Designing a Roof Runoff Water Reclamation System

Assessing Feasibility and Cost Analysis of Implementing a Reclaimed Water Powered Hydroponic Garden in Collaboration with the National Grid Sustainability Hub and Clark University

An Interactive Qualifying Project

submitted to the faculty

of

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

Degree of Bachelor of Science

Submitted by:

Alex Murphy

Melanie Lasso

Advisor

Prof. Chickery Kasouf

In Cooperation with

Adrian Hubley and Colleen Gardner of the

National Grid Sustainability Hub

Abstract

The National Grid Sustainability Hub houses interactive exhibits and educational materials to promote both their Smart Energy Solutions Program and their available sustainable opportunities. National Grid asked our team to address the issue of flooding on the sidewalk around the building and to incorporate both gardening and sustainability into our solution. To achieve these goals, our team designed a roof runoff water reclamation system that will be attached to a sustainable solar-powered hydroponic garden. We first researched and prioritized system constructs based on feasibility and then presented the three most cost effective and sustainable solutions to stakeholders.

Acknowledgements

The successful completion of this Interactive Qualifying Project would have been possible without the help of many contributors. We would like to thank the following individuals:

- Professor Chickery Kasouf who has advised us from beginning to end on this project.

- Our sponsors Adrian Hubley and Colleen Gardner of National Grid, who have helped guide and support us throughout the planning and research of this project

- Tom Wall, a member of the National Grid facilities team, who helped guide us gain an understanding of the building and helped guide us in the design aspect of the system.

- Derek Lundstrom, the Associate Director of Facilities at Clark University.

Executive Summary

In fall 2013, the National Grid Sustainability Hub was opened. The Sustainability Hub was created to be a model home to show National Grid customers how they could live more sustainably and save money while doing so. Inside the Sustainability Hub there is educational material and examples of household appliances that save water and energy. There's also information about National Grid's Smart Energy Solutions Program. The idea of creating a water reclamation system to gather rain water along with creating a hydroponic garden fits well into the environmentally friendly and sustainable theme. Through creating a water reclamation system water is gathered during rainfall and can be used inside a home, or in our case water a hydroponic garden. The hydroponic garden, although there is no usage of soil and mostly water, the water usage is actually less than what a normal garden uses.

In order to complete this project, we first started by gaining a familiarity with the topics of water harvesting/ reclamation and hydroponics. To do so, we met with a research librarian at WPI's Gordon Library. There we learned information about both of these topics. We then performed research on our own to gain even more knowledge. Not only did we have to learn more about the aforementioned topics, we needed to gain an understanding of the building and the limitations of what we could do. In order to do this we contacted Tom Wall, a member of the facilities team at National Grid. Through speaking with him we learned limitations such as not being able to use the roof. He also was able to help us choose a location for the garden and system.

In addition to meeting with Tom Wall we also met with Derek Lundstrom, the Associate Director of Facilities at Clark University. Derek was able to show us the basement of the building to and tell us more about what space we could use throughout the building for our project. With him it was determined that the gutters would be on the side of the building leading into the back shed and the cistern would most likely be in the basement along with a pump to pump the water up to the garden which will be in the entrance of the building. Through these interactions were we able to create a list of materials and a budget for this project. Using SolidWorks, a CAD model of the gutter system that will be needed was created.

Overall, this system, including the garden will create an added educational opportunity for the National Grid customers who enter the sustainability Hub. Most of the system will not be visible to the customers, therefore, the garden will attract the customer attention and the system as a whole can be discussed while admiring the garden. This garden will also serve to bring the Sustainability Hub closer to the Clark community by supplying them with fresh lettuce and herbs.

Table of Contents

Chapter 1: Introduction

National Grid's Sustainability Hub is a facility, donated by Clark University, whose main goal is to provide education about energy efficiency and emerging technologies to both the community and customers of National Grid to allow them to live a more sustainable life. The Sustainability Hub was created in parallel with National Grid's Smart Energy Solutions Program, which launched its pilot in January 2015 and has been made available to 15,000 customers to date. The Smart Energy Solutions Program was designed to provide customers with new technology that makes it easier to conserve energy in the home and save money in the process. The Sustainability Hub showcases a number of green alternatives to household appliances ranging from dishwashing machines, to wall insulation, to electric car charging ports.

Continuing with an environmentally friendly theme, National Grid has consulted with our IQP team to enter the realm of sustainable gardening. Our project will introduce a plan for a community garden at the Sustainability Hub that is hydrated by a roof-runoff water reclamation system and can be implemented into the tour of the facility. The garden will be shared among the members of the Hub, the community, as well as the Clark campus.

Initially, our greatest problem was to determine the most feasible area for the garden. Some locations considered were the sidewalk around the Sustainability Hub, the roof of the building, and the alleyway between the Sustainability hub and the neighboring building. However, the area surrounding the Sustainability Hub is not currently able to support any type of garden. After consulting with our sponsors, it was decided the location will be inside the building at the entryway of the Sustainability Hub run by hydroponics. The Sustainability Hub is modeled after a household, complete with appliances and even a turf front yard area. This mock front yard is perfect for the garden as the space is currently not being utilized. Our next challenges were to determine how the runoff rainwater is to be collected, where the system is going to be located in respect to the building, and how it is going to be connected to the garden.

With help from our sponsors, our group spoke directly to Derek Lundstrom, the Associate Director of Facilities at Clark University. Through this interaction we quickly found out what could and couldn't be done. Our end goal for this project is to provide a sustainable hydroponic herb garden to the National Grid Sustainability Hub that requires minimal maintenance and gives employees and interns of the building, as well as Clark University's Dining Services, fresh and free produce. We will accomplish this by designing a water harvesting system to lead water from the lower roof, by the use of a gutter, to a cistern (location to be determined). Our team would also like to incorporate solar power into the project as it further emphasizes the sustainable message. With the creation of a hydroponic garden we hope to draw attention to the system and educate customers on a way to produce their own sustainable garden.

Chapter 2: Background

2.1 The History of Rainwater Reclamation Systems

Evidence of rainwater harvesting methods have been dated as far back as 4,000 years ago. Some ruins of ancient water runoff collection systems are even still standing in Israel. Rainwater harvesting has been proven as an effective way to sustain life during droughts and in areas of the world prone to dry climates. Even today in places like Sub-Saharan Africa, harvested water from rainstorms is commonly used to provide water for families and communities without access to the water systems that we take for granted in more developed parts of the world. Rainwater reclamation systems are making a comeback in developed countries around the world. They are now widely used in Australia, Europe, the Middle East, and gaining traction in North America. The interest in implementing rainwater reclamation systems correlates with the trending desire for countries, businesses, and homes to be as environmentally friendly and sustainable as they can be.

2.2 The Benefits of Rainwater Harvesting

Rainwater harvesting has many attractive attributes. The water itself is typically neutral in its pH level and is not polluted with contaminants that the public is showing more and more concern for; everybody wants to drink clean water. Low sodium levels are also associated with most rainwater collection systems, which is another health benefit that using these systems provide [1]. The tendency for rainwater to have a neutral pH is effective when being used with appliances that scale with the use of “hard” water, such as showerheads, tubs, sinks, dishwashers, laundry machines due to calcium and magnesium deposits that come from the plumbing’s water source [2]. Having some type of rainwater reclamation system is extremely useful in dry areas that lack groundwater or substantial access to a plumbing systems from a water source.

Collecting rainwater also reduces the amount of flooding and pollution caused by an overflow of drainage systems.

Although these attributes of water harvesting systems should be enough to spark interest in the average consumer, there are still plenty of people and businesses who won't take the time to actually implement a system like this in their facilities. However, projects like these provide potential for savings on quarterly utilities bills. Introducing rainwater reclamation systems to homes and businesses saves people money in a variety of ways. After the cost to construct a system, all of the collected water is free. The average cost of installing a household reclamation system is about $3.00 per gallon of system size [3]. This can fluctuate depending on the amount of piping and number of pumps needed for individual systems, but it is safe to say that our system will not be too complex or exceed a 55-gallon size. This puts our systems cost at around $165. The average household in Worcester is currently paying $397 per year for water [4]. Although the Sustainability Hub is modeled after a household, the facilities daily water usage does not reflect one. The building is fit with a sustainable washer and dryer, dishwashing machine, kitchen sink, and bathroom, but they are mainly there for display and tour purposes and not used nearly as much as the average household family would. Because of this, our project has potential to provide the Sustainability Hub with a zero water sewage output, adding further to their green initiative. This is without factoring in the constant rise in water utility rates, which could lower the payback period even further. Homeowners save money on their utility bills by incorporating the collected rainwater into their daily lives. Harvesting rainwater also reduces the costs of adding water distribution networks as well as the expansion of water treatment plants [1].

2.3 Components of Rainwater Harvesting Systems

These systems range from large and complex water harvesting systems implemented at corporate buildings in major cities, to small cisterns at individual households. These household harvesting systems are generally simple to construct without experience in plumbing and construction. There are six basic components that are essential to having successful reclamation system: the catchment surface, the gutters and downspouts, the leaf screens, the storage tank, the delivery system, and the treatment system [5]. Figure 2-1 shows all of these components on house for a typical rainwater harvesting system. The main components are discussed below.

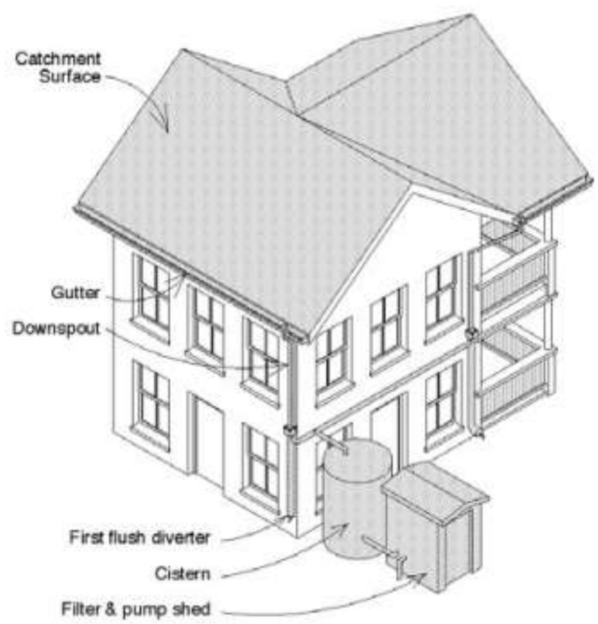


Figure 2-1: Rainwater Harvesting system installed in a typical household. Retrieved from: http://www.twdb.texas.gov/publications/brochures/conservation/doc/RainwaterHarvestingManual_3rdedition.pdf

The catchment surface is the surface where the rainwater will be caught and proceed to run-off. This is often and ideally the roof of a building. Types of fixings for the catchment surface include metals, clay or concrete tiles, asphalt, tar or gravel shingles, as well as slate [5]. Each of these materials have pros and cons to using them. Metals are commonly used because of how smooth the surface is. This is ideal because the quantity of water increases with the smoothness of the roof surface. Clay and concrete catchment surfaces are both porous and have the potential for bacterial growth in the pores. This can be reduced using sealant but this increases the chances of toxins being released into the water. Tar and gravel shingle are not common but can be appropriately used for irrigation purposes. Slate is another material, like metal, that is ideal because of the smoothness. However, slate can be expensive and may not be used due to budget constraints [5].

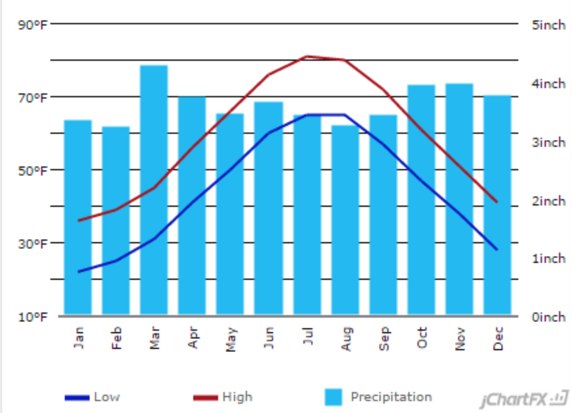
Storage tanks can vary from system to system depending on the needs of the system and how much water is to be collected. Precautions to avoid contaminations and tampering should be taken. If outside, the storage device may pose the risk of being tampered with by an animal and if not closed tight enough the inside water can be contaminated. Water tanks can be the breeding ground for mosquitos and algal growth if the container is not tightly sealed [6]. An easy solution to prevent algae growth is buying an opaque container, or painting it to be so. [5] There are key features that a storage tanks need to have. These features include an inlet for the rainwater to enter, an outlet for the water to be delivered to the desired location, and an air vent for water to escape during the collection [7]. This piece of equipment is often the most expensive component of the water harvesting system. As stated earlier the size of the storage tank varies with the needs of the system, there are other factors that contribute to the size of the storage tank as well. Some of these factors are the amount of precipitation in the local area, budget, and the amount of space available for this harvesting system. [5]

2.4 Gathering Climate Data

Before designing a rainwater harvesting system, one should research the climate of the area and get an understanding of the average rainfall that happens throughout the year. In New

England, we see an average rainfall of about 47.7 inches over the course of the year [8]. We also see, on average, about 120 days with rainfall precipitation. This means that during two thirds of the year, Massachusetts gets no rain during the day. The amount of average rainfall per month, surprisingly, is relatively equal throughout the year. The vernal months and the autumn months tend to have slightly higher average levels of rainfall, but in general each month appears to obtain between 3 and 4 inches of rain every year. This data only considers rainfall and not snowfall [8].

Boston Climate Graph - Massachusetts climograph



Totals and averages

Annual high temperature:	58.7°F
Annual low temperature:	44.1°F
Average temperature:	51.4°F
Average annual precipitation - rainfall:	43.56 inch
Days per year with precipitation - rainfall:	120 days
Annual hours of sunshine:	2633 hours
Av. annual snowfall:	-

Climate data for Boston, MA - 2108 - 1981-2010 normals - weather

Jan: January, Feb: February, Mar: March, Apr: April, May: May, Jun: June, Jul: July, Aug: August, Sep: September, Oct: October, Nov: November, Dec: December

Figure 2-2: Monthly Rainfall averages in Massachusetts. Retrieved from: http://www.usclimatedata.com/climate/worcester/massachusetts/united-states/usma0502

2.5 Alternative Water Collection

Since we do not live in a tropical environment that constantly produces a lot of rain, we should definitely also consider the other types of available water sources that we could incorporate into our system. There are many types of water around us that can be used in the garden. Rainwater is classified as “atmospheric water”, however, we could potentially use storm water, greywater, black water, and alternate water in our system to maximize the water availability for the garden [1]. Storm water is just rainwater that has hit the ground or roof. This can be captured using gutter systems around the edges of the roof and drainage systems along the edges of the building. Greywater is the wastewater that passes through bathtubs, showers, sinks, and laundry machines during use. Since the Sustainability Hub is modeled after a clean-tech home and has said home appliances, we should be able to capture that water and run it into the basement if needed. Black water is the water that passes through kitchen sinks and toilets as they are used. Depending on the need for access to a larger quantity of collected water, this may be an option to use. Alternate water is used to describe the captured water in other appliances such as air conditioners, dehumidifiers, etc. [1]. Although alternate water would most likely provide us with the least amount of additional water, the ease of access to it is worth implementing it into the system. All that would be required to access this water would be for somebody at the Hub to dump it into the tank.

Before implementing a reclamation system in the building it is important to consider a number of factors that will determine its general size. We will need to determine the type of piping, as well as its length and width. We will also need to determine the size of the water storage tank and what methods we will be applying to it in order to treat the water of impurities. Lastly, we need to discuss with building managers about whether or not the building has an internal or external drainage system. Having an internal drainage system would be ideal and would allow us to keep the tank in the basement of the Sustainability Hub and bypass water through an already existing pipe system, leveling off into the old one again as the tank reaches maximum capacity. One 55-gallon drum barrel is optimal for this system because it is large enough to contain all forms of reclaimed water that we will be harvesting and can fit into the basement of the building.

2.6 Hydroponics

While water reclamation systems can be used for many purposes, we are focusing on using this water to create a sustainable garden. When considering different types of gardens, a key factor to keep in mind is the limited space at the Sustainability Hub because of the urban environment. Initial thoughts were roof-top gardening, community gardening and hydroponics. However, the roof of the Sustainability Hub is not a feasible location. While attempting to gain access to the top of the building, our team learned that the roof is long overdue for renovation and is unstable for any type of recreation. Even the route through the upper levels of the building was deemed by Clark University as being too dangerous to leave up to chance. Therefore, community gardening and hydroponics will be discussed further.

While hydroponic systems are still being used and optimized, the idea of not using soil to grow crops is a very old concept. It is believed that the Hanging Gardens of Babylon fed plants by allowing water to trickle down the stepped gardens down through the plant's life. [9] In 1925, the difficulties of maintaining the soil and fertilizer in a greenhouse led U.S researchers to begin to investigate a way to replace soil with a nutrient solution or create an artificial soil that can be soaked with nutrients and serve the same way as soil would. [10]

Hydroponic gardening is an indoor method of gardening that does not require soil. In traditional gardening, the soil holds the nutrients that are necessary for the survival of the plants. In hydroponic gardening, the necessary nutrients are pumped into water and absorbed by the plants, thus eliminating the need for soil. Without the need for soil, plants can be grown in any climate, with some extra equipment and maintenance in more extreme climates. Hydroponics are also more efficient than soil gardening. It takes only 20% of the space when compared to traditional farming and the plant growth is sped up so you can have more harvest cycles than you would have with soil gardening. [9] These characteristics alone make hydroponics very appealing for large company use and home use. At the Sustainability Hub, hydroponic gardening would be ideal because of these reasons, as well. Other advantages include no pests or plant disease and no weeds growing around the plants. This gives the owner peace of mind and saves them the time that it would take to address the issues associated with generic garden maintenance.

Although the premise of hydroponic gardening stays constant, there are many variations of this idea. Solution culturing and medium culturing are the two main types of hydroponic gardening. Medium culturing uses a medium other than soil to grow the plants in. While solution culturing uses solely a nutrient and water solution with no solid medium for the roots. Within these two types of hydroponics, there are various techniques that can be used.

2.6.1 Solution Culturing

Nutrient film technique (NFT) is usually what people think of when they think about hydroponics. The nutrient film technique (NFT) is a form of solution culturing. For NFT, a shallow pipe with holes drilled in top is used. PVC pipe is commonly used because it comes in various sizes and is easily attainable. The pipe should be tilted so the nutrient pump can be at the top and use gravity to help the nutrient solution move down the pipe to all the plants and then is recycled back to the system. The holes are where the plants are placed, the plants should be placed far enough so that the roots can touch the nutrient solution. While this technique is considered to be easy to set-up and maintain, there are some issues that come along with it. For this technique, water flow needs to be constant. So a major concern is if the water pump stops working for whatever reason, it is likely that the plants will die soon after. The pH of the nutrient solution should be monitored often as well to make sure it is neutral. Inconsistencies in the pH will be harmful to the plants. [9] [11]

Water culture is a type solution culturing method. This one of the simplest techniques that can be used. A platform, commonly Styrofoam, is used to hold the plants. It floats on the nutrient solution with the plant roots hanging below in the nutrient solution air pump and air stone needed to pump air into water to allow plants to get oxygen. [12]

2.6.2 Medium Culturing

Ebb flow systems is another commonly used technique. As opposed to the NFT, this method is a technique is medium culturing method. In this system plants are placed in some type of medium that's not soil. The medium serves are a way to hold the roots in place, it does not serve as a nutritional source. A nutrient solution is pumped into the medium, allowing it to be thoroughly soaked by the solution. The pump is then turned off while the plants absorb the nutrients and the solution drains downward into a reservoir where it will be recycled. When the plants need nutrients again the pump is turned on allowing this process to repeat periodically. This technique is best for short/small plants, such as herbs. This system is easy to set-up and maintain but does require regular cleaning to avoid mineral build up in the pump. If build up did occur, this would prevent the plants from getting the nutrients they require to survive. [9] [12]

2.7 Aquaponics

Aquaponics is an alternate form of hydroponics. This of gardening that allows you to raise fish and grow plants all in one system. This may be appealing to the Sustainability Hub for added aspect of having fish tank as well. Within this system water pumps to the fish tank, then to plants, and from the plants it is then recycled back to the pump. This system uses the waste from the fish as a fertilizer to provide nutrients to plants. Medium culturing and solution culturing can be used in the technique. One issues is that the fish tank will have to be cleaned often to avoid algae and other bacterial growth. [12] [13]

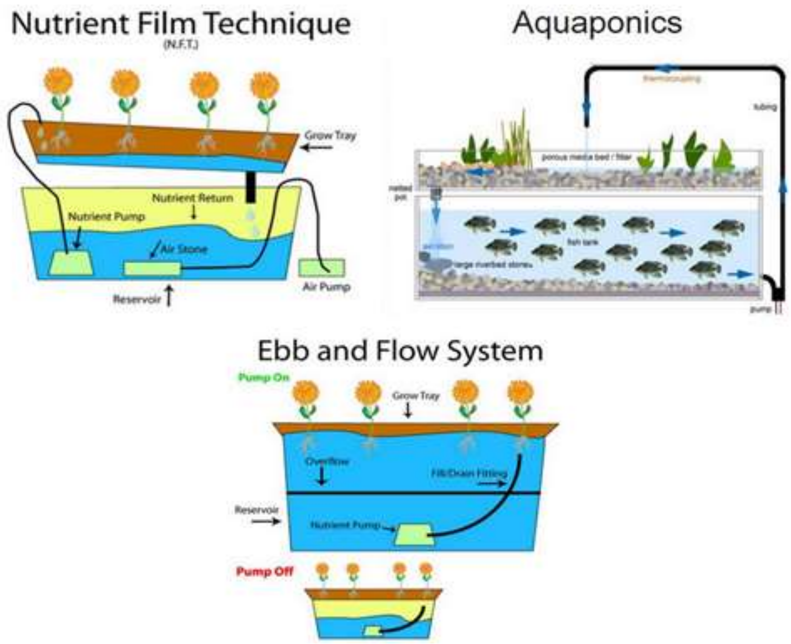


Figure 2-3: Basic Systems for each technique discussed. Retrieved from: http://epics.ecn.purdue.edu/sgsc/projects.html

Our sponsors at the Sustainability Hub have expressed interest in having an indoor garden that will allow them to grow herbs. For this reason, it is believed that one of these methods discussed will best fit their needs.

2.8 Plant Selection

Choosing the plants or herbs to be used in the garden is going to be very reliant on the access to sunlight and amount of available water, and the amount of other maintenance required by employees of the Sustainability Hub to successfully grow and harvest these plants. The glass windows that surround the first choice area for the garden are east-facing and provide and appear to provide an adequate amount of sunlight for photosynthesis. However, as we do not yet know the amount of water that the system will be able to provide, choosing herbs that do not require a substantial amount of water and maintenance to grow and use will be essential to the success of the garden.

While most types of plants can be grown hydroponically, there are many factors to consider when choosing the best plants to grow in a certain hydroponic system. Our focus is to see what herbs and possibly vegetables can be grown with little to no maintenance and will produce a high yield of produce. Important factors to be considered are the size of the roots, the size and weight of the produce itself and whether it is easy to maintain. Plants with roots that take up a lot of space should be grown separately as to not disturb the growth of the other plants [14]. The size of the produce may affect the growth of the individual plant depending on the weight and if the vegetable has support. Some vegetables and herbs that are easy to grow are: lettuce, tomatoes, radishes, chives, oregano, and basil. Because of the weight of the produce, tomatoes are harder to grow because they require a support while growing. Radishes are relatively easy to grow but grow best in direct water culture which is not suitable for our location. Lettuce and basil are both easy to grow and grow best in an NFT system. On the other hand, oregano and chives grow best in an ebb and flow system or a drip system. Another thing to keep in mind is that herbs grow best at about 70 degrees, so a light may need to be used to obtain that heat.

2.9 Water Treatment

Water treatment is a necessary step in making sure the water will not negatively affect the plants grown. Possible defects are stunted growth, mineral toxicity, bacterial contamination, and elemental deficiency symptoms. Filtration and sanitation are the two main steps in water treatment. Filtration will separate organic material from the water supply, but to prevent disease, sanitation needs to be performed. The disc filtration method is commonly used when the water is not as contaminated. This usually includes rainwater collected off roofs. Disc filter are made to last a long time with easy maintenance in mind. This type of filter has layered rings that the water passes through at high pressures. Debris and other organic materials are separated from the filtered water. This step in the treatment process will prevent organic material from contaminating the water. Other things to keep in mind are the pH level and the nutrient concentrations. The pH level that the garden should be kept at is ~ 6.3. [10] Nutrient concentrations can vary depending on what is being grown. Different plants require different nutrients, therefore this issue can be addressed when the types of plants are chosen.

2.10 Summary

This background section identifies the main components of our project, primarily by giving background on the different parts of a water harvest system. We provide a background on the different hydroponic systems that can be chosen from to be incorporated into our system at the Sustainability Hub. Also discussed are the types of plants that can be grown in a hydroponic system. Water treatment, while not a great concern when simply collecting rain roof runoff water to water plants, is an important aspect to consider adding if an added grey water system is to be considered in the future. With this background information, we had a good understanding of the components that would go into a water harvest system. Through consulting people like Tom Wall and Derek Lundstrom, we were able to then get a concrete understanding of how our personal project could work.

Chapter 3: Methodology

The goal of this project was to both find a way to harvest roof-runoff rainwater and implement a type of community garden for associates of the Sustainability Hub to use. In order to meet these expectations we focused on the feasibility of structure ideas based on the availability of resources within and around the building. We investigated the process that would need to take place in order to provide the sponsor with the most cost efficient and accessible project.

A number of factors were decided upon while discussing an optimal garden for the Sustainability Hub. We used both the potential for vandalism and the amount of accessible sunlight to determine the location and types of plants to arrange the garden around. Next, our group consulted with the Clark University facilities manager as well as contacts within National Grid that were familiar with the infrastructure of the building. These consultations were done to best educate ourselves with the setup and accessibility of the different floors of the building and enabled us to propose the best location for both the reclamation system and the garden. We also analyzed similar home projects and their budgets to help determine a cost estimate for creating this system at the Sustainability Hub as well as a CAD model to provide a visual to the stakeholders who would be reviewing our project proposal.

3.1 Choosing a Location

The water reclamation system that we planned on implementing at the Sustainability Hub was to be installed to provide a community herb garden with the sustenance it requires for growth while also minimizing the energy needed to do so. Before we could tackle this project, we needed to gain knowledge regarding water harvesting and hydroponics. Once we had the necessary background knowledge to successfully complete this project, our first step was to choose a location for the water harvesting system and the garden. We did so by weighing the pros and cons of each location. Aspects taken into consideration for the garden were accessibility, amount of sunlight, and vandalism. Our initial prospects were the roof, the alley way in between the Sustainability Hub and the Clark University Bookstore, and the sidewalk on the opposite side of the building.

3.1.1 The Roof

The roof was our initial ideal location for the garden and water harvesting system. Our team consulted with Tom Wall, a member of the National Grid facilities staff, and was told that due to the poor condition of the roof, this option would be very unlikely. The roof itself needs to be replaced and only hasn't due to a lack of funding from the university. Another concern about having this system on the roof is getting to the roof posed as a safety issue for anyone who was to go up there, therefore the garden's future caretakers would be at risk.

3.1.2 The Alleyway

Another location considered was the gated alleyway along the side of the Sustainability Hub. However, due to lack of sunlight and ease of access this location was not ideal. Even if the alley got enough sunlight throughout the day, city regulations and fire codes would most likely have prevented us from creating a sufficiently sized garden in that area.

3.1.3 The Sidewalk

Our third option was then to have the garden located on the other side of the building and exposed to the public. Our sponsor originally deemed this area as a good idea. However, after considering that the garden would be constantly open to tampering and vandalism on the corner of the inner city of Worcester, we came to the conclusion that a public garden would most likely not work out as planned.

3.1.4 Inside the Building

After analyzing the three initial potential garden locations, it was time to think outside the box; or in our case, inside. The Sustainability Hub is modeled after the perfect sustainable home. Its displays include a kitchen, a living room, a washer and dryer, and also a front yard. The mock front yard is located at the front of the building and separated from the street by big glass windows. Our team decided that this area would definitely be the most suitable spot for the garden. It is shielded from the street, yet provides the feel of being outdoors from the way the Sustainability Hub is set up. There is ample space for a garden on the imitation grass, and best of all, the glass windows provide the area with plenty of sunlight throughout the day. Figure 3-1 displays the outside view from the front of the Sustainability Hub. It shows the large glass windows that border the inside location for the garden. Figure 3-2 shows the inside entrance where the garden would be located.

Figure 3-1: Outside Windows of the Sustainability Hub showing that an ample amount of sunlight could be provided to the garden if the system were to be located in the entrance of the Sustainability Hub.

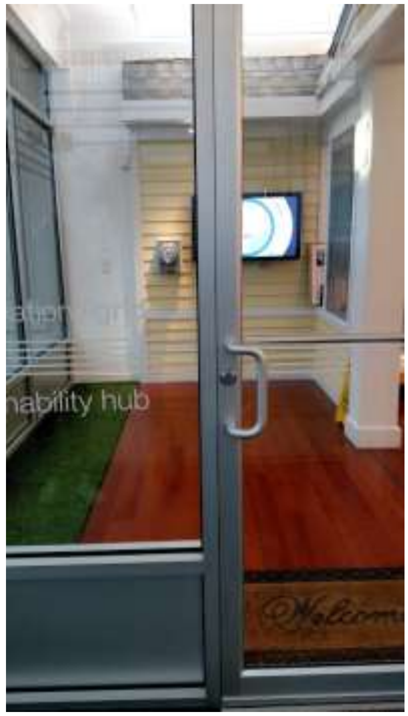


Figure 3-2: The inside location where the garden could be located.

3.2 Preparation Meetings

After, our group decided that we needed more information about what the limitations of the building were. Because the building is owned by Clark University, we not only spoke to Tom Wall, a Project Manager for National Grid, but we also met with the Associate Director of facilities at Clark University, Derek Lundstrom.

3.2.1 Tom Wall

Tom has a lengthy history with both our sponsor and the building owners. He spent 25 years as a facilities worker for Clark University and is extremely knowledgeable about the Sustainability Hub's layout and infrastructure. He also works for National Grid as a Project Manager. Tom quickly became our main contact for building related questions and issues. Within just a few minutes of meeting him, he had already begun to help us give this project a more specific direction. Tom was extremely effective in helping our team separate goals that were unrealistic from what we could actually implement. He was able to educate us on the poor status of roof conditions and the difficulty in accessing it, which quickly eliminated our idea for a rooftop garden. Tom also reached out to the Clark University dining hall and scheduled an appointment for our group to view a hydroponic system that is currently up and running at the school, which allowed us to get more of an idea of the feasibility of sizes of gardens and types of plants our group could grow. Lastly, got us in touch with his friend and Assistant Director of the Clark facilities crew, Derek Lundstrom.

Figure 3-3: Shown is the Hydroponic garden located in one Clark University's dining halls.

3.2.2 Derek Lundstrom

Derek was another key element in our search for building access and project feasibility. He was able to provide us access to the alleyway next to the Sustainability Hub, as well as the basement of the building. His knowledge and expert opinion further enabled our group to determine the materials we would need and helped us better choose the placement for each piece of the water reclamation system.

3.3 Presentation

For this project to move forward and get the necessary approval and funding, our team created a presentation that included the critical information regarding our proposal. This presentation was created to be presented to our sponsors at the National Grid Sustainability Hub and representatives of Clark University. To perfect our presentation, we had our liaison with National Grid, Adrian Hubley, give us feedback. Our presentation includes a summary of our project along with what we hope to bring to the Sustainability Hub with the addition of our water harvesting system and garden. After getting feedback from Adrian, our group added a bill of materials, and a CAD model to the presentation.

3.3.1 CAD Model

For the location and addition of the system to be apparent to someone who has not been working closely with our group, it was decided that a CAD model be made in order to show this. Before the CAD model could be created, a 3D modeling software needed to be chosen. Our options included, SolidWorks or AutoCAD. After considering the capabilities of each program, the best fit was chosen. For this CAD model to be accurately created, specific measurements of the building, such as the length of the building and the height to the lower roof, were needed. To gather this information, our group went to the Sustainability Hub and recorded it ourselves.

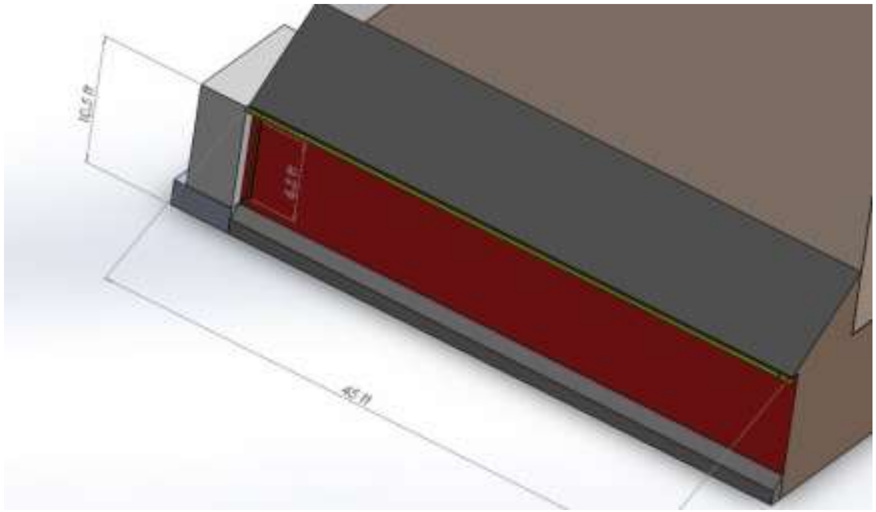


Figure 3-4: The CAD model showing the dimensions of the building side and the gutters that would be installed. The gutters can be shown leading into the back shed.

3.3.2 Bill of Materials

A bill of materials (BOM) was created to give an accurate estimate for the total cost of the proposed water harvesting system. Our team included the cost of the gutters, the water barrel, PVC pipe, the water pump, and the cost of labor for the installation of the gutters and a through the floor hole.

Bill of Materials			
Item type	**Item Name**	**Model #**	**Price**
Gutters	Amerimax Home Products 5 in. x 10 ft. K-Style 30-Degree White Aluminum Gutter	24002010120	$19.98 / 10ft *Need~45ft
PVC	Need to determine size wanted		
55 Gallon Barrel	55 Gal. Black Industrial Plastic Drum	PTH0934	$69.99
Water Pump	FloJet Quiet Quad Water System Pump - 12VDC		$77.70
Gutter and hole Installation			$50/hr * Need 2 workers for 4 hours
		Total Price:	~ $640

Figure 3-4: Bill of materials showing the individual cost of each item and the total cost of the entire system.

Chapter 4: Results

4.1 The Water Harvesting System

As stated in the background there are key components that go into creating a water harvesting system. While this project was not approved in time for the system to be created, we have planned out each of locations and materials of the different components of the water harvesting system. These key components include the catchment surface, the gutters and downspouts, and the storage tank.

4.1.1 The Catchment Surface

The catchment surface in our case would clearly be a section of the roof. After consulting with Tom Wall and the Clark University facilities staff, the most suitable catchment surface for the rainwater would be the angled roof at the side of the building (Figure 1-2). The smoother the surface, the more efficiently the rainwater will trickle down into the gutter system. The current roofing already provides us with a smooth, tar surface, angled perfectly for gutter collection, so it would be more cost-effective to leave it intact and incorporate it into the system.

Figure 4-1: View of the catchment surface from behind the building

4.1.2 Gutters and Downspouts

Next we need to decide on the type and size of gutters and downspouts to use. Since we are only using the one area for water collection, only one gutter would need to be installed parallel to the long side of the roof. In terms of a downspout, it is possible to attach a rubber tubing to the exit of the gutter and feed it into the extremely convenient shed of which the roof houses. The bill of materials shows that the gutter would cost ~ $20/10 ft. With the side of the sustainability Hub being ~ 45ft we would expect spending $80-$90 of gutters. The gutter would then lead into the shed that is behind the Sustainability Hub. This leads us to the discussion of the storage tank location.

4.1.3 The Storage Tank

Figure 1-2 displays the inside of the shed on the side of the Sustainability Hub. As you can see, there is plenty of space for a water storage tank in there. Placing the cistern indoors minimizes the negative impact that the weather and other external forces can have on the system. The shed is kept locked at all times and has no cracks or openings for wildlife or leaves to enter the room. Our team believes that this is the best location for the cistern. However, there is also potential to have place the cistern located in the basement of the sustainability hub, and even directly next to the hydroponic system in the front of the building.

Figure 4-2: The inside of the shed behind the Sustainability Hub where the cistern could potentially go.

Through consulting Derek Lundstrom, our group gained access to the basement of the Sustainability Hub to assess the feasibility of having the water cistern there. This would be done using gravity to run the water from the gutter, through tubing, and into the barrel for collection and storage. Figure 4-3 provides an image of the optimal spot in the basement for said storage tank. This section of the basement is clear of debris and level. It also sits directly beneath the front of the Sustainability Hub, where our garden will be located, and gives the plants easy access to the water through a hole in the floorboard.

Figure 4-3: Location in the basement of the Sustainability Hub where the citern could be located

The third option for the location of the water storage tank is directly next to the garden at the front of the Sustainability Hub. This would be our last choice. This option would require approval from Clark University and other stakeholders because to run the tubing from the gutter directly into the front of the building a hole would need to be created through the side of the building. Having the cistern directly next to the garden also takes up a lot of the limited space in the area, as well as being an eyesore to the entrance of the building.

While there are many location options for the water storage container to be placed, we have decided that the water will be stored in a 55 gallon barrel. The cost of an industrial barrel of this size would be $69.99, as can be seen in our BOM.

4.2 Presentation at the Sustainability Hub

The presentation day was made up of two separate project presentations, our team and another IQP team focused on solar panel implementation at the Sustainability Hub. We invited our sponsors, our advisor, National Grid and Clark University employees who helped us to design this project, as well as outsiders who had a general interest in hearing our presentation. The audience was also made up of invitees from the solar panel IQP team. There were also a few notable figures in the crowd who represented the National Grid stakeholders that we were presenting our pitch to. These company stakeholders included Patrick Cody, the Lead Engineer Supervisor for the Worcester branch; Lisa Morgera, Senior Analyst and Demand Response Coordinator; Mike Thompson, Manager for Account Development; Nicholas Corsetti, Senior Program Manager for Smart Energy Solutions; and John Isberg, Director of Community and Customer Management. Their approval is needed before any system implementation can occur so their presence was essential to our proposal. John Isberg is also organizing plans to create another Sustainability Hub for National Grid in Providence, Rhode Island based off of the success of the Worcester location, and is incorporating our proposal into the new facility.

4.3 Collaboration with Solar Panel Team

At the end of our presentation our team had a chance to discuss our presentation with the solar panel IQP team and their advisor and potential implementations to the Sustainability Hub that could overlap the two projects and maximize sustainability within the facility. Two ideas that were brought up were creation of a heating coil for the water storage tank and using the harvested solar energy from the other team to power our pump and move the water from the cistern into the hydroponic garden. Adding a heating coil around the water storage tank eliminates the possibility of ice being formed during the winter months and ensures the greatest amount of water available for cycling through the garden. Replacing an electric powered water pump with one that uses solar energy would allow the hydroponic system to run entirely on its own, without the aid of outside energy sources. Implementing an entirely self-sustaining garden reflects the epitome of what the Sustainability Hub is about and would be a perfect addition to the building tour.

4.4 Incorporating the Garden into the Tour

While our project contains two main parts, the garden and the water harvesting system, the only visible part of our project will be the garden. This garden can be incorporated into the Sustainability Hub tour serving as an educational point for the National Grid customers. Educational information can be placed near the garden showing how water harvesting systems and hydroponic gardens work. As well as information educating them on how to add these systems into their home so they can live more sustainably and save money. With the Sustainability Hub always looking for ways to stay modern with their sustainable methods, our project provides the National Grid Sustainability Hub with a new and current way to provide their customers with more knowledge.

Chapter 5: Conclusion

Adopting a "green initiative" as the National Grid has done with both the creation of the Sustainability Hub and the implementation of energy saving programs for customers is a smart and environmentally-friendly approach on B2C marketing. The goal of our project was to provide the Sustainability Hub with the ability to incorporate a new type of sustainability into the facility, roof water reclamation and hydroponic gardening. Our group consulted with our sponsors and facilities teams from National Grid and Clark University to investigate, analyze, and determine the best method and location for project implementation. Our team constructed a CAD model and bill of materials for the system and garden and organized a presentation to National Grid stakeholders to propose the plans for approval. This chapter provides our recommendations for action that the Sustainability Hub can take to expand their vision for a sustainable home.

5.1 Recommendations

Based off feedback back and our thoughts, we have a simple recommendation. This school year, 2015-2016, there were two IQP teams working with the National Grid Sustainability Hub. We believe that an integration between the two projects is possible. The other IQP team was working on designing a solar awning for the sustainability Hub so they could utilize the solar energy that is abundant and not currently being used to the fullest of its potential. Once this system is installed, the solar energy could be used to power the pump that the will be used to water the garden. This would further increase both of the project's sustainable theme.

References

[1] Texas Water Development Board. (1997). Texas Guide to Rainwater Harvesting 2nd ed. Austin, Texas: Texas Water Development Board in Cooperation with the Centre for Maximum Potential Building Systems.

[2] Water Quality Association. (2015). Hardness. Retrieved from https://www.wqa.org/Learn-About-Water/Perceptible-Issues/Scale-Deposits

[3] Hammerstrom, J., & Pushard, D. (2015). Is Rainwater Harvesting a Good Investment? Retrieved November 12, 2015, from http://www.harvesth2o.com/Is_RWH_a_good_investment.shtml

[4] Chang, A., & Carroll, M. (2015). Map: Massachusetts water usage and cost, by town. *The Boston Globe*. Retrieved November 14, 2015, from http://www.boston.com/yourtown/specials/water/massachusetts_water_usage_map/

[5] Kinkade-Levario, Heather. *Design for Water : Rainwater Harvesting, Stormwater Catchment, and Alternate Water Reuse*. Gabriola Island, BC, CAN: New Society Publishers, 2007. ProQuest ebrary. Web. 7 October 2015.

[6] Daily, C., & Wilkins, C. (2012). *Basic Components of a Rainwater Storage System* (1st ed.). The University of Arizona. Retrieved from http://extension.arizona.edu/sites/extension.arizona.edu/files/pubs/az1565.pdf

[7] Gdrc.org,. (2016). *An Introduction to Rainwater Harvesting*. Retrieved 1 March 2016, from http://www.gdrc.org/uem/water/rainwater/introduction.html

[8] "Climatology for Worcester MA." *Earth System Research Laboratory: Physical Sciences Division*. U.S. Department of Commerce, 2015. Web. 10 Nov. 2015.

[9] Hossain, M. A., Hassan, M. S., Mottalib, M. A., & Hossain, M. (2015). Feasibility of solar pump for sustainable irrigation in bangladesh. *International Journal of Energy and Environmental Engineering, 6*(2), 147-155. doi:10.1007/s40095-015-0162-4

[10] Cross, N. (2013). *Guide to hydroponic gardening for the novice: How to grow great vegetables without soil*. Place of publication not identified: Speedy Publishing Books.

[11] "History." *College of Agriculture and Life Sciences*. University of Arizona, 2015. [Online]. Available: http://ag.arizona.edu/hydroponictomatoes/history.htm.

[12] "Students Growing Sustainable Communities (SGSC)." *EPICS Program.* Purdue University, 2015. [Online]. Available: http://epics.ecn.purdue.edu/sgsc/projects.html.

[13] Bednar Jr., A., & Brown, G. (2008). Basic Hydroponic Systems and How They Work. Retrieved October 15, 2015, from http://www.simplyhydro.com/system.htm

[14] Parsons, W. (2015, April 20). 15 Best Fruits, Vegetables, and Herbs for Hydroponics. *1000Bulbs.com*. Retrieved November 13, 2015, from http://blog.1000bulbs.com/15-best-hydroponics-foods/