrastructure, and a step by step outline of how to go about utilizing green infrastructure in the form of a rain garden to remedy storm water runoff issues. The benefits of instituting green infrastructure can be seen both in a monetary and aesthetic sense. The construction of a rain garden on the WPI campus should serve as a model to the Worcester community in an effort to disseminate the motive of sustainability beyond the walls of WPI. In continuation of this project we hope to work with a program through WPI that brings members of the wider community to campus to actually construct the rain garden. We hope that through this process, people will be provided with a hands-on experience that will enhance their understanding of the benefits of rain gardens and motivate them to build their own.

Further research on this project can take into consideration different methods by which to divert storm water runoff to the desired rain garden locations, options for plant sources in an effort to reduce the cost of construction, and also, other methods by which to disseminate the use of rain gardens to the wider community.

In an effort to move forward with this project it is our home to remain in contact with the directors of Camp Reach and members of the Facilities Department at WPI to coordinate the implementation process of the rain garden at WPI. As pricing is a crucial aspect in determining the feasibility of constructing the garden, further efforts would have to be made in conjunction with Facilities at WPI in order to ensure the best value for every aspect of implementation is achieved. We hope that sufficient information has been provided within this report in order to allow progression to the next piece of the project: implementation.

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# APPENDICES

**APPENDIX A:**

School Map

Pictures of Each Site

Site Grading Chart & Explanation Sheet

Blueprint of Location & Marked Blueprint

Preliminary AutoCAD Design

**APPENDIX B:**

Water Testing Results

Soil Testing Results

**APPENDIX C:**

Plant Listing

WPI's Proffered Plant Nurseries

Pricing of Plants & Materials

**APPENDIX D:**

Implementation Instructions

**APPENDIX E:**

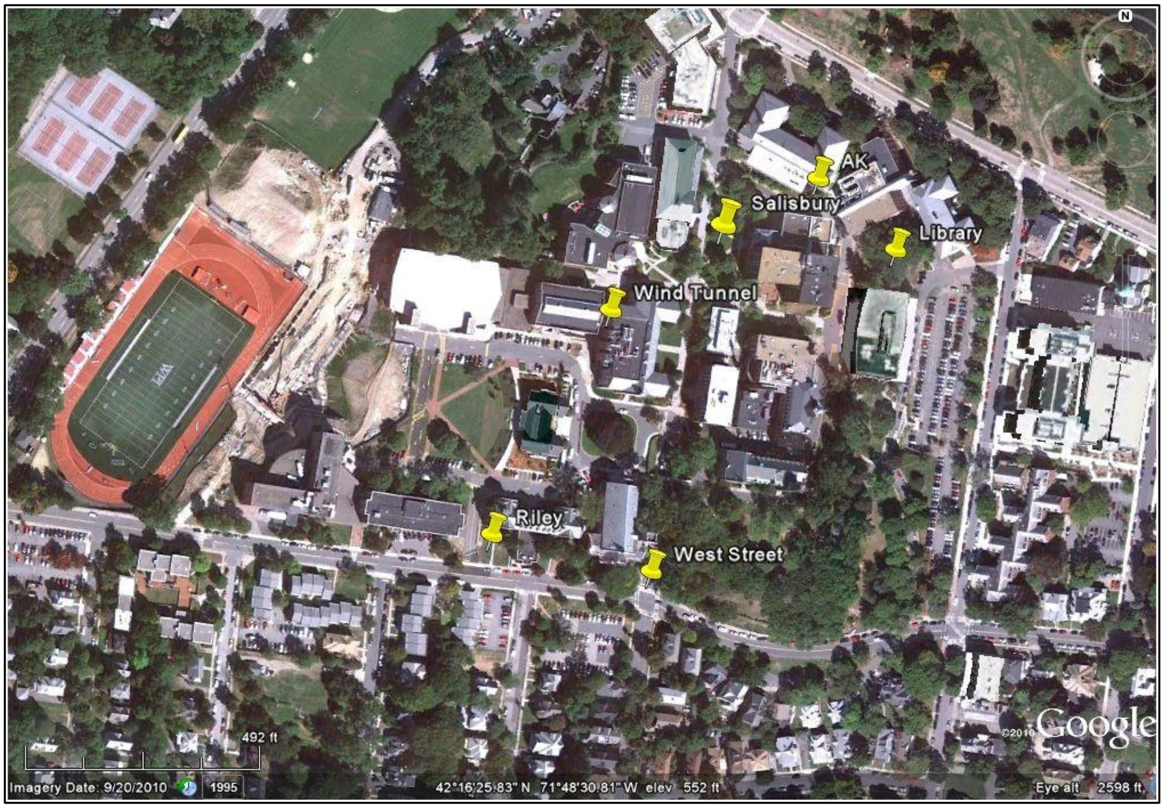
Sample Site Explanation Stand

**APPENDIX F:**

Sustainable Landscape Design: The Presentation

Contact Information

**APPENDIX A:**




**Appendix A- Figure 1:** An overhead view of the WPI campus and surround community. The six points highlighted in yellow are the sites around campus that were originally selected to be examined for the possibility of hosting a rain garden. The six locations depicted are: outside the back of Riley Commons, along the West Street corridor, in the Wind Tunnel between Higgins Laboratories and Alumni Gymnasium, outside of Salisbury Laboratories, outside of Atwater-Kent, and between Gordon Library and Fuller Laboratories.

**Appendix A- Figure 2:** Shown here are photos of each of the potential rain garden locations. Shown in order are: along the West Street corridor, between Gordon Library and Fuller Laboratories, outside of Atwater-Kent, outside of Salisbury Laboratories, in the Wind Tunnel between Higgins Laboratories and Alumni Gymnasium, and outside the back of Riley Commons.

| | 7 | 10 | 6 | 10 | 5 | 7 | 5 | 50 |
|---|---|---|---|---|---|---|---|---|
| **Location** | **Slope** | **Visibility** | **Light** | **Pooling** | **Area** | **Build-ability** | **Proximity** | **Total** |
| Library | 6 | 10 | 3 | 8 | 5 | 6 | 5 | 43 |
| AK | 7 | 8 | 4 | 8 | 2 | 4 | 3 | 36 |
| West St | 7 | 10 | 3 | 7 | 0 | 0 | 5 | 32 |
| Salisbury | 7 | 10 | 6 | 4 | 4 | 7 | 5 | 43 |
| Wind tunnel | 1 | 10 | 2 | 8 | 2 | 1 | 1 | 25 |
| Riley | 7 | 7 | 6 | 7 | 4 | 6 | 5 | 42 |

**Appendix A- Figure 3:** Shown here is the grading chart that was adopted to rank each of the locations that were selected. In choosing a location on the WPI campus, there were several criteria that we evaluated in order to determine the most usable and effective space. As you can see, the seven categories include the slope, capacity for water pooling, area, lighting, and visibility of the location, as well as the proximity of the location to neighboring buildings and utilities, and the ease of construction at the site. Each category was given a certain maximum value, reflecting it's importance. For example, the ability of the garden's location to pool water effectively, allowing for proper absorption, is much more important than it's proximity to a building. This is due to the fact that most of these locations would be far enough away from surrounding buildings and utilities in the first place to prevent overflow into the foundations. The only true exception to this would be the implementation of a rain garden in the wind tunnel, which would result in a design right up against the buildings. Following is an explanation of each of the grading categories:

**Slope-** Twelve percent is the ideal slope for a rain garden. This is recommended because at this slope water is able to flow without over powering the garden.

**Visibility-**For our project visibility to the student body/public is key because it is meant to be used as a demonstration site to the community we live in.

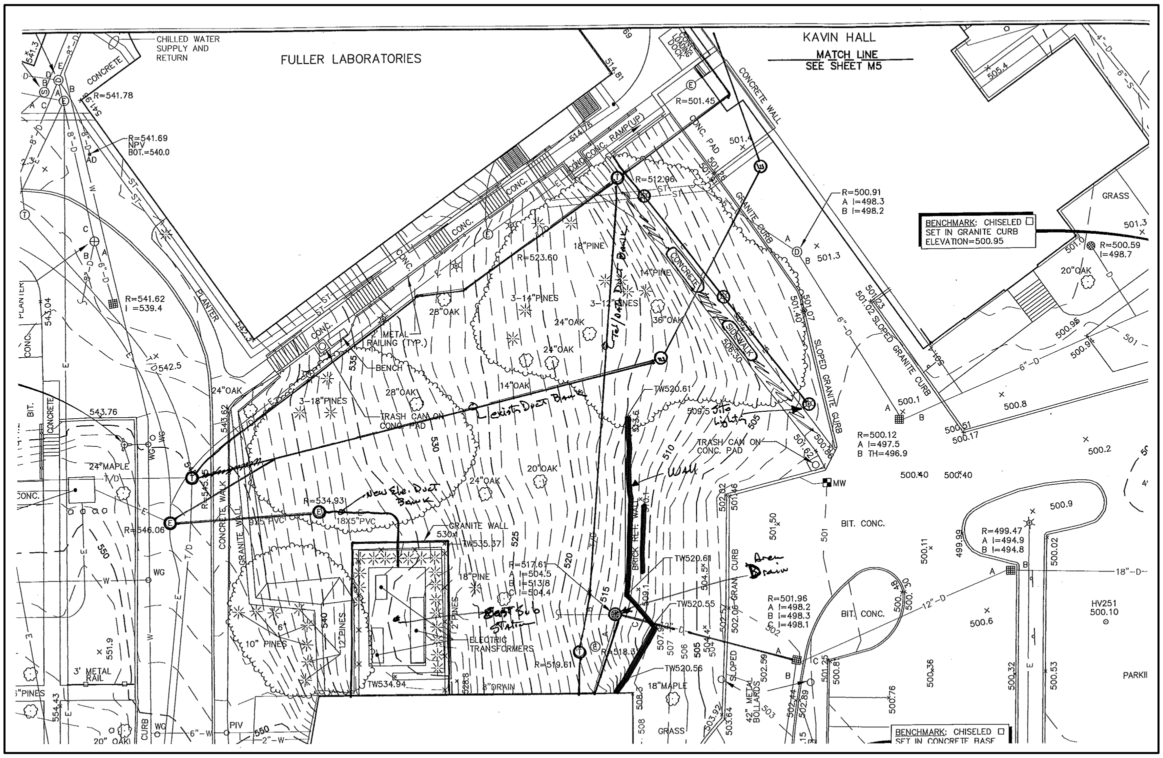
**Light-**Light is a very important factor in growing plants. There are a lot of spaces on campus with trees and tall buildings that shadow the land, hence plants were found that can grow in partial shade.

**Pooling-** The amount of water that accumulates on the designated sites or flows through them. The point of this garden is to stop the pooling from occurring and **entering into** the drain sewers.

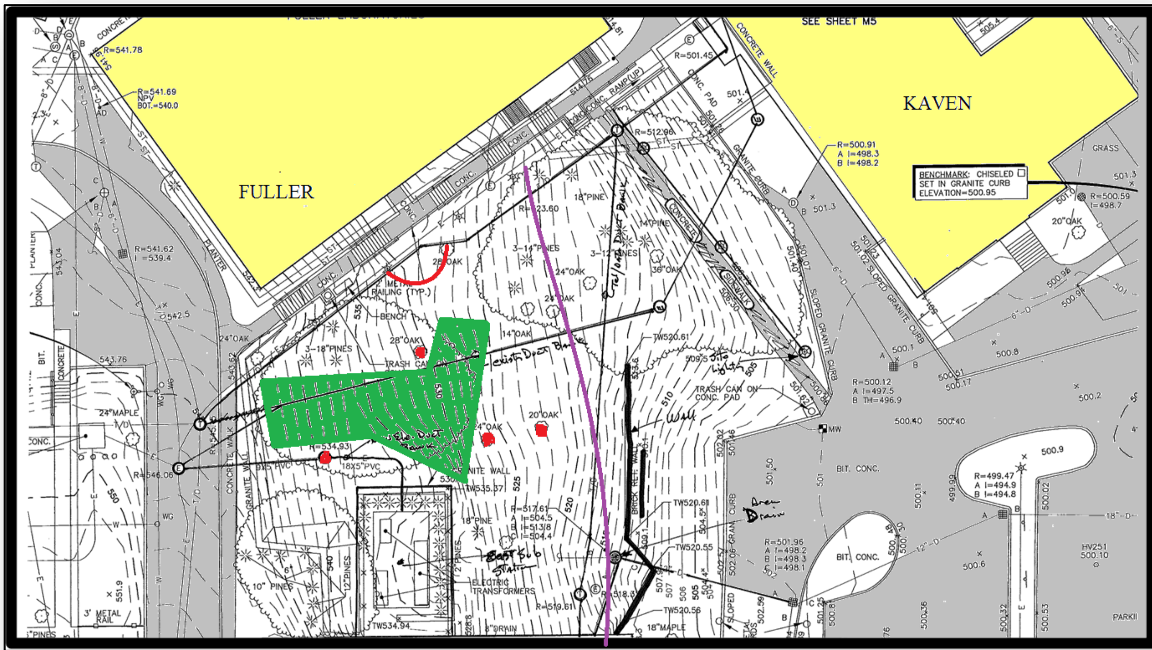
**Area-** This category takes into account the amount of usable land that is available to be worked with. With more land available, there are more possible designs and styles of rain gardens that could be implemented. Also, the general shapes of the designated areas were taken into consideration, as certain figures (such as rectangles) are far more effective than others (such as long, snaking parcels of land).

**Construction -** This refers to the ease of several aspects of building on the land. These include the need (or lack thereof) for the diversion of water, the removal of substances such as asphalt, and the installation of new drainage systems.

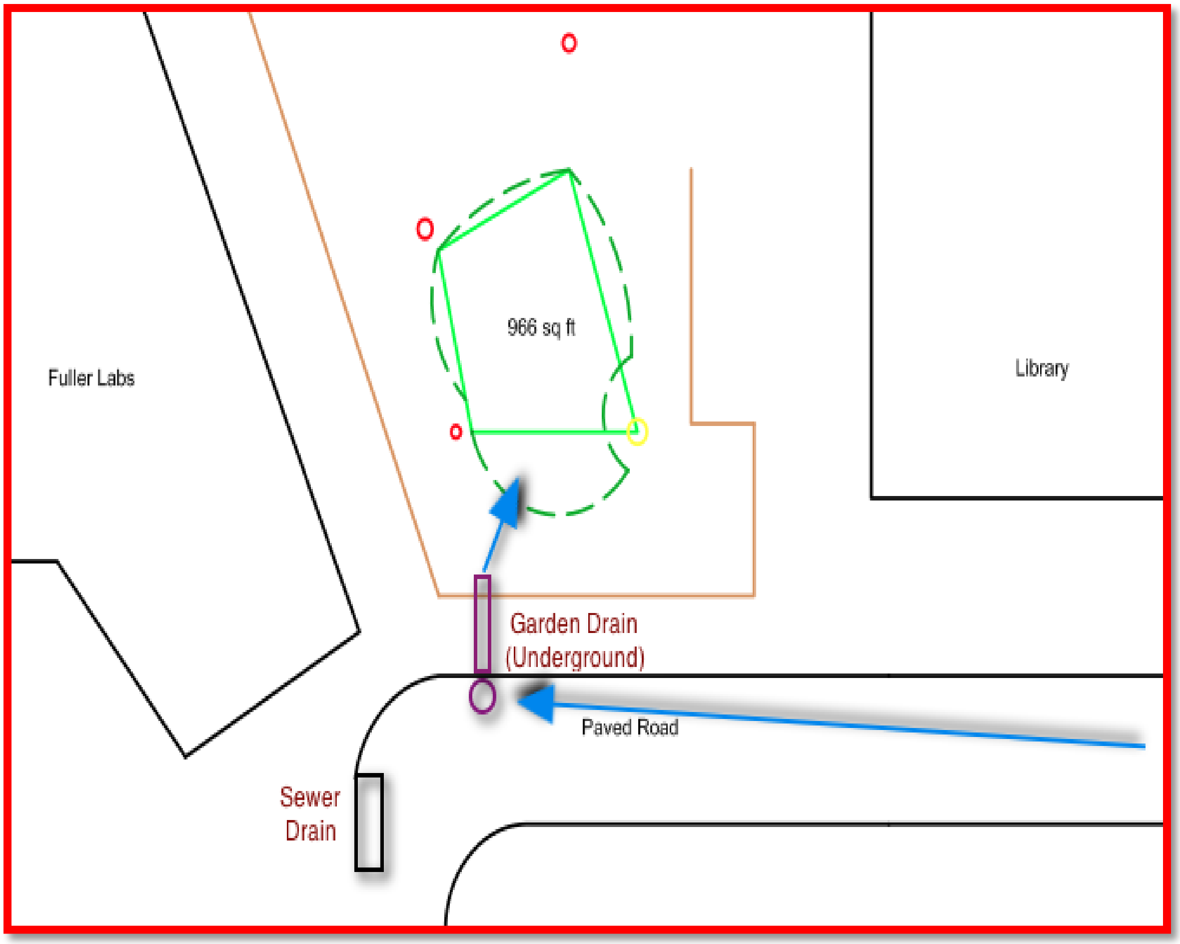
**Proximity-** This refers to the relative distance to a building. This category is important because there are limitations on how close to a building a rain garden can be built. It should be approximately 10 feet  away from the foundation.




**Appendix A-Figure 4:** Shown here is the building and utilities blueprint, courtesy of WPI utilities manager Christopher Salter. This topographical map represents the elevations changes, dimensions, and constructed apparatus of the are selected for the building of a rain garden.




**Appendix A-Figure 5:** Shown here is an overhead view of the location we selected to design our rain garden. Shaded in yellow are Fuller Laboratories and Kaven Hall for reference. The grey areas on the map highlight all some of the impermeable surfaces in the area, namely pavement and sidewalks. Also of note are the rooftops of the buildings. The dotted lines here represent the change in elevation across the area. Due to the increase in the slope near the bottom of the hill, represented by the area right of the vertical purple line, we chose to locate designs towards the top of the land. Also, this area is closer to the aforementioned runoff water from the access road. Shown in green on the map is an outline of the area that we deemed would be most appropriate to build the rain garden.




**Appendix A-Figure 6:** Shown here is the preliminary design of the rain garden to be implemented on the WPI campus between Gordon Library and Fuller Laboratories. This AutoCAD depiction shows the measured area best suited for the building of such a rain garden from initial surveying, shown on the map by the green square. This area is approximately 966 square feet. The dotted green shape represents the largest area of usable land in order to make the rain garden most effective. A rain garden design based off of this area would be in the range of 1050 – 1100 square feet.

**APPENDIX B:**

Microbac®

**Microbac Laboratories, Inc.**

Massachusetts Division

100 Barber Avenue • Worcester, MA 01606

Phone: 508-595-0010
Fax: 508-595-0008
www.microbac.com

**CERTIFICATE OF ANALYSIS**

| | | |
|---|---|---|
| MASS. WALK-IN 4TH Q 2011 | Project: Karen Oates | Report: 1127184 |
| 100 Institute ROad | Project Number: Oates | Reported: 11/23/2011 08:53 |
| Worcester, MA 01609 | Project Manager: Karen Oates | |

**OUTSIDE DRAIN**

**1127184-01 (Stormwater) Sampled: 11/10/2011 14:00; Type: Grab**

| Analyte | Result | Reporting Limit | Units | Prepared | Analyzed | Analyst | Method | Notes |
|---|---|---|---|---|---|---|---|---|
| **WET CHEMISTRY (MASSACHUSETTS DIVISION)** | | | | | | | | |
| Nitrate as N | ND | 0.400 | mg/L | 111111 1455 | 111111 1455 | HCL | SM 4500-NO3-E | |
| **Phosphorus, P** | **4.71** | 0.0100 | mg/L | 111611 1200 | 112211 1200 | HCL | SM18 4500-P B, E | |

**Notes and Definitions**

ND Analyte NOT DETECTED at or above the reporting limit

dry Sample results reported on a dry weight basis

**Certifications**

*Below is a list of certifications maintained by Microbac Laboratories, Inc. All data included in this report has been reviewed for and meets all project specific and quality control requirements of the applicable accreditation, unless otherwise noted. A complete list of individual analytes pursuant to each certification below is available upon request.*

Massachusetts DEP M-MA003
Massachusetts DPH State Dairy Laboratory 0056

*The results in this report apply to the samples analyzed in accordance with the chain of custody document. This analytical report must be reproduced in its entirety.*

Nancy Burnett

Nancy Burnett, Laboratory Director

For any feedback, please contact Nancy Burnett, Laboratory Director. You may also contact Sean Hyde, Chief Operating Officer at sean.hyde@microbac.com or James Nokes, President at james.nokes@microbac.com.

Page 1 of 2

**Appendix B-Figure 1:** These are the results of water quality testing reports, received back from Microbac Laboratories in nearby Worcester. This test was conducted to examine levels of harmful Nitrates and Phosphorous in the water. The tests revealed no pertinent levels of Nitrates in the water, yet a moderate amount of Phosphorous. The sampled water was taken from the drainage culvert outside of Fuller Laboratories, adjacent to the selected rain garden site.

| Micronutrient | PPM | Soil Range |
|---|---|---|
| **Boron (B)** | 0.5 | 0.1-2.0 |
| **Manganese (Mn)** | 0.7 | 3-20 |
| **Zinc (Zn)** | 3.1 | 0.1-70 |
| **Copper (Cu)** | 2.2 | 0.3-8.0 |
| **Iron (Fe)** | 12.7 | 1.0-40 |
| **Sulfur (S)** | 12.5 | 1.0-40 |

| Soil pH | **5.7** |
|---|---|
| **Buffer pH** | 6.7 |
| **Nitrogen : NO3-N** | 0 ppm |
| **Organic Matter** | 4.3% (Desirable range 4-10%) |

| Nutrient Levels | PPM | Low | Medium | High | Very High |
|---|---|---|---|---|---|
| **Phosphorus (P)** | 4 | XXXXXXX | | | |
| **Potassium (K)** | 95 | XXXXXXXXXXXXXXXXXXXXXXXXX | | | |
| **Calcium (Ca)** | 684 | XXXXXXXXXXXXXXXXXXXXXXX | | | |
| **Magnesium (Mg)** | 173 | XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX | | | |

SOIL ANALYSIS REPORT FOR ESTABLISHED TURF 11/21/11

SOIL AND PLANT TISSUE TESTING LAB
WEST EXPERIMENT STATION
UNIVERSITY OF MASSACHUSETTS
AMHERST, MA 01003

LAB NUMBER: S111116-101
BAG NUMBER: 104560

SOIL WEIGHT: 5.38 g/5cc
CROP: EXISTING LAWN

NIKOLE STONE
155 HIGHLAND ST, APT #1
WORCESTER, MA 01609

COMMENTS: NCSTONE@WPI.EDU

SAMPLE ID: SUSTAINABLE LANDSCAPE

---

LIMESTONE AND FERTILIZER RECOMMENDATIONS FOR ESTABLISHED TURFGRASS

Apply 50 lb of calcitic limestone/1000 sq ft.
Lime may be applied at any time, but mid-autumn or early spring is best.

Recommendation: 2 lb/1000 sq ft P2O5, and 2 lb/1000 sq ft K2O.

To provide the above recommendation you may follow the directions below, or you may devise your own fertilizer program using the recommended amounts of phosphorus (P2O5) and potassium (K2O) along with one pound of Nitrogen per 1000 sq feet. It may necessary to raise nutrient levels over several applications.

SAMPLE ID: SUSTAINABLE LANDSCAPE

---

LIMESTONE AND FERTILIZER RECOMMENDATIONS FOR ESTABLISHED TURFGRASS

Apply 50 lb of calcitic limestone/1000 sq ft.
Lime may be applied at any time, but mid-autumn or early spring is best.

Recommendation: 2 lb/1000 sq ft P2O5, and 2 lb/1000 sq ft K2O.

To provide the above recommendation you may follow the directions below, or you may devise your own fertilizer program using the recommended amounts of phosphorus (P2O5) and potassium (K2O) along with one pound of Nitrogen per 1000 sq feet. It may necessary to raise nutrient levels over several applications.

Apply a 20-3-12 fertilizer @ 5 lbs/1000 sq ft in late April, late June, and very late August.
If more convenient you may substitute the late April recommendation with the same application made 1 to 2 weeks after your last fall mowing.
In addition apply superphosphosphate (0-20-0) @ 5 lbs/1000 sq ft in very late August.
Following year apply a 30-3-3 fertilizer @ 3 lbs/1000 sq ft at the three application dates given above.
Include another late August superphosphate application.
Retest in two years.

Consult the interpretation sheet enclosed or obtain one of the Turf Guides referenced on the backside of the interpretation sheet.

| MICRONUTRIENT | | PPM | SOIL RANGE | MICRONUTRIENT | | PPM | SOIL RANGE |
|---|---|---|---|---|---|---|---|
| Boron | (B) | 0.5 | 0.1-2.0 | Copper | (Cu) | 2.2 | 0.3-8.0 |
| Manganese | (Mn) | 0.7 | 3 - 20 | Iron | (Fe) | 12.7 | 1.0- 40 |
| Zinc | (Zn) | 3.1 | 0.1- 70 | Sulfur | (S) | 12.5 | 1.0- 40 |

```
---------------------------------------------------------------------------------
  SOIL pH    5.7          NITROGEN: NO3-N =    0 ppm
  BUFFER pH  6.7          ORGANIC MATTER:  4.3 % (Desirable range  4-10%)

NUTRIENT_LEVELS:_PPM_|______Low___Medium__________High_______  Very High
Phosphorus (P)     4 |XXXXXX
Potassium  (K)    95 |XXXXXXXXXXXXXXXXXXXXXX
Calcium    (Ca)  684 |XXXXXXXXXXXXXXXXXXXXX
Magnesium  (Mg)  173 |XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

CATION EXCH CAP       PERCENT BASE SATURATION          MICRONUTRIENT LEVELS
    7.5 Meq/100g        K= 3.1 Mg=17.5 Ca=42.4           ALL NORMAL

EXTRACTABLE ALUMINUM:   61 ppm  (Soil range: 10-250 ppm)

The lead level in this soil is low.


VISIT www.umass.edu/soiltest  FOR FURTHER INFORMATION ON SOIL TESTING AT UMASS.
```

**Appendix B-Figure 2:** Here are the soil tests results from the University of Massachusetts Soil and Plant Tissue Testing Laboratory. With a pH of 5.7, there will need to be several pounds of lime added to the soil in order to increase the pH to a desirable range of about 6.1-6.5. As shown in the second part of the chart, the organic composition percentage of 4.3 falls in the desirable range, and all the macronutrients are in regular amounts. There are decently high levels of potassium, calcium, and magnesium, but they are in controllable and healthy amounts.

## APPENDIX C:

### PLANT LISTING

### A Partial Listing of Plants to be Suitable for Growth in a Rain Garden at WPI

A. Partial Shade

- i. Lower Water Section
    1. Dwarf Folthergilla
    2. Witch Hazel
    3. Rhododendron Canadense
    4. Red Twig Dogwood
- ii. Herbaceous
    1. Purple Joe-Pye Weed
    2. Harlequin blueflag
    3. Interrupted Ferm
    4. Greek Valerian
- iii. Mid-Range Medium Moisture
    1. N. Maidenhair Fern
    2. Eastern Red Columbine
    3. Frinded Bleedginheart
    4. Fringed Bluestar
    5. Wild Geranium
    6. Woodland Phlox
    7. Indian Pink
    8. Laborador Violet

9. Golden Alexander

B. Shade

1. Dolls Eye
2. Purple giant hyssop
3. Apios Americana
4. Bluebell bellflower
5. Lanceleaf coreopsis
6. Roundlobe hepatica

---

**Pleasant View, Paxton, MA**

**Bigelow Nurseries, Northborough, MA**

**Weston Nurseries, Hopkinton, MA**

---

**Appendix C-Figure 1:** Here is a listing of the proffered plant nurseries that landscaping and facilities use on the WPI campus for the majority of vegetation needs. In talking with Alan Carlsen of maintenance and grounds upkeep, these 3 nurseries were pointed out for potential sources for plants for the implementation of a rain garden on the WPI campus. The first, Pleasant View, was deemed to be rather pricey, with limited selection. They did, however, have plants of a high quality. The second, Bigelow Nurseries, was commended for having a decent selection, especially of perennials and native plants (both quite important to rain garden growth). The final store, Weston Nurseries, was acknowledged to have a great selection of plants, but of a considerably further distance – both problematic and costly when considering the purchase of plants in bulk.

## Native Perrenials Plants

| | | Plant | Type | PH | Min Temp C | Blooming | Water Use |
|---|---|---|---|---|---|---|---|
| Partial Shade | Lower Water Section | Dwarf Folthergilla | shrub | 5.6-6.5 | -28.8 | Feb-May | high |
| | | Witch Hazel* | tree/shrub | 5.6-7.5 | -39.9 | Sept-Dec | medium |
| | | Rhododendron Canadense* | shrub | <6.8 | -45.5 | Apr-May | high |
| | | Red Twig Dogwood* | shrub | 6.1-6.5 | -39.9 | May-June | medium |
| | Herbaceous | Purple Joe-Pye Weed | herb | ? | ? | July-Sept | medium |
| | | Harlequin blueflag* | herb | 6.1-7.8 | -34.4 | May-Aug | medium |
| | | Cardinal* | herb | 6.1-7.8 | -45 | July-Sept | high, medium |
| | | Interrupted Fern | herb | 6.1-7.8 | -39.9 | June | high |
| | | Greek Valerian* | herb | 6.8-7.2 | -39.9 | April-June | medium |
| | Medium Range-Medium Moisture | N. Maidenhair Fern | Fern | 6.1-7.5 | -39.9 | - | medium |
| | | Eastern Red Columbine | herb | 6.1-7.5 | -39.9 | Feb-July | medium, low |
| | | Fringed Bleedingheart* | herb | 5.6-7.5 | -39.9 | Mar-Oct | medium |
| | | Fringed Bluestar* | herb | ? | ? | Mar-June | medium |
| | | Wild Geranium | herb | <6.8 | -39.9 | Mar-July | medium |
| | | Woodland Phlox | herb | 5.6-7.5 | -39.9 | Mar-May | medium |
| | | Indian Pink* | herb | 6.1-6.5 | -28.8 | Mar-May | medium |
| | | Labrador Violet* | herb | 5.6-7.5 | -39.9 | April-June | medium |
| | | Golden Alexander* | herb | 6.1-7.5 | -34.4 | April-Aug | high, medium |
| Shade | | Dolls Eye | herb | 5.1-6.5 | -34.4 | April-June | needs moist soil |
| | | Purple giant hyssop* | herb | - | -34.4 | June-Sept | - |
| | | Apios Americana* | vine | 5.6-7.5 | -31.6 | May-Sept | medium |
| | | Bluebell bellflower* | herb | 6.6-7.5 | -28.8 | June-Sept | - |
| | | Lanceleaf coreopsis* | herb | ? | ? | April-June | medium |
| | | Roundlobe hepatica* | herb | <6.8 | ? | Mar-April | low, medium |

**Appendix C-Figure 2:** Shown here is a listing of plants that were deemed appropriate for use in a rain garden on the WPI campus at the selected location. These plants are all of the partial shade / shade lighting region. This means that these plants will be able to thrive in the Library plot of land, even if the trees overhead fill in during the summer months. The chart also shows what type of plant it is, the optimal pH for proper growth, the minimum temperature for survival, the blooming season, and how much water it can consume. In the design options offered for the rain garden, all plant combinations can be found on this chart.

| Material / Plant | Price | Store |
|---|---|---|
| Red Twig Dogwood | $36.00 | Weston Nurseries |
| Witch Hazel | $55.00 | Weston Nurseries |
| Rhododendron Canadense | $48.00 - $69.00 | Weston Nurseries |
| Cardinal | $24.28 for 3 | Weston Nurseries |
| Harlequin Blueflag | $9.50 | Weston Nurseries |
| Golden Alexander | $35.00 for 6 | Agrecol |
| Fringed Bluestar | $42.00 for 3 | Klehn's Song Sparrow |
| Indian Pink | $16.00 | Plant Delight Nursery |
| Lanceleaf Coreopsis | $5.29 | Weston Nurseries |
| Roundlope Hepatica | $9.00 | Munchkin Nursery & Gardens |
| Purple Giant Hyssop | $35.00 for 6 | Agrecol |
| Doll's Eye | $14.95 | Weston Nurseries |
| Apios Americana | $19.50 for 3 | Local Harvest |
| | | |
| Coarse Sand | 27.95 per cubic yard | Landscaper's Depot |
| 3-Cut Hardwood Mulch | $32.00 - $36.00 per cubic yard | Landscaper's Depot |
| Gardening Compost | $40.00 per cubic yard | Landscaper's Depot |
| 3/4 Inch Crushed Bluestone | $20.00 per cubic yard | Landscaper's Depot |
| Pennington Fast-Acting Lime | $15.00 per 30lb bag | Landscaper's Depot |
| Gardening Topsoil | $19.00 per cubic yard | Landscaper's Depot |
| | | |

**Appendix C-Figure 3:** Here is a listing of a selection of materials and plants needed to build a rain garden, and the pricing of each one. These prices reflect current values, and for the average buyer. However, buying in bulk or for the purpose of a sustainable landscape design may incur changes in the price. For example, many plant nurseries will offer discounts in the range of 10-15% off on plants and gardening materials that are purchased with the intent of creating a rain garden.

**APPENDIX D:**

**Implementation Instructions:**

Rain gardens are both very environmentally beneficial and easy to build. As stated by The Rain Garden Network, "Basically, rain gardens are an inexpensive, simple to implement and environmentally sound solution to urban storm water runoff". Any rain garden, no matter the size, helps to alleviate the quantities of storm water runoff entering into the drainage and sewer systems in the community. Rain gardens can range from small, planter style beds in small lawn city locales to large, open-field designs dug into the surface which channel water from a nearby roadway into the garden. For the rain garden to be built on the WPI campus, there will be a series of steps to be taken regardless of the final design to be chosen. These rain gardens will be great long term additions that can be easily implemented and will help to mitigate the effects of storm water runoff. This section will detail all of the steps that are required to create such a garden, and will result in a complete final product.

**Part 1: Materials**

Determining the materials required to make a rain garden is the essential first step in the building process. Materials needed for the construction of a rain garden will include:

- Plants
- Top Layer Soil
- Sand
- Compost

- Hardwood Mulch
- Limestone
- Bluestone
- Construction / Gardening Tools

In each case, there are multiple factors in deciding which type of each material is best. The types of plants selected are based off of the general criteria of certain aspects of the garden. These include: the amount of sun available, temperature of the region, the average amount of rainfall, size of the plants, pH and composition of the soil, among others.

One important factor is to make sure that there are not too many or too few plants. One common rule is to plant a plant about every 12 inches or so, based off of the sizing of the previous plant (Chesapeake Bay Foundation). In one of the rain garden designs on campus, the sizing of the garden area is to be about 1,036 square feet, based off of surveying measurements. Though the larger sizing of some plants, such as the Red Twig Dogwood or Witch Hazel, will require lower quantities to fill the garden properly, a garden of this size will need a multitude of plants. WPI works with three main nurseries to purchase plants for the school grounds. These are: Pleasant View (Paxton, MA), Bigelow Nurseries (Northborough, MA), and Weston Nurseries (Hopkinton, MA). Also, we can look for local nurseries that will give discounts on large amounts of plants that are being used for sustainable landscape designs, such as rain gardens. For example, Project Native of The Lady Bird Johnson Wildflower Center, a branch of the University of Texas at Austin aimed at sustainable landscape designs, offers a 10% discount on plants purchased for use in rain gardens and other sustainability developments (Project Native).

In some cases, the soil from the initial excavation can be used from the original site. However, to make a nutritious bedding for the plants, sometimes new soil has to be brought in that is not contaminated or polluted (Storey, Beth). In most all professionally built rain gardens, new soil is brought in and used. It is estimated that a rain garden of approximately 800 square feet will need a total soil mixture of about 44 yards, when dug down and refilled to a height of 18 inches below the surface. In the case of the rain garden designs on the WPI campus, the current soil is of a nutritious enough value that soil does not need to be brought in for this purpose. However, with an average soil pH of 5.7 in the selected location, certain additives will have to be added to the soil in order to maintain a slightly higher level. We estimated that about 16-25 pounds of lime would be needed to be added to the soil to reach a desirable pH range of 6.1 – 6.5. A Pennington Fast-Acting Lime compound, in 30 pound bags, runs about 15 – 2- USD per bag. Also, several yards of sand should be added to the soil in order to give it a higher level of absorbency. Based on the rain garden design selected, we will need 23, 22, or 16 yards of sand, respectively. Regardless, it will be proposed that new soil be brought in, in order for the plants to have the best conditions for survival. In the rain garden proposal of 1036 square feet, it is estimated that about 57 yards of soil composition would be needed (if dug to the average depth). However, the soil in itself would be about 14-15 yards of this total number.

Adding a stone edging to a rain garden is a common practice. Using ¾ inch cut bluestone, or other such rocks, has several functions within a rain garden. This can both act as a visually appealing edging and a solid border. On a relatively flat rain garden, a perimeter of small-cut stone can help to keep the top layers of soil and mulch in place, and help to build up a small edge to keep larger amounts of runoff water contained within the garden. (Hill, Cindy). Due to the slope on the WPI garden site of 12.3% grade, there will be a need for a berm or embankment of some sort on the Eastern side (lower part) of the garden. Three-quarter inch bluestone can be used to line the berm. Again, this will provide both an extra layer of holding, while at the same time present a visually appealing front. About 3 yards of ¾ inch cut bluestone, at about 20 USD per yard, would be needed for each design.

Limestone is a commonly-used soil additive to increase the health and effectiveness of a rain garden. In order for a large group of plants to grow well together, there must be constant soil conditions that cater to the tendencies of the plants selected. One key aspect of plant survival is to have the proper pH in the soil. Most soil may need to be slightly more acidic than it naturally is for proper rain garden conditions. One great substance to slightly lower the pH soil is lime. Lime is the most common soil-altering substance used today in garden growing. “Limestone is an alkaline agent with the ability to neutralize, or partially neutralize strong acids” (pH Adjustment). This is usually mixed into the soil mixture that is laid down in the garden. (Innovate to Conserve Natural Resources). Adding lime to the rain garden design on campus could greatly benefit the plants. We estimated that about 16-25 pounds of lime would be needed to be added to the soil to reach a desirable pH range of 6.1 – 6.5. A Pennington Fast-Acting Lime compound, in 30 pound bags, runs about 15 – 2- USD per bag. As With a soil pH of 5.7, and a buffer pH of 6.7, the addition of neutralizing limestone will not negatively affect the garden in any way. However, as new soil will be brought in, the mixture could already be acquired with an appropriate pH for successful plant growth.

Sand helps to greatly increase the absorption rate of water into a rain garden bed. The idea of a rain garden is to easily collect all the rain that is running off of the impermeable landscape. Since plants can only absorb water as fast as they can store and process what is necessary for survival, selecting a soil mixture that will help to absorb all of the water and retain it while the plants slowly process it is key. One way to do this is mix sand into the soil. Sand is very absorbent, and will help to hold storm water runoff of a rain of up to 1.5 to 2 inches for as long as 24-36 hours, the optimal time for a rain garden to handle such an amount of water (New Jersey Agricultural Experiment Station of Rutgers University). In attempting to collect the soil of a runoff area of over 3,800 square feet of the WPI campus, it will be necessary to use sand as part of a mixture to allow for retention of runoff of a large area. The total amount of course sand needed would be 27-28 yards of material of the mix of the 57-yard total.

The addition of compost in a rain garden helps to supply the plants with natural nutrients and minerals without using artificial and potentially dangerous fertilizers. For a rain garden to work properly, the plants that make up the garden need to be able to survive as well. With the amount of sand that is needed in the garden to make it exceptionally absorbent, some of the nutrients that would have been contained in the higher quantities of soil have to be accounted for. In order to do this, compost is usually added to the mixture to provide some of the nutrients that are needed to stimulate plant growth naturally, absent of inorganic and alien substances such as fertilizers (Tucker, Molly Farrell). The addition of compost will ultimately help any rain garden on the WPI campus to quickly take root and grow more prosperously in face of the harsh weather. In order to be effective for a garden of the proposed size (about 1036 square feet), about 7-8 yards should be used. A quality compost can be bought for about 30-40 USD per yard.

Similar to the addition of ground stone edging to a garden, the use of mulch has dual purposes. First, the mulch helps to act as a very absorbent top layer to the soil composition right below it, help to hold water in the depressed rain garden and keep the soil below it from running off downstream. Secondly, hardwood mulch helps to give a visual stimulant to the garden, as well as a positive aroma. (Virginia Department of Forestry). In order to cover the garden's area, we will need about 8,7, or 5 yards of compost (based on the design size chosen). Since the garden will be considerably wet for long periods of time, it should be noted that shredded hardwood mulch, which is sturdier and lasts much long in wet conditions, should be used as opposed to other kinds.

In the two rain garden designs without a berm, the building of the rain garden will involve digging below the surface to create the initial layers of soil. For this, tools such as a rake, shovel, and wheelbarrow will be needed. Also, a rototiller would be beneficial in order to mix up the compound and add supplemental ingredients such as lime. Also, in order to prep for the site determination, such tools as measuring tapes (or surveying equipment for a more professional measure) are needed to designate the size of both the garden and the runoff area. In come cases, part of the runoff area may be altered using pavers or bricks and mortar (Low Impact Development Center, Inc). One design calls for the use of a strip of porous concrete along the Eastern side of the access road, just upstream of the suggest drainage location. In the implementation of a rain garden in the selected area on the WPI campus, most of the tools to be used would be quite rudimentary and accessible. For example, tools such as a rake, shovel, or measuring tape can be acquired from most anywhere, especially Grounds & Facilities personnel. Also, the use of this equipment, if owned by the school, would be free. Surveying equipment was even borrowed for free courtesy of the Civil Engineering Department, giving exact numbers on distances, angles, heights, and slopes all around the selected location.

**Part 2: Method**

In order to start building a rain garden, there will need to be some digging done. In the case of a professionally built rain garden, there will be a need for a landscaping company to come in and dig out some material, as well as have it removed. A safe estimation on labor, for a rain garden, is to assume that the labor costs will be anywhere in the range of 1.5 to 2.5 times the cost of the materials for the garden. Of course, this is for a rain garden that is constructed entirely by a landscaping company (Hodgkins, Kimberly). Dig Safe is a free service that will work to determine utilities in the area and if a predetermined area is unsafe to dig in. State laws demands that utility services are notified before any excavation is done, and Dig Safe works with contractors to notify any pertinent utility company if digging is planned in one of their respective areas. Just give the pertinent information listed on the website and they will come, free of charge, to determine whether the selected location is safe to work on (Dig Safe Systems, Inc.). It is best to plant during the spring or early fall. Obviously, it is impractical and illogical to plant during the winter, and it is too hot for most plants during the middle of the summer. During the middle of spring, it is not yet too hot for the plants at a young age, yet there is enough sunlight and heat for them to grow. Also, the soil will retain more water than it would during the summer, and it is not hard like it would be during the winter months (Wisconsin Department of Natural Resources).

Cost is another important factor in building a rain garden, determining whether or not a garden could actually be built, and to what extent of size and detail. Before building a rain garden, the potential budget of the garden and the actual predicted cost should be taken in consideration. The larger a garden is, and the more material that has to be removed, factors in. Most small, home-owned gardens can cost in the range of 3-5 USD per square foot. However, if nicer plants are used, top grade materials, and constructed by professional landscapers, the cost of building such a rain garden could be as high as 12-15 USD per square foot (Department of Natural Science at Edgewood College, Madison, Wisconsin). In the case of the WPI rain garden project, the budget of the project is limited by two different points of concern. First of all, several different designs are being offered to the school as part of the proposal. These will all be of different value; and as such, of differing price. The school can choose which option is best suited by design and price – and can further seek out alterations in the proposal to fit the idealized budget. Also, seeing as the actual implementation of this rain garden design would be funded solely by the school, WPI has the claim to giving any budget that they see fit.

Based on the materials selected to be used in the rain garden, a list of prices of rain garden materials is as follows:

- Coarse sand: 26 USD / cubic yard
- Hardwood mulch: 32-36 USD / cubic yard
- Compost: 30-40 USD / cubic yard
- Crushed Bluestone: 20 USD / cubic yard
- Limestone: 15 USD / 30lb bag
- Top layer soil: 19 USD / cubic yard

Though rain gardens are designed to be self sustaining, there are some minor pieces of maintenance that can be done on a semi-regular schedule to ensure the best growth and functionality of the garden as a whole. Occasionally, use a flat shovel to remove any excess sediment, leaves, or debris. Both for visual appeal and for healthy root and herb growth. Remember to retest the soil every 3-5 years and make appropriate amendments to such things as pH and % organic compound. Remove or replace plant material that is not thriving. Each spring, prune dead vegetation and deadhead flowers. Add mulch every spring to maintain a three inch mulch surface layer (Boyajian, Amy). All of the aforementioned rain garden maintenance is rather simply, and could easily be achieved by any work study student, or grounds keeping and maintenance crew. However, in keeping with WPI's goals to spread their knowledge and prioritization of sustainability and a green future to others, such tasks as garden upkeep could be taken on by others. For example, groups such as WPI Frontiers, the WPI Green Team, or even the President's Task Force on Sustainability work to promote green alternatives and environmental sustainability.

The building of a rain garden requires an implementation plan that orders each step properly and tells concisely what needs to be done, and to what extent. The implementation plan should take one from nothing but a list of supplies, to a fully functioning rain garden. An important note: It is most effective to start the actual construction of the rain garden in the spring when the abundant rains will allow for best plant establishment and easier digging. Construction during the summer/autumn start will also work, but the plants may need more water until they become established. In order to create an efficient rain garden, it must be sized appropriately. The commonly accepted ratio of drainage area to surface area of the rain garden is 3:1. It is important that this number is relatively close because a rain garden receiving too much water will flood, kill the plants, and leave a large body of un-absorbed water – negating the original intention of the garden. In the rain garden at the Worcester Youth Center, the 1000 square- foot rain garden is positioned to collect storm water runoff from a parking lot in excess of 15,000 square feet, leading to the eventually flooding of the youth center basement (Donna Williams). In a normally-proportioned rain garden, an average 1-inch rain storm would drain out in anywhere between 24 and 26 hours. This also negates infestation, as mosquitoes and other wetland insects take 7-10 days to lay and hatch their eggs by drip irrigation (Construction Storm Water Pollution Prevention Bulletin). With most of the selected sites on campus having a slope in the range of 8-15%, collecting too much water from too large an area would not be an overwhelming issue.

Most excess water, in surplus of what is absorbed by the garden, would just continue to run further down the land. To combat the over-saturation of the selected rain garden site, some of the water could be diverted away from the site as well. In the example of the site just west of Riley Commons, water could be collected off of the roofs in rain barrels. If this is too much water, some could be diverted to another location, while the rest was fed into the garden site by drip irrigation (Construction Storm Water Pollution Prevention Bulletin).

Determining the slope of the rain garden area ensures that the rain garden will be as efficient as possible. Finding the slope of the rain garden area can be done in an easy, albeit simple, fashion. First, measure out a horizontal length with a measuring tape. Then, measure the height off the ground that the lower edge of the measuring tape is. Using these two numbers, simply divide the rise (vertical change) over the run (horizontal length), and multiply this number by 100. This will result in the percent grade of the slope. This number should be in the range of 10 – 15% grade. Such a slope is desirable so that storm water runoff will be able to easily flow towards and into the garden, yet it will limit the water from overflowing due to a steeper grade (Earth Partnership for Schools – Madison Arboretum at the University of Wisconsin). On the site selected for the WPI rain garden, multiple testing methods were used. The rise over run method was first implemented to get the general idea of the area. However, in using school surveying equipment, a more precise number can be determined. It was found that the area in question has a percent grading of about 12.3%.

The actual building process can begin once the preliminary site evaluation has been completed, leading to basic site cleanup and preparation. The first step in preparing the rain garden location is to remove the existing grass, shrubs, trees, and soil. The target area needs to be completely delineated. Using a shovel or machinery, tear up the top layering of the soil so that the entire area will be completely bare (AES Rain Garden Installation Manual). On the WPI rain garden site, the potential building area is merely covered in grass and moss. This area was chosen, in part, due to it's openness and availability for construction. Though the trees around the target area are full and provide a fair amount of shade, they have been taken into consideration in the design, and therefore do not have to be chopped, pruned, or relocated.

The next step is to excavate the sight so that the garden is at a proper level, slope, and depth in the ground. The normal desired depth of an appropriately sized rain garden is commonly designated as 18-24 inches into the ground. This ensures that there is enough of a basin to collect the water and contain it in the root area of all the plants in the rain garden. However, this number can deviate, based on the slope of the rain garden location, and the soil composition of the site. Better location soil can lead to a shallower garden, whereas a rather steep location will require different depths at different points in the rain garden (Massachusetts River ways Program, Department of Fish and Game).

The addition of soil amendments while building the rain garden ensures that the plant selections will have the best possible chance of growing into strong and effective plants. As most plants grow best in a certain pH, it is important to make sure that the soil accommodates these needs. Selecting plants that all fall into the same pH grouping means that the entire garden can be of one general composition, making upkeep much easier. Using a rototiller, adding several yards of lime to the soil will help to keep a slightly lower pH, better for most native plants to thrive. The site selected for the WPI rain garden will implement solely species from the area that are accustomed to the soil and climate of New England. As such, the general pH that this entire collection will thrive in is in a range of about 6.0 to 6.3. This is relatively normal for the naturally occurring soil in this region. That being said, there may be a need to add a modicum of lime, based off of the results of the soil testing procedures conducted on our test sample.

To ensure the capture of water at the bottom slope of the rain garden, a berm can be built up so as to limit storm water runoff proceeding past the edge of the rain garden. The berm should be located on the lowest end of the garden, that which is furthest away from the main runoff source. The berm should bring the lower end of the slope to about the height of the base level of the higher ground. Such a berm can usually be built up using the previously excavated soils. (University of Nebraska, Institute of Agricultural and Natural Resources). In the case of excessive amounts of storm water runoff, the addition of an overflow edge will help to prevent the garden from holding in too much water. Use a layer of bluestone or semi-permeable, harder surface and layer this against the berm. This helps to allow for overflow out of the garden in cases of extreme runoff, while maintaining the garden's edge (Middleton, Amy and Sarah Clark). A simple overflow edge can be construed in the WPI rain garden design by the proper shaping of the berm. Adding a layer of bluestone to the surface of the berm at the bottom of the garden will suffice. In the event that the water fills up to the edge of the berm, the harder top layer will allow the accumulating water to slowly trickle over the top and out of the rain garden.

The addition of plants to the rain garden can be done once all of the preliminary steps have been taken, ensuring a healthy environment for the rain garden species. Using only native species if possible, begin to plant based off of the preliminary designs. Make sure that each species has enough room to grow, and that each individual plant has at least a twelve inch radius around it in all directions. Using native species helps plants to growth without a higher chance of alien infections, and allows for a higher chance that the different species will coincide together (Middleton, Amy and Sarah Clark). The rain garden design on the WPI campus consists of partial shade to full shade habitat plants. All selected plants are native to the area, and fall under the 5b hardiness categorization (the norm for the Worcester area). With a tentative plan for 10 different species zones in the garden, each individual plant will have plenty of room to grow in the rain garden.

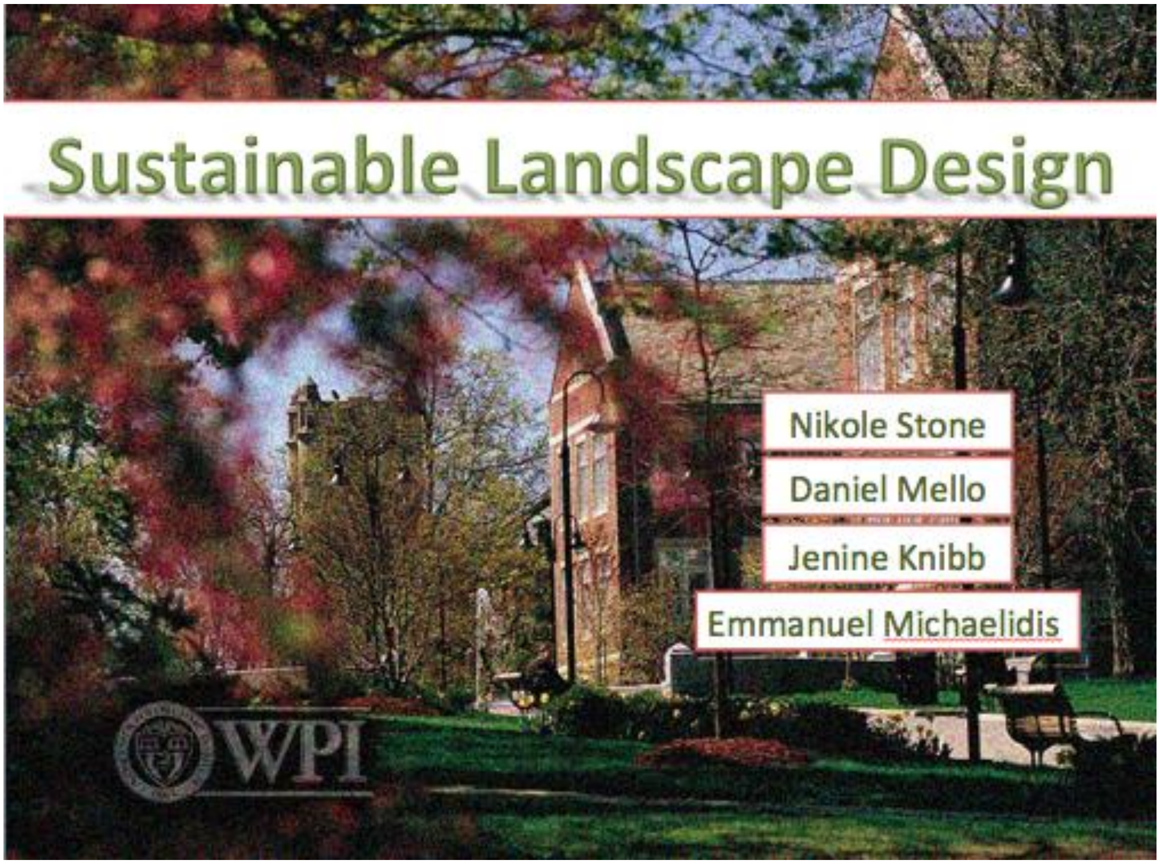
To finish off the implementation of the rain garden, apply a layer of mulch over the entirety of the garden's surface. Allow for a 3" depth mulch (triple-shredded hardwood with no dye) to be spread throughout the entire rain garden. For every 100 square feet of rain garden, you will need about 1 cubic yard of mulch (at the aforementioned 3" depth). This mulch layering will help to keep the soil layers below properly packed, and acts as a super-absorbent top layer to allow for the pooling of storm water (Tucker, Molly Ferrell). In the rain garden design to be implemented on the WPI campus, there is an estimated area of 1,036 square feet. This means that, at the given values, about 10-11 yards of mulch will be necessary to cover the entire surface properly.

All of these aforementioned steps help to bring about the full construction of a functioning rain garden. Though a relatively simple process, the design of the rain garden is broken down so that all steps can be related to any given area where such a rain garden is desired.

**APPENDIX E:**

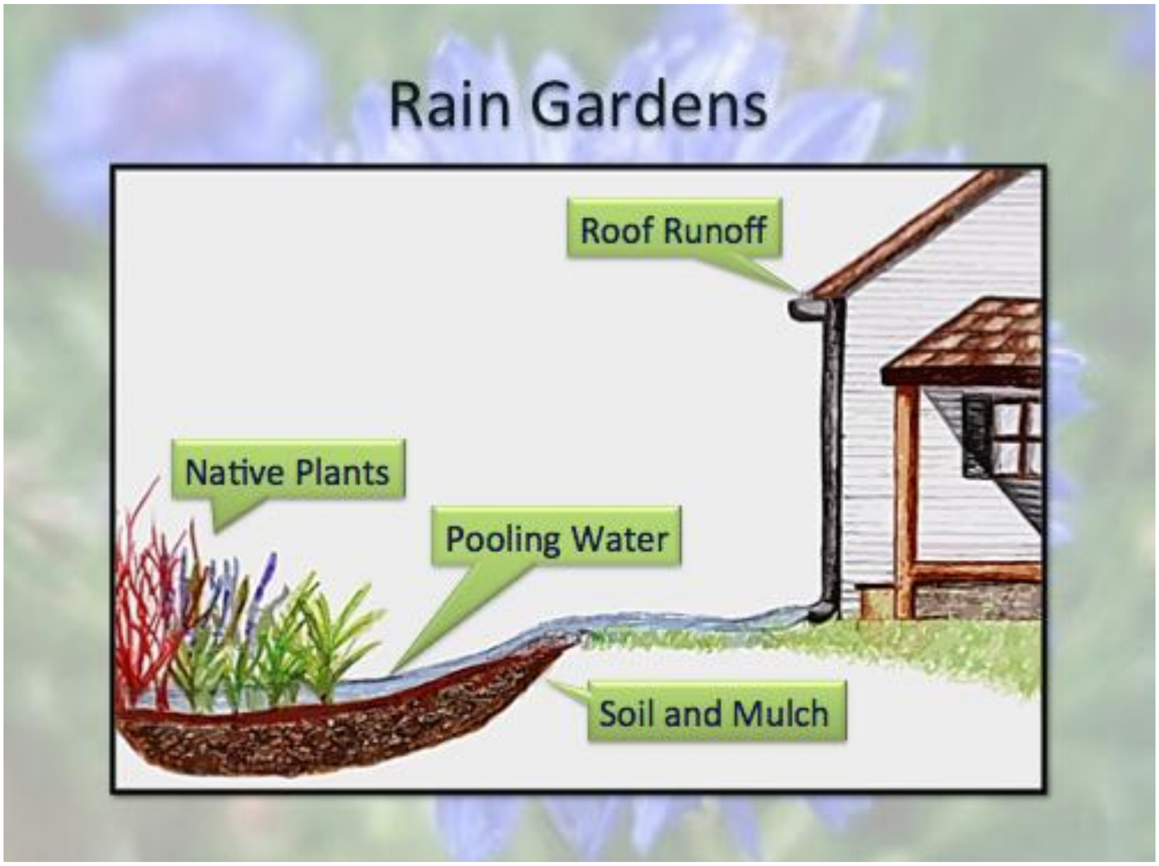

**Appendix E-Figure 1:** Shown here is a potential design for the information stand to be located at the rain garden site. This stand will be placed at the railing along the access road in front of the library (essentially in the location the above picture is taken from). This stand, to be erected before construction, can remain even after implementation of the garden as an educational tool and artistic piece to garner interest. The sign tells what a rain garden is and how it works. It also gives support for reasons to build one's own garden, as well as a few specifics about the rain garden at WPI in particular. This stand will also include the email alias, website, and any other contact information of the Worcester Rain Gardens IQP group, who are currently working to create multi-media materials of dissemination about the need for rain gardens and the resulting benefits to the community at large.

**APPENDIX F:**

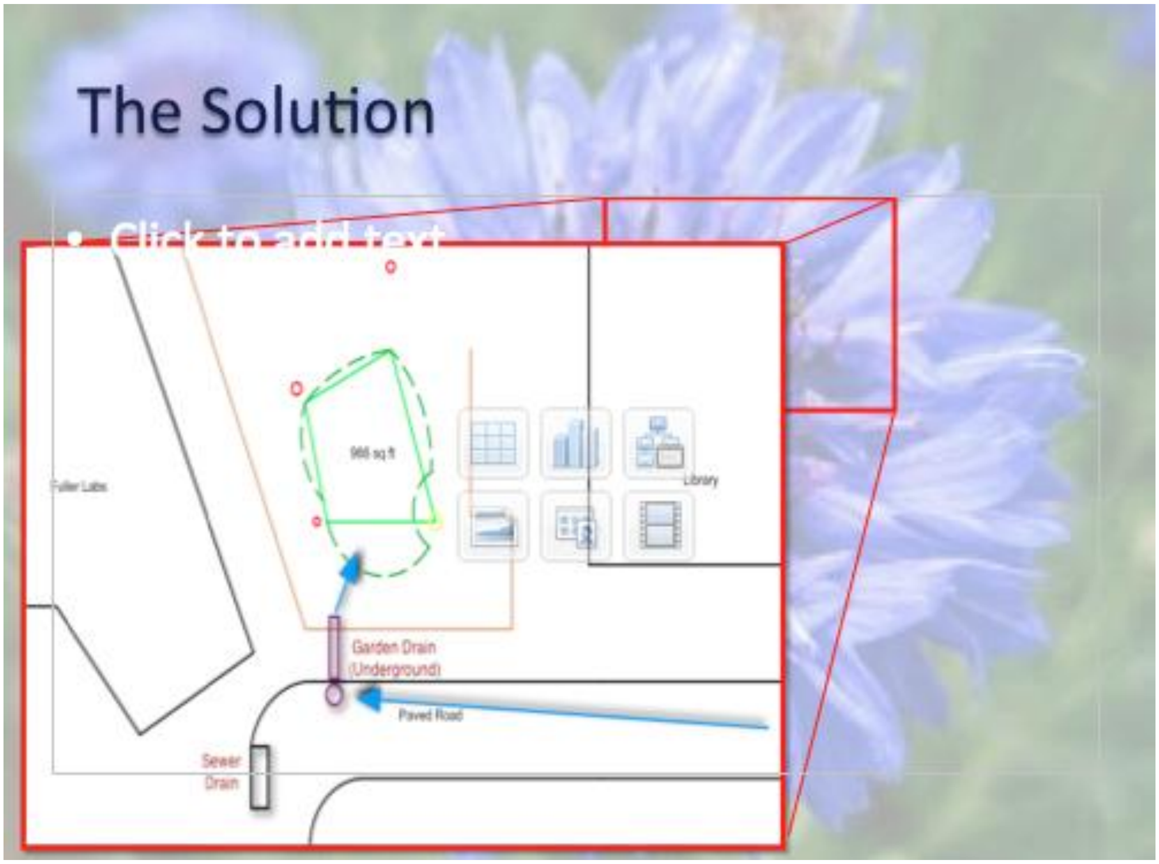



**Appendix F-Figure 2:** Final presentation, title slide.


**Appendix F-Figure 3:** Final presentation, visual representation of the rain garden.




**Appendix F-Figure 4:** Final presentation, representation of a functioning rain garden.



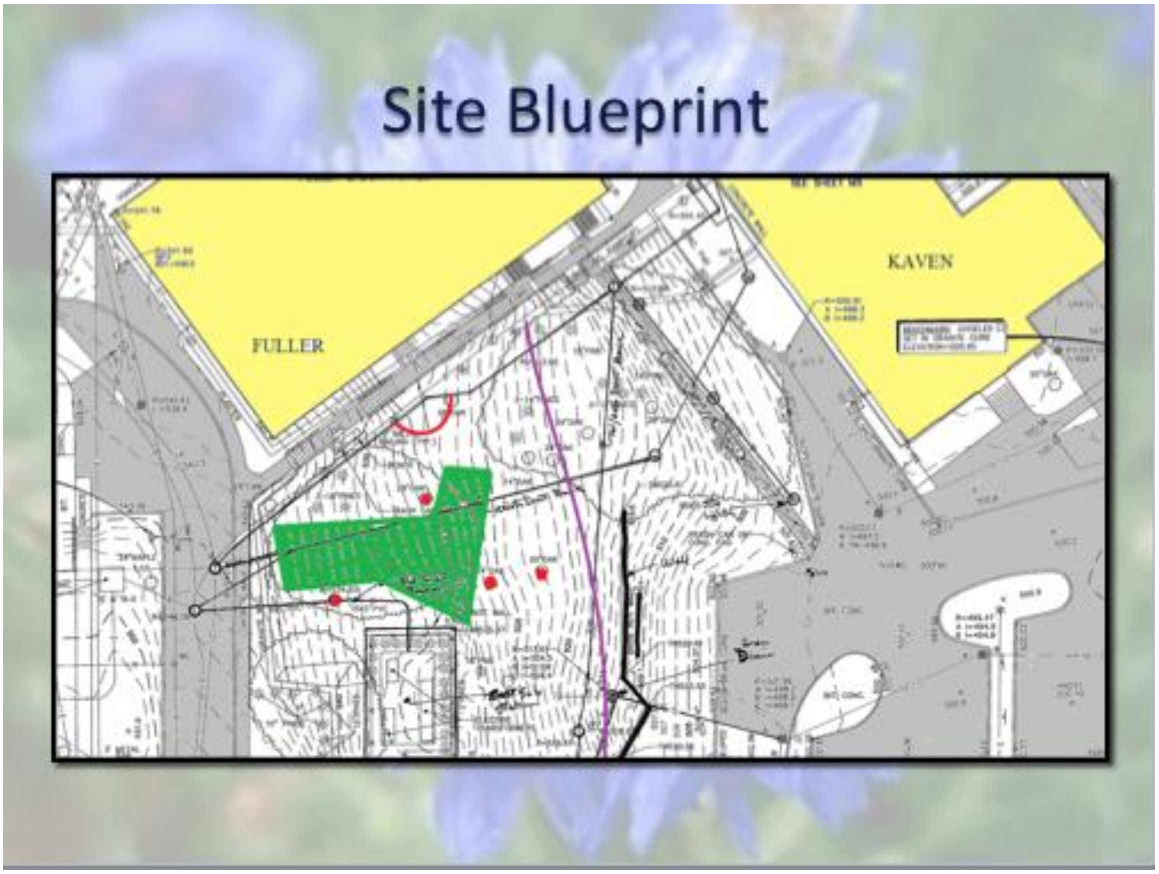

**Appendix F-Figure 5:** Final Presentation, morphing slide showing the preliminary AutoCAD design for a rain garden between Gordon Library and Fuller Laboratories.

Rain Garden Site

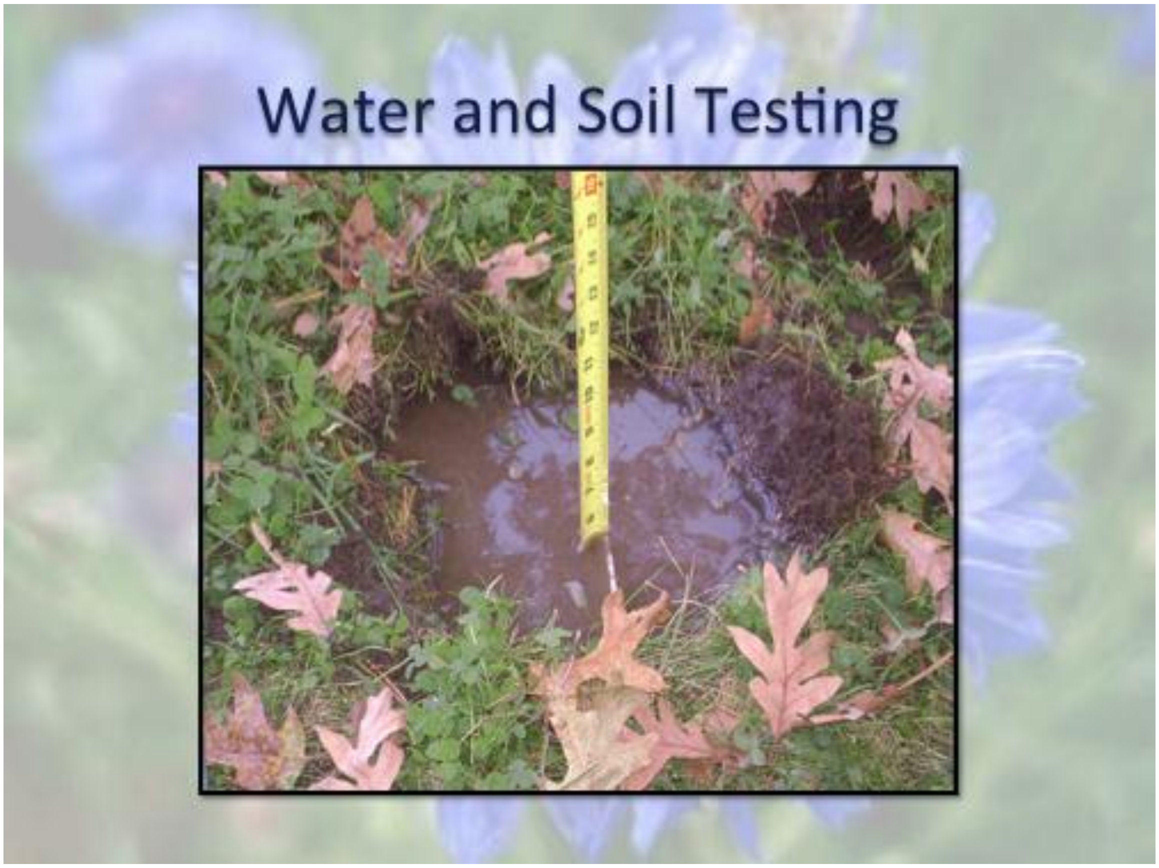
| Categories | Rating |
|---|---|
| Slope | 7 |
| Pooling | 10 |
| Area | 5 |
| Proximity | 5 |
| Light | 6 |
| Constructability | 7 |
| Visibility | 10 |
| **Total** | **50** |

**Appendix F-Figure 6:** Final Presentation, scaling of 7 criteria to grade a potential rain garden site.

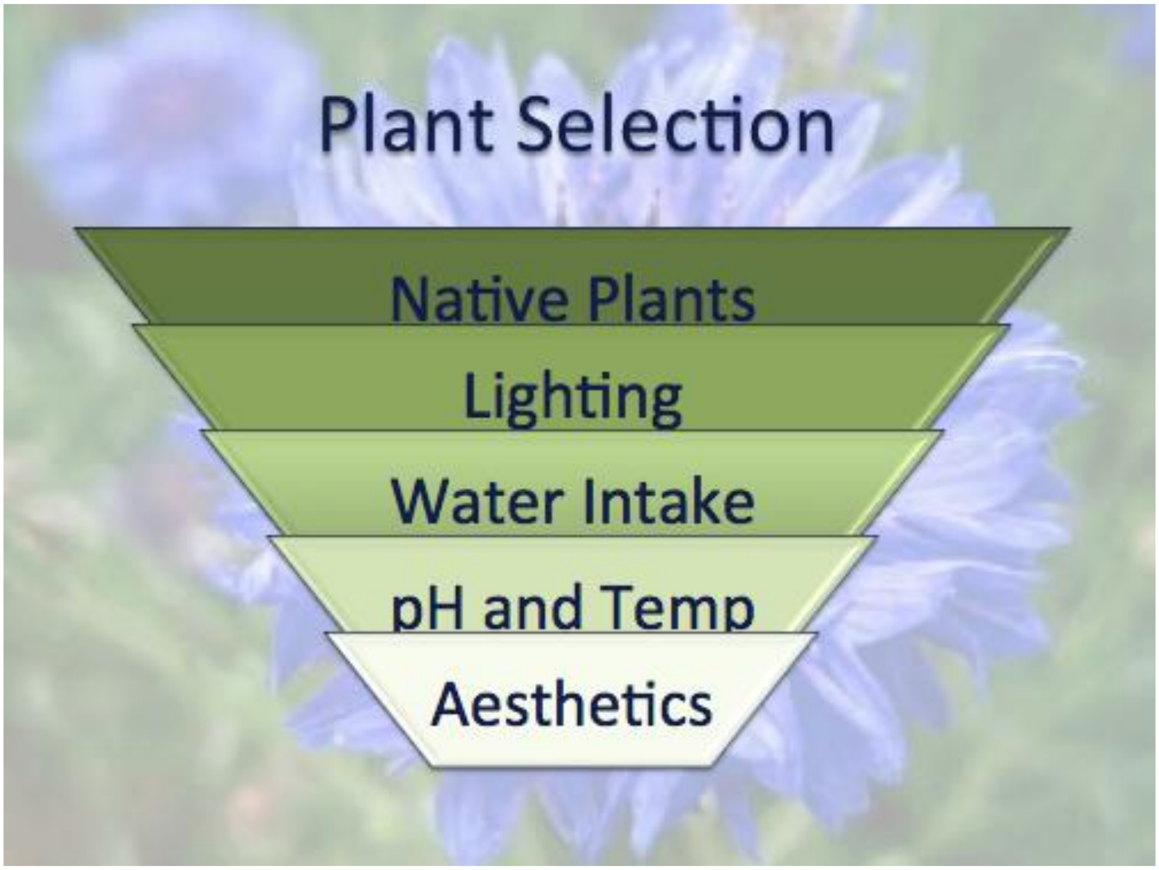

**Appendix F-Figure 7:** Final Presentation, visual of each considered rain garden location and the respective grade received (out of 50).



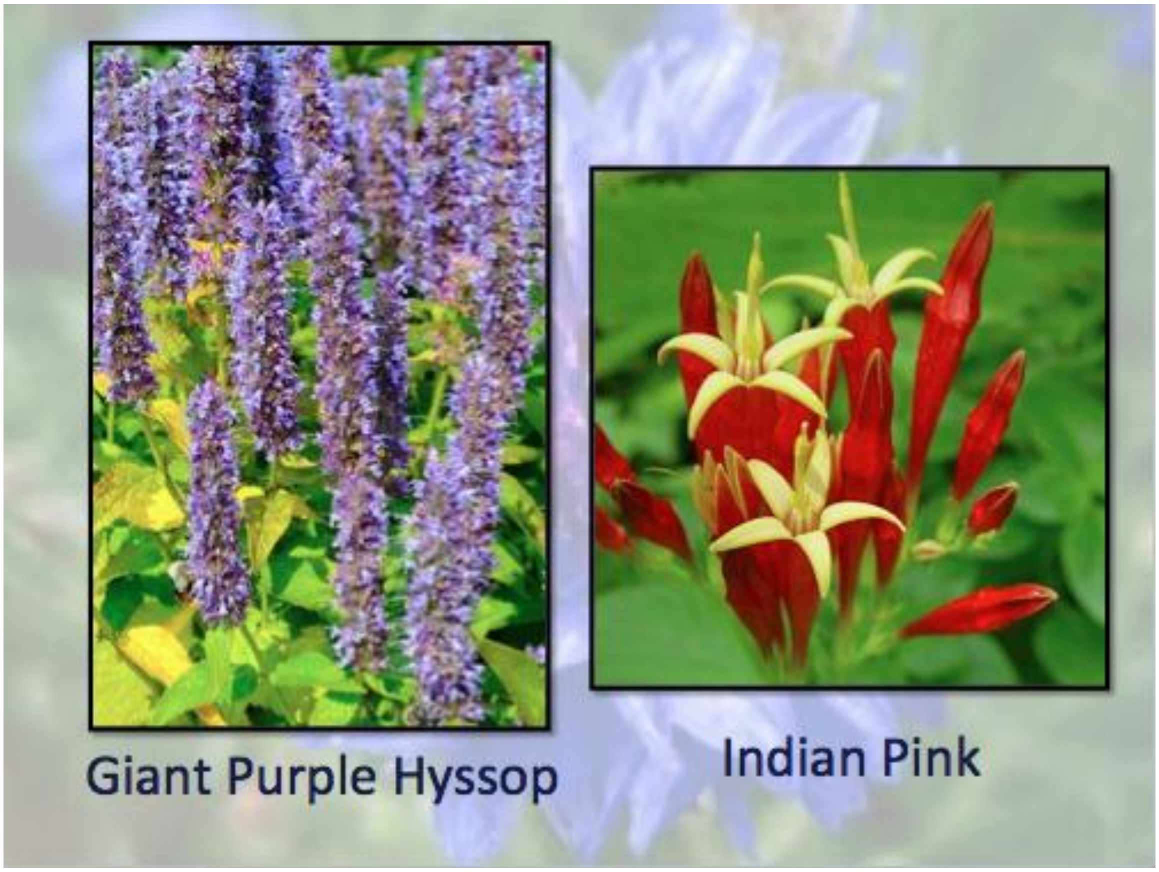

**Appendix F-Figure 8:** Final presentation, detailed topographical blueprint of the potential rain garden location to pinpoint the optimal location along the hill.



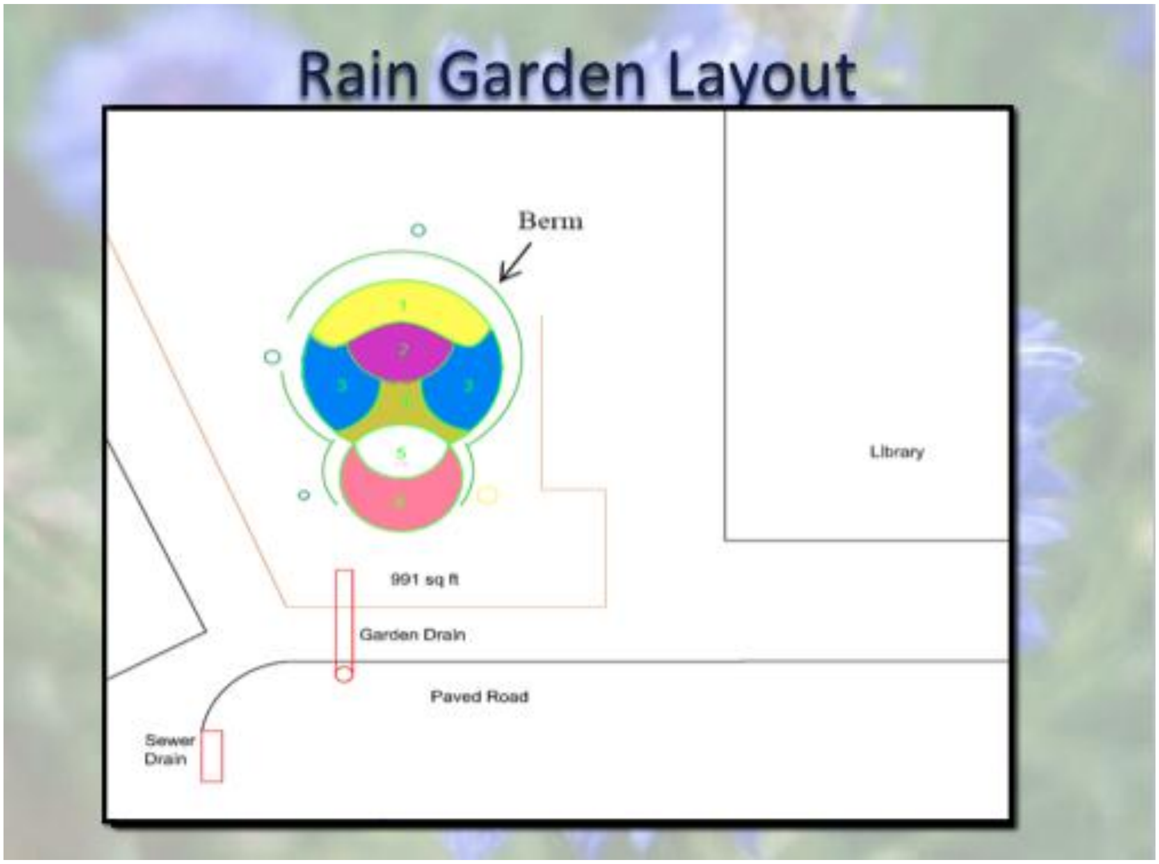

**Appendix F-Figure 9:** Final presentation, depiction of percolation test to determine general soil quality and compatibility.




**Appendix F-Figure 10:** Final presentation, representation of 5 categories considered in choosing plants to fill in the designed rain garden.



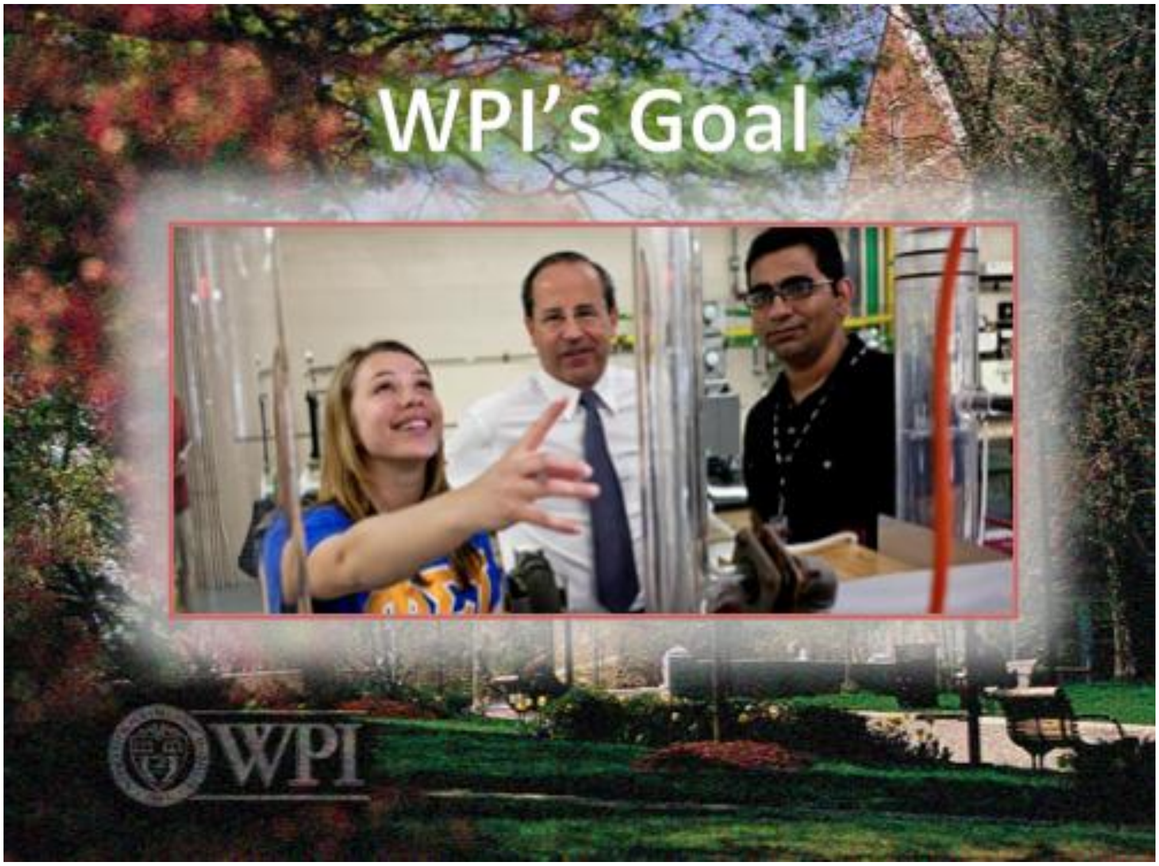

**Appendix F-Figure 11:** Final presentation, example of plants selected in some of the proposed rain garden designs that meet the aforementioned requirements.




**Appendix F-Figure 12:** Final presentation, AutoCAD representation of one of the rain garden designs that can be implemented on the WPI campus. This example includes a berm, which accounts for higher levels of water retention and allows for avoidance of complications in regards to digging underground during construction.


**Appendix F-Figure 13:** Final presentation, which includes a possible design for the information stand to be located along the access road overlooking the rain garden site.


**Appendix F-Figure 14:** Final presentation, slide representing an example of dissemination of the rain garden project to groups such as Camp Reach. Environmental engineering designs, like those of sustainable landscape designs, offer a great opportunity for such groups to learn about the benefits and possible ideas for similar developments of their own.




**Appendix F-Figure 15:** Final presentation, depiction of slide to represent the WPI mission to further society and cause advancement in such fields that will help the community.


Thank you for your consideration of this project. We aim to bring about such ideas as rain gardens as a way of augmenting the strained gray infrastructure of Worcester with a greener component. Through this project, we want to bring these ideas of sustainability to the masses, starting within our own community at WPI. For any comments, concerns, or inquiries, feel free to contact our address of sustainablelandscape@wpi.edu. Thanks again!

**-Sustainable Landscape Design Team**