# Rainwater Catchment

Designed by Team RainBeaus:

Luiz Gustavo, Ethan Ramirez, Laurel Smith, Rebecca Stark

HUMBOLDT STATE UNIVERSITY

Redwood Coast Montessori
A community of joyful scholars

# Table of Contents

# Table of Figures

## Table of Tables

# 1 Problem Formulation

## 1.1 Introduction

The problem formulation section addresses the issue that this project will be solving. The solution will be a rainwater catchment system created by the RainBeaus for Engineering 215, during the fall 2014 semester. This section includes the objective of the project and the black box model.

The client is the Redwood Coast Montessori School located in Manila, California. Since its beginnings in 2005, the school's mission has been to provide K-8 students with a world-class education through independent learning experiences, particularly by interacting with the environment around them. Located in the coastal sand dunes, the students are faced with plentiful hands-on learning opportunities.

## 1.2 Objective

The objective of this project is to design and build an environmentally friendly rainwater catchment system that will water the school's garden. The system will utilize upcycled materials and will be a permanent part of the school for years to come.

## 1.3 Black Box Model

The black box model, shown below, is a visual representation of the world before the project is finished and the state of the world after the project is finished.

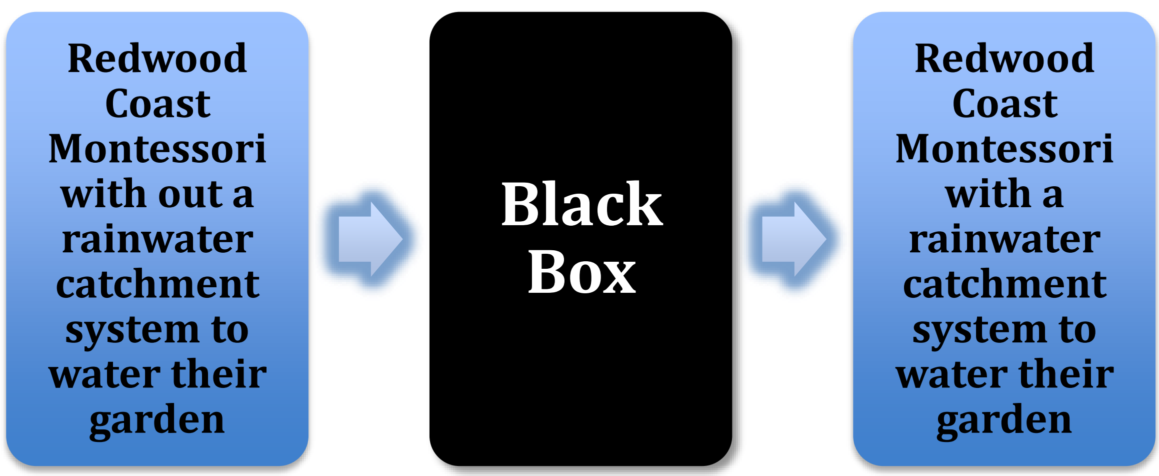



**Figure 1: Black Box Model shows the state of the world before and after the creation of a rainwater catchment system for Redwood Coast Montessori School**

# 2 Problem Analysis

## 2.1 Introduction

This problem analysis describes the requirements and constraints of a rainwater harvesting system to be used onsite at Redwood Coast Montessori. For instance, the system must provide a sufficient amount of water (~5 gallons/day) for K-6 students to tend to a garden of edible plants on a weekly basis. This problem analysis also lists and describes client specifications, criteria and constraints, usage, and production volume.

## 2.2 Specifications

Specifications are items that are completely necessary and must be completed in order for the project to be successful. The following specifications were discussed with the client and determined to be necessary in order to adequately satisfy the client's needs. The primary requirements for the Redwood Coast Montessori Rainwater Catchment System include:

- Removability
- Location (close proximity to the garden)
- Sign stating that water is not intended for human consumption
- Containing a lockable water spigot
- Maintaining water quality standards

## 2.3 Considerations

These elements must be considered in order to ensure the success of a functional, durable, and reliable rainwater catchment system at Redwood Coast Montessori. The primary factor in determining these considerations is the site's coastal location, as this environment will definitely play a role in the lifespan of this system.

- Salty air is corrosive to certain materials (particularly metals)
- Sand exposure can weaken certain materials, especially when combined with salt exposure
- Children will be using this system and need to be able to do so safely and easily
- Vandalism of the system is always a possibility
- Theft of system parts

## 2.4 Criteria and Constraints

Criteria are requirements that can be ranked accordingly, provided they are still within the confines of a number of constraints. These rankings can be changed, but the end product that will offer the highest amount of client satisfaction is dependent upon the criteria most important to the client. The table below describes design aspects that must be met within the corresponding constraints.

**Table 1: A table of Criteria and Constraints for the rainwater catchment system created by the RainBeaus**

| Criteria | Constraints |
|---|---|
| Adaptability | School administrators must be able to add supplemental tanks, if necessary |
| Easy to use for children | Ease of use for K-8 children |
| Safety | Poses no risks to students |
| Durability | Functions safely for a minimum of five years with minimal maintenance |
| Cost | We have a $400 budget, but keeping our costs under budget is desirable |
| Numbers of gallons stored | 55-300 gallons, more is better |
| Percentage of Upcycled Materials | Use of recycled materials, more is better |
| Aesthetics | Professional appearance, fits in with environment |
| Maintainability | Non-professionals must be able to fix/maintain system using a maintenance sheet |
| Educational | Encourages student interest in sustainability |

## 2.5 Usage

With the help of teacher supervision, Redwood Coast Montessori students, grades K-8, will use the rainwater catchment system to satisfy the school's gardening needs. Approximately five students will use the system every two to three days. The students will take turns filling up watering cans to be used on the various plants around the campus, including those in the green house, around the entrance, and in garden beds. The system will also be used to inform students about the process of rainwater catchment and the importance of sustainability.

## 2.6 Production Volume

One system will be constructed for Redwood Coast Montessori. This system will have the ability to add one or more units. This can be completed at any point in the future by a non-professional using written instructions that will be left at the school after the original system is finished.

## 2.7 Literature Review

The literature review is a section of research done by the RainBeaus that contains information that will help advise the team while designing the rainwater catchment system. The writing for the literature review is all done by the RainBeaus and is based off of information from various sources that are listed in Appendix A.

### 2.7.1 Montessori Education

The advent of Montessori education began in 1907 with the physician and educator Maria Montessori. Her idea of alternative education spread to the United States. Nancy McCormick took up the cause in the 1950s. Montessori's idea was to create an educational system based upon the idea that a child is eager for knowledge and learns best in a system that develops the whole child (American Montessori Society 2013). A Montessori education is meant to develop a child's physical, social, emotional, and cognitive ability. A traditional educational system only helps to develop a child's cognitive development. Every Montessori school must have certain components that are recognized by the American Montessori Society (AMS).

These components consist of multiple age groups, large uninterrupted blocks of work time (usually 3 hours), and the individual choice of the child to choose a work activity (American Montessori Society, 2013).

#### 2.7.1.1 A Typical Classroom

Montessori classrooms create a very different environment from a typical public school classroom. The classroom is set up to promote "independence, freedom within limits, and a sense of order" (Montessori, 2014). The classroom contains areas arranged by subject, as well as the freedom of movement for the children. An example of a typical classroom is shown below in Figure 1. The teacher is meant to help the students by creating projects specific to each child, promoting improvement. The teacher is never meant to correct the child but instead help them learn by themselves. The classroom is also mixed with students from several grades. This mixed classroom helps to promote problem solving, peer teaching, and socialization of all students (Montessori, 2014).

**Figure 2: A picture of a typical Montessori Classroom with children working independently http://goo.gl/N7I9SF**

#### 2.7.1.2 K-8 Children

Children in grades K-8 are considered to be school-age children, the stage of development from ages 6-12. At this age, many children are becoming ready for more independence in every aspect of their life, including their education. It is important to promote sound decision-making and self-discipline at this time in their development. A typical child is starting to understand logical concepts but tends to focus on one aspect while ignoring others. Their ability to problem-solve is fairly developed (Child Development Institute, 2013). A child's self-confidence is very important at this age and a negative experience can affect them for the rest of their lives. At this age, children begin to: have the ability to reflect on their own successes and failure; widen their world to include peers and adults outside of their family; and understand social comparison and competition (Eccles, 1999). A child at this age needs structure and support to promote a healthy development.

#### 2.7.1.3 Redwood Coast Montessori

Redwood Coast Montessori is a traditional public Montessori school located in Arcata, California. The school's mission is to be a school for diverse students in grades K-8, in

Humboldt County, to have the option to attend a school with a high caliber educational system based on the Montessori Method. The school began in 2005 as a single classroom on a traditional public school campus. As enrollment grew, the Montessori became an independent public charter school in the Arcata School District. The school also shares the area with the Manila Community Center, moving to its current location in 2012. (Redwood Coast Montessori, 2014). The school's current location is in the coastal sand dunes and allows the children to have an interactive education with the rare sand dune environment.

### 2.7.2 Site Constraints and Client Conversation

Redwood Coast Montessori asked HSU engineering students to design and develop a rainwater catchment system that would provide water for a surrounding garden. This water would be non-potable and only used for gardening purposes. The storage tank must be equipped with large, noticeable signs stating that collected water is not meant for human consumption. The client's primary requests are for the system to be semi-permanent and to be built in a manner that allows it to be moved to different stations throughout the school. Rainwater will be stored in large barrels spanning over a 55 gallon to 300 gallon range. The storage system will also have the capabilities to add further storage drums depending on the client's future water needs. These barrels will be used as fill stations for watering cans and again, must be clearly labeled that stored water is not to be used for direct human consumption. As a whole, the system must be functional, childproof, uphold water quality standards, and be designed in a manner that deters possible theft and vandalism. Redwood Coast Montessori is located in a shared space with the Manila Community Center, which occasionally serves as a concert venue further increasing the need for durability and theft deterrence.

The school has a roof that holds potential for a rooftop catchment system, with sloped gutters and unattached downspouts. However, the materials used to construct the roof are unknown, possibly containing unhealthy levels of zinc, copper, lead, or other materials treated to repel molds, mosses, and algae.

The site itself is located on the Samoa Peninsula, a coastal location subject to considerable sand, fog, salt, and rain, all of which create conditions that drastically reduce the lifespan of many materials. Consequently, the catchment system must be durable enough to withstand these conditions, while also retaining portable qualities and manageable maintenance levels for administrators. It must be accompanied by clear instructions for maintenance of system health and a water quality high enough to safely use stored water on edible plants. If water quality is determined to not be able to meet this standard, collected rainwater can be used for ornamentals only. Maintaining good hygiene is essential for this project, as children will have direct contact with the harvested water.

**Figure 3: Garden at Redwood Coast Montessori that will be supplied with harvested rainwater, taken by the RainBeaus**

### 2.7.3 Climate in Arcata

The climate in Arcata is needed by the RainBeaus to pick materials to withstand the weather along with precipitation information. The information is used to find that amount of water that could be captured and stored for use by Redwood Coast Montessori

#### *2.7.3.1 General Characteristics of Arcata Weather*

Climate is a subject fundamental to rainwater catchment system projects, especially the precipitation aspect. Based on reliable precipitation information, it can measure the amount of water that it is possible to catch and store in the building and evaluate the feasibility of the work. The climate of Eureka region is maritime climate, prevailing throughout the year and 90 percent of the annual precipitation occurs from October through April. Temperatures are moderate and the lowest rates are around 30 degrees Fahrenheit while the highest are around 70 degrees during a typical year. This small temperature range is due to the city's close proximity to the ocean (National Weather Service Forecast Service, 2014).

#### *2.7.3.2 Amount of Predicted Water Harvested Monthly*

To calculate the amount of water that can be harvested monthly the area of the roof is needed. Figure 4 below shows the section of roof that will be used for water catchment system.

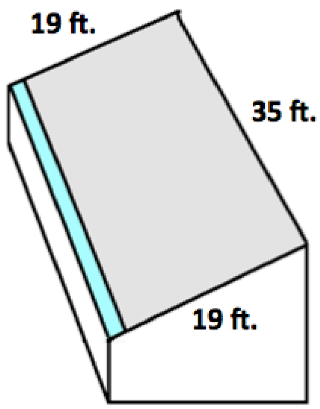



**Figure 4: A picture of the section of roof that will be used to catch water for the system, created by the RainBeaus on 11/17/14**

The area of the roof is then multiplied by the rainfall depth in inches and then a conversion factor of 0.623 to get the amount of harvested water in gallons (Woodson et al, 2014). This formula was used to create Table 2 below that shows the predicted gallons of water that could be harvested every month at Redwood Coast Montessori. This is also shown in Figure 5, which is a graph of the month versus the predicted amount of harvested water.

**Table 2: The predicted gallons of water that could be harvested every month at Redwood Coast Montessori created by the RainBeaus on 11/17/14, the average rainfall from http://goo.gl/1y9pgt**

| Month | Average Rain Fall (in) | Harvested Water (gal) |
|---|---|---|
| January | 4.95 | 2051 |
| February | 4.21 | 1744 |
| March | 7.86 | 3256 |
| April | 3.25 | 1346 |
| May | 2.09 | 866 |
| June | 1.25 | 518 |
| July | 0.33 | 137 |
| August | 0.26 | 108 |
| September | 0.43 | 178 |
| October | 3.91 | 1620 |
| November | 5.14 | 2129 |
| December | 8.31 | 3443 |

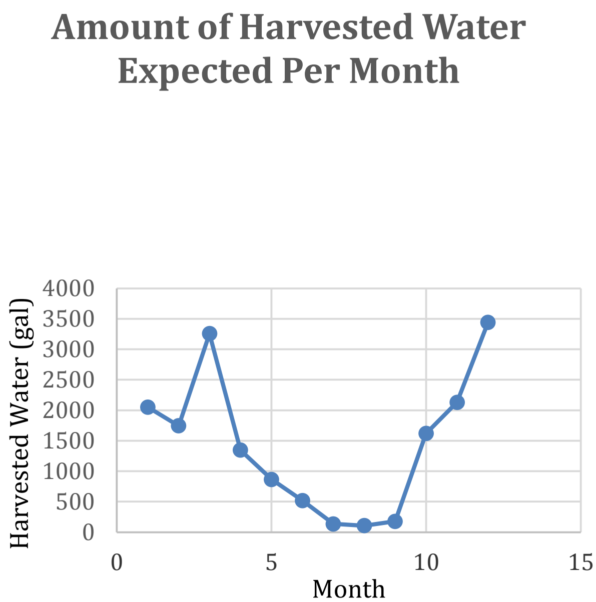



**Figure 5: A graph of the month versus the amount of predicted harvested water at Redwood Coast Montessori created by the RainBeaus on 11/17/14**

### 2.7.4 Rainwater Collection

When creating a rainwater catchment system it is important to consider how to collect the water for storage and concerns of the catchment process like debris and contamination.

#### *2.7.4.1 General Characteristics of Rainwater Harvesting Systems*

The most common methods to collect rainwater in urban buildings use roofs with gutters, though the catchment area may be a hillside, or even a parking lot. Therefore, there is a range of solutions that comply with the objective of rainwater utilization. For instance, the storage may be buried, suspended or on the ground. Basically, "the four elements of rainwater harvesting systems are collection area, conveyance, storage and end use" (Jensen, 2008).

### 2.7.5 Contaminants and Water Storage

The general health of a rainwater catchment system depends primarily upon factors related to the site of harvest, methods of storage, and the point at which stored water leaves the system.

#### *2.7.5.1 Rooftop Debris*

For a rooftop catchment system, large and small-scale debris often collects at the point of catchment and can consequently flow into the system, a problem frequently combated by the use of filtration systems. Most of the items that collect on rooftops are some form of organic material, including sticks, leaves, dirt, bird droppings, insects, as well as contaminated litter (World Health Organization 2008). As they decay, these items all degrade the quality of stored water, as well as causing sediment buildup, which impacts the overall effectiveness and functionality of the system. Screens are often placed in the gutters that deliver water to the storage tank, preventing debris from reaching the tank (Macomber, 2010). However, these screens must be cleaned periodically to prevent debris buildup that would block water from entering the gutters (Macomber, 2010).

### 2.7.5.2 Microbial and Pathogenic Contamination
Microbial and pathogenic contaminations are further potential health risks that often arise in improperly filtered and stored rainwater. E. Coli, a bacterium found in the intestinal tract of warm-blooded organisms, is frequently found in stored rainwater (WHO, 2008). Pathogenic contamination is marginally less common, but similarly hazardous to public health. Cryptosporidium, Giardia, Campylobacter, Vibrio, Salmonella, Shigella and Pseudomonas are all pathogens that can be found in rainwater, though in smaller concentrations than unprotected surface waters (WHO 2008).

### 2.7.5.3 First Flush Diversion Systems
The first few minutes of rainwater collected from a roof contains higher levels of contaminants and should not be stored in a rain barrel for use on plants. Higher microbial concentrations, for instance, are associated with the first flush of rainwater, though concentrations generally decrease as seasonal rainfall continues. (WHO, 2008). Diversion systems are often enacted to combat contaminants transported by rainfall early in the season. First flush diverter devices are ordinarily installed in one of two locations: directly before the tank or near a downspout (Macomber, 2010). In terms of functionality, a first flush diverter is typically a device comprised of a PVC pipe with another perpendicularly attached PVC pipe, containing a buoyant ball (Macomber, 2010). This ball gradually floats to the surface as the system collects the first flush of rain, the pipe arm becomes full with the ball having completely floated to the surface, allowing rainwater free of debris to flow into a storage tank (Macomber, 2010). A small hole at the end of the pipe arm allows water to slowly flow out of the device, preparing the system for the next rainfall (Macomber, 2010). To avoid rooftop debris contamination, 10-50 gallons of water should be diverted for every 1000 square feet of roof area (Macomber, 2010). First flush diverters can be either be built or bought commercially.

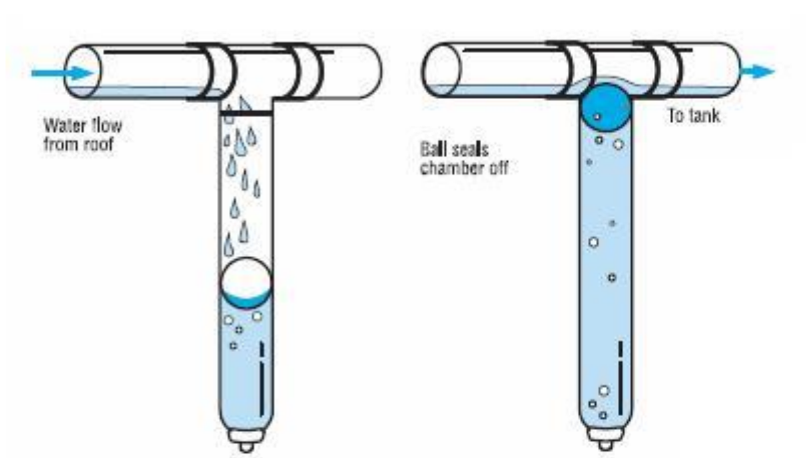



**Figure 6: An example of a T-pipe first flush diverter device, used to divert the first flush of contaminated water away from a storage tank. (Blair, 2014)**

### 2.7.5.4 Roofing Material Contamination
Metal contamination can occur over time via corrosion and is dependent upon materials used in the catchment system. Copper, zinc, and lead are the most common metal roofing contaminants (Hart and White, 2006). Metal used for piping and storage tank linings has been found to be prone to corrosion as storage time increases (Hart and White, 2006). Concentrations of copper and lead have been found to greatly decrease with increased

usage of plastic piping, as well as the reduction of lead within piping solder (Hart and White, 2006).

##### *2.7.5.5 Catchment Tank Contamination*

Storage tanks face a variety of methods of contamination including cracks in the tank, unprotected openings, and using contaminated materials to withdraw stored water (Texas Commission on Environmental Quality, 2007). If a tank is not fitted with a properly sized lid and mosquito-proof mesh, the stored water can become a breeding ground for mosquitoes and other insects that are potentially hazardous to human health.

### 2.7.6 Materials

There are a number of components to consider when constructing a rainwater catchment system. The material type of each of these components has great weight on the usability of the water and how well it can be stored and kept clean.

#### *2.7.6.1 Water Storage Tanks*

Tanks for water storage vary depending on how much water they will be storing and the expected uses of the harvested water. Different materials will affect the usability of the water and the length of time the water can be held before becoming unusable. For smaller scale systems, collection from rooftops, typically use cisterns or small tanks for storage (Gould and Nissen - Petersen, 1999). The type of tank changes the adaptability of the system, making it either more or less difficult to move the structure or add on additional storage systems.

#### *2.7.6.2 Corrugated Steel and Enclosed Metal*

Corrugated steel and enclosed metal tanks are large steel structures that hold in them a bladder for the actual containment of water. They are typically widely available and cheaper in price. Depending on the type of enclosure it can either be assembled on-site or off. Those assembled off-site and then shipped may cost more due to their large size for transportation. Their water capacities range from hundreds to thousands of gallons of water (Texas A&M Agrilife Extension, 2014).

#### *2.7.6.3 Wooden Tanks*

Tanks can be constructed from wood and made to fit any particular need. However, the woods specifications can affect its ability to retain water safely and efficiently. Redwood for example will dry out over time causing it to shrink and water to drip out. Any time of wood needs to be treated for outdoor use and be sealed extremely well to hold water.(Texas A&M Agrilife Extension, 2014).

#### *2.7.6.4 Fiberglass*

Fiberglass is very versatile fairly light and durable. They can be stored above or below ground and applied to nearly every kind of project. Their sharp edges however, can be a danger (Texas A&M Agrilife Extension, 2014).

#### *2.7.6.5 Polyvinyl Chloride (PVC)*

PVC piping is widely used and available in a multitude of applications. The pipes are fairly light and durable. There are several sizes of PVC pipes that can be used for both independent and industrial building. Joining methods for PVC are also numerous with the most common being gasket bell-end joints. The connections can be sealed together with various solvents to insure water tightness (Opus, 2014).

***Screens***

Screens filter out large debris before entering the storage systems. This can be done with a screen tray placed in between pipes; the tray must be cleaned out regularly after rainfall in order to prevent clogging. Another method of screening is to place an open slanted screen between two pipes that stops contaminants as they drop down gutters and allows them to fall away out of the system (Texas A&M Agrilife Extension, 2014).

### 2.7.7 Plant Life

To protect the plants being watered from a rainwater catchment system the collected water must be safe and the amount of water being given to the plants correct.

#### *2.7.7.1 Salinity*

Total soluble salt content of water is measured through conductivity testing in millisiemens/meter. The type of soil the plants are in also affects the tolerability of the plants to salt; more salty water requires that the soils have more drainage ability. There are four groups of plants rated by their tolerance to salt: highly salt-sensitive (0-90 mS/m), mildly salt-sensitive (90-270 mS/m), slightly salt-sensitive (270-635 mS/m), and salt tolerant (635-2365 mS/m) plants (Western Australian Agriculture Authority, 2006).

#### *2.7.7.2 Acidity*

Excessive acidity of water can affect the uptake of nutrients by plants and may reduce the effectiveness of certain pesticides. Normal pH range should be from 6.5 to 8.4 (Western Australian Agriculture Authority 2006).

#### *2.7.7.3 Heavy Metals*

One of the largest impacts for plant health is heavy metals. Many plants need small concentrations of heavy metals like Cd, Co, Cu, Hg, Mo, Ni , Pb and several others to grow but when those concentrations exceed specific amounts it caused heath problem for the plants even leading to their death if the concentration is high enough. Table 3 below shows the critical limits for water used for basic plant agriculture. The numbers are the maximum quantity of the heavy metal that can be in the water without causing plant damage (Anthony, 2002).

**Table 3: A table of the maximum metal concentrations of Cd, Cu, Pb, and Zn in plant water without causing plant damage (Anthony, 2002)**

| | Dissolved metal concentrations (mg $m^{-3}$) | |
|---|---|---|
| Metal | Plants[a] | Aquatic organisms[b] |
| Cd | 2.0 | 0.34 |
| Cu | 2.5 | 1.1 |
| Pb | 15 | 11 |
| Zn | 25 | 6.6 |

#### *2.7.7.4 Water Quality Testing*

Water quality testing is typically done one of two ways. The first is to take a sample of the water and send it out to a water testing facility where they test it for the concentration of heavy metals but also other factors like dissolved oxygen content, pH, concentrations of nitrate and phosphate, and other tests that depend on the testing facility. The other option is to but a water testing kit, which typically includes a Lab Pro and several probes. This allows the ability to test the water at the site and takes less time since the water does not need to be shipped (North Coast Laboratories, 2013).

##### *2.7.7.5 Water Needs*

Vegetables and other edible plants require varying amounts of water to survive and produce food. However, the Australian Heronswood garden calculated an average of 570L of water used per m2 of garden during one of their hottest months and longest droughts (The Diggers Club 2014). Typical gardens require a minimum of 1 inch of water per week. For a 20ft x 10ft garden this is equivalent to approximately 125 gallons; about 5 gallons per 8 square feet (Veggie Harvest 2014).

### 2.7.8 Examples of Rainwater Harvesting Systems

To come up with the best rainwater catchment system for Redwood Coast Montessori it is important to consider which type of rainwater harvesting system to use: agricultural, micro-catchment, or domestic.

#### *2.7.8.1 Agricultural RWH*

Agricultural RWH is an effective way to increase water productivity of rainfall. These can be in situ, collecting water from the surfaces it falls on and storing it within the soil. Landscape requirements must be met in order to effectively implement a system such as this. Landscape surfaces must generate sufficient runoff, elevation differences allow water to be moved by gravity into specially prepared landscapes for collection and storage, and these prepared landscape areas and soil must be appropriately deep and structurally suitable for retaining runoff (Helmreich and Horn, 2009).

#### *2.7.8.2 Micro-catchment Systems*

Specially contoured areas increase runoff concentrating it in a planting basin that allows plants to access it but prevents evaporation. The storing "basin" is rooted within the soil storing it effectively and inexpensively (Helmreich and Horn 2009).

#### *2.7.8.3 Domestic RWH*

Rainwater is collected from rooftops, courtyards, and streets and stored nearby in tanks either above or belowground. Tanks can be made of a vast array of materials however, it is crucially important that they are able to minimize contamination from humans, environmental factors, algae, and mosquitoes. DRWH systems have the advantage of being located within close proximity of their use and can be very cost effective depending on the scale and materials used for the project (Helmreich and Horn 2009).

### 2.7.9 Removal of Water from Barrel

Once the water is caught and stored it needs to be able to be removed from the storage barrel so that it can be used. Extra captured water that can not be stored also needs to have a way to leave the system.

#### *2.7.9.1 Water Spigot*

A water spigot is used as a way to get the water from a rain barrel into a watering can. It has the ability control the flow of water. A water spigot is traditionally placed on the bottom of the barrel so the natural water pressure will cause water to flow out of the spigot. The water is stopped and started typically by turning a knob that is connected to an object (usually a bolt) that either blocks the pipe to stop the flow of water or unblocks the pipe to start the flow (InspectAPedia, 2014). This is shown in the Figure 7 below.

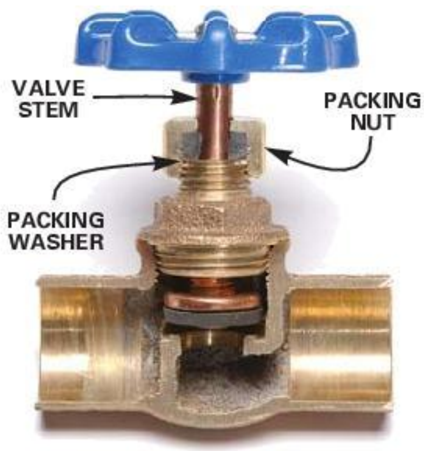



Figure 7: A picture of a typical water spigot, http://goo.gl/kCUGZw

#### 2.7.9.2 Overflow Hole

Once a barrel is full of rainwater there must be a way to get rid of extra water. This is traditionally done with an overflow hole. A hole is drilled near the top of the barrel so that when the water reaches that level it spills out the side of the barrel through the hole. This makes sure that the barrel does not overflow and spill everywhere. The hole can be attached to a pipe so that the overflow water can be directed to a place where the water will be useful and not cause damage to the area around the barrel (Macomber, 2010).

# 3 Alternative Solutions

## 3.1 Introduction

This section describes the alternative design solutions for the rainwater catchment system produced by the brainstorming sessions explained below. In general, each generated solution fulfills the client's specifications and criteria constrained within limitations on costs, mobility, and simplicity that were discussed in section 2, Problem Analysis. All of the alternative solutions are described within their own section that includes a detailed description of the system and a labeled diagram.

## 3.2 Brainstorming

We had two separate brainstorming sessions to compile all of the alternative solutions for this section. In order to encourage creativity, the first session began with the introduction of the wildest ideas possible for catching and storing rainwater. One of those ideas was essentially a gigantic umbrella. We then began brainstorming as many completely different systems as possible. Once we ran out of ideas in that respect, we conversed about what could be altered on each of the systems to make different systems. We then stopped the brainstorming for that session and compiled the workable ideas into several systems. The next brainstorming session occurred a few days later after everyone in the group had time to brainstorm independently. This session's structure was very similar to the first session apart from the fact that we also tried to brainstorm themed systems to get more ideas. One such themed system was the eco-system where every part is as upcycled and environmentally friendly as possible. We then closed this session of brainstorming and compiled the final eight systems. The notes taken during both brainstorming sessions can be viewed in Appendix B.

## 3.3 Alternative Solutions

Alternative solutions are possible system designs for a rainwater catchment system at the Redwood Coast Montessori. The designs described in the following sections were generated in the brainstorming sessions explained above and based upon research conducted in the Literature Review. All of the systems are possibilities for the final rainwater catchment system at the school that will be built by the RainBeaus. The alternative solutions for the school that will be discussed in this section include:

- The Seeing Sandbox
- The Sunken Sandbox
- Filtration Station
- PVC (Pretty Very Cool)
- Eco-system
- The Not As Eco-System
- The Tarp and Tank Wagon
- The Catch ALL

### 3.3.1 The Seeing Sandbox

The Seeing Sandbox is a water catchment and storing system that has educational value in mind. The system is compiled of an above ground sandbox structure, PVC pipes, and a 55 gallon recycled food drum. The start of the system is at the roof of the school. The gutters on the building have several holes in them to allow the water to drain out. All of the holes except the one nearest the system are plugged to insure that all of the water that falls onto the roof while it is raining is directed to the specific hole in the gutter. The water from that hole is then directed away from the gutter using 2in PVC pipe to the middle of the sandbox structure. The sandbox structure is approximately 6ft x 6ft x 1.5ft and is located close to the roof on top of the ground. The box's contents are used to filter the water before it is put into the drum for storage. The entire box is covered in two layers of tarp. The first foot of the box is filled with different sized rocks and sand. At the top is sand followed by small rocks and finally large stones. The use of rocks and sand for a filtration system is called biosand filtration. After the large stones there is a wire mesh support system and screen that holds up the stones about 6in from the bottom of the box. This is where the clean water collects till it is pumped into the storage drum. The water is pumped using a submersible power pump into a pipe that transports the water from the box into a 55 gallon recycled food drum. This part of the system can be seen through a 1.5ft x 2ft glass panel on the box. This panel allows students to see how the system works and encourage student learning about natural filtration.

The food drum is used to store the water and is located 2ft off the ground on a circular cement block. The elevation of the drum is necessary so that when filling up a watering can the person can place the can below the spigot. The spigot is located at the bottom of the drum and can be locked by placing a combination lock around the spigot so the knob cannot be turned. The last part of the system is the overflow hole, which is located at the top of the barrel. This hole is connected to a PVC pipe that directs the overflow water away from the barrel. The entire system's diagram can be seen below.

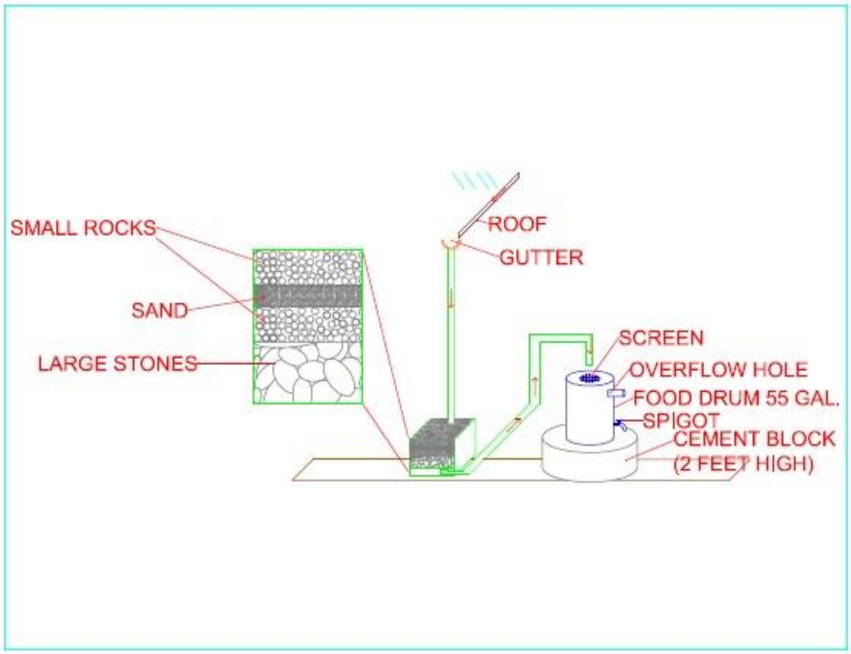



**Figure 8: The Seeing Sandbox diagram created by the RainBeaus on 10/15/14**

### 3.3.2 The Sunken Sandbox

The sunken sandbox is a variation on the previous system the seeing sand box with a few adjustments. The system starts with the rain that falls onto the roof. That water is then directed to the gutters because of the angle of the roof. The gutters on the building have several holes in them to allow the water to drain out. All of the holes except the one nearest the system are plugged to insure that all of the water that falls onto the roof while it is raining is directed to the specific hole in the gutter. The water from that hole is then directed away from the gutter using 2in PVC pipe to the middle of the sandbox structure. The sandbox structure is approximately 6ft x 6ft x 1.5ft and is located close to the roof. The box is all underground with the top of the box being level with the ground. Since the box is level with the ground it allows any runoff water from the surrounding area to go into the box to be filtered and used. The entire box is covered in two layers of tarp. The first foot of the box is filled with different sized rocks and sand. At the top is sand followed by small rocks and finally large stones. After the large stones there is a wire mesh support system and screen that holds up the stones about 6in from the bottom of the box. This is where the clean water collects till it is pumped into the storage drum. The water is pumped using a submersible power pump into a pipe that transports the water from the box into a 55 gallon recycled food drum.

The food drum is used to store the water and is located 2ft of the ground on a support of cinder blocks. The elevation of the drum is necessary so that when filling up a watering can the person can place the can below the spigot. The spigot is located at the bottom of the drum and can be locked by placing a combination lock around the spigot so the knob cannot be turned. The last part of the system is the overflow hole, which is located at the top of the barrel. This hole is connected to a PVC pipe that directs the overflow water away from the barrel. The entire system diagram can be seen in Figure 4.

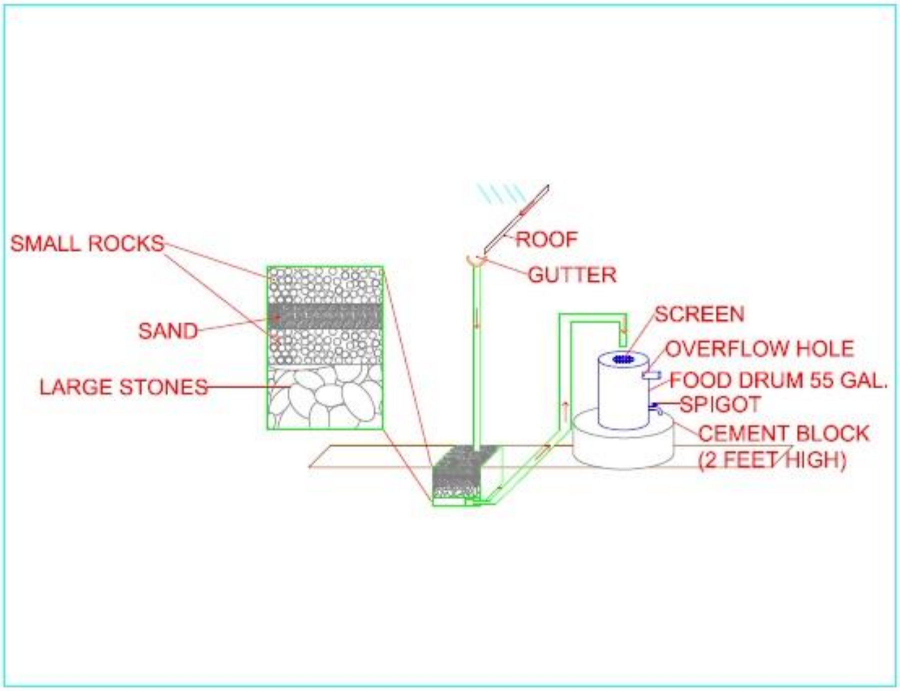



**Figure 9: The Sunken Sandbox diagram created by the RainBeaus on 10/15/14**

### 3.3.3 Filtration Station

The filtration station is a rainwater harvesting system consisting of mostly upcycled materials, including a student-built cement tank and base, a support made of an unspecified material, and a number of components in the biosand filtration system. As suggested by its name, a focal part of this system is the biosand filter, which is comprised of rock, sand, and PVC piping. Though the filter is located about 10 feet above the ground, near the roof, and is equipped with a viewing pane to encourage student interest in the filtration process.

The PVC piping, mosquito-proof mesh screen, faucet, and a few other components of the biosand filtration system will be purchased. The concrete tank and base are comprised of a combination of concrete mixed by the RainBeaus and interior supports made of a structurally sound material, possibly chicken wire. By mixing the concrete, it is possible to build a sizable tank (~100-300 gallons) at a fraction of the cost that would be incurred by purchasing a new one. PVC piping costs approximately $1.59/foot; and the system would need approximately 20 feet, costing about $31.80. One faucet (hose bibb) costs approximately $5. The biosand filtration system will be comprised of mostly upcycled materials. It is necessary to test the support materials in order to determine what material(s) will work to maximize durability in a damp, salty coastal environment. This system is fairly simple in the respect that it only harvests water from one roof.

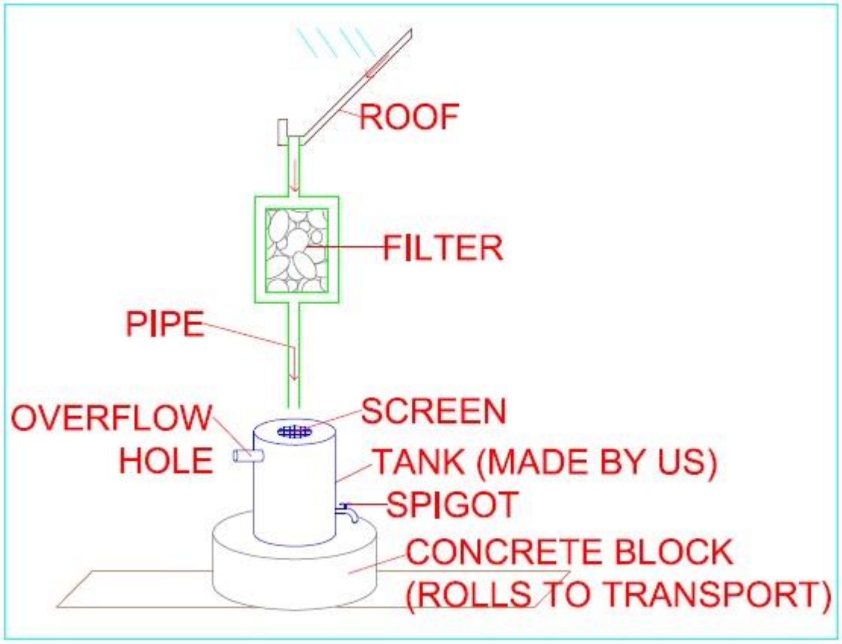



**Figure 10: The Filtration Station diagram created by the RainBeaus on 10/15/14**

### 3.3.4 PVC (Pretty very cool)

System 5 is comprised of mostly upcycled materials, with the exception of the PVC piping. This system relies heavily upon gravity, with captured rainwater flowing from an area of high elevation to a lower elevation. Rainwater flows down the school's sloped roof, bypassing its gutter system via a simple structure made of tarp and wood, into a u-shaped collection device. This device allows water to enter the PVC piping system and to flow through the biosand filtration system. After it is filtered, it flows down more PVC piping, and enters the tank after running through a mosquito-proof mesh screen. It is also educationally-focused, with a biosand filter complete with viewing pane.

The 55 gallon food drum, cinder blocks, wood, support material, and a number of components from the biosand filtration system are all upcycled, minimizing our costs. The mosquito-proof mesh, tarp, collection device, faucet, and PVC piping will all be purchased. PVC piping costs approximately $1.59/foot; we need approximately 20 feet of piping, which will cost $31.80. One 6 ft x 8 ft polyethylene weather resistant tarp is priced at approximately $6. One faucet (hose bibb) costs approximately $5. This system is relatively simple in that it will only harvest water from one roof.

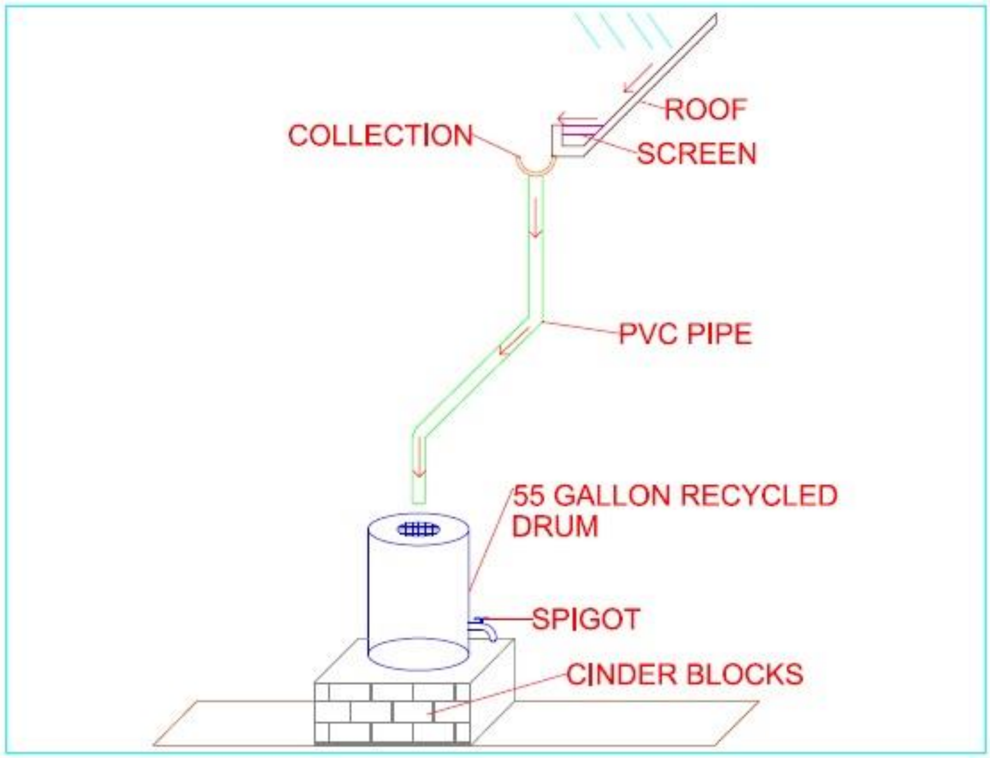



**Figure 11: The PVC system diagram created by the RainBeaus on 10/15/14**

### 3.3.5 Eco-System

The Eco-System is a system designed to use the most amount of recycled, up-cycled, donated, and diverted waste product materials possible while still being sufficiently safe and effective for collecting rainwater. This idea takes advantage of the abundance of wasted plastic materials easy found around Arcata to be resurrected as both plastic piping for transportation of the water from the rooftop and as tank construction material where the water can be stored. The system starts at the roof of the school closest to the system. The roofs gutters have drainage holes that are all plugged except the hole closest to the system, which helps to divert the majority of the rain that falls on the roof through one hole. The water that comes through the gutter hole then travels through the plastic piping away from the roof. The plastic pipes are secured to a drain in the existing roof gutter in such a way as to allow for easy removal if it is needed in the future.

The water that is traveling through the plastic pipe then goes through a biosand filter that cleans the water for storage. From the filter the water is finally taken to a water tank that is compiled of trash (mostly old bottles), wire mesh and cement. The tank is located 2ft of the ground on top of a foundation of earth tires. The added elevation to the tank will allow a watering can to be easily filled from the spigot. The spigot is located at the bottom of the tank and can be locked using a combination lock around the knob. An overflow hole is located at the top of the tank so that extra water can be moved away from the tank through more plastic pipes.

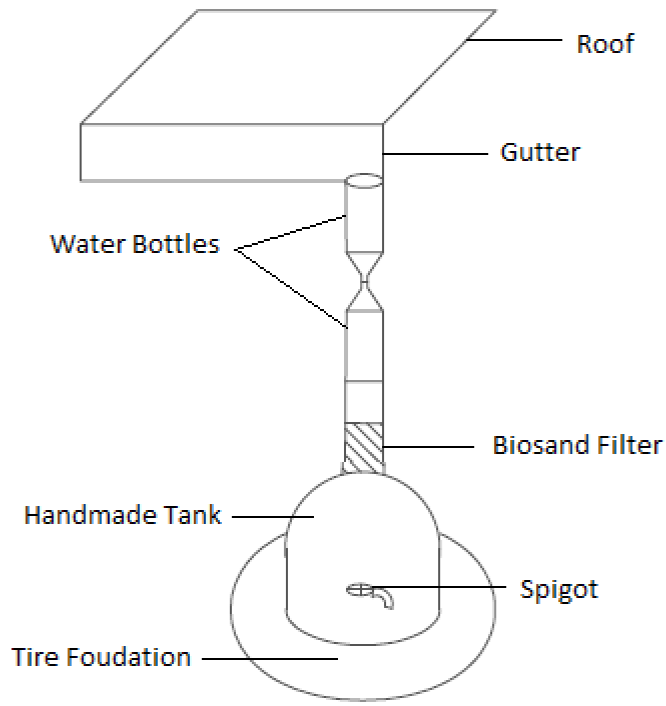



**Figure 12: The Eco-System diagram created by the RainBeaus on 10/15/14**

### 3.3.6 The Not As Eco-System

The Not As Eco-System is a system that is a variation of the Eco-System that is easier to construct while still having the overall eco-friendly theme. The system starts at the roof of the school closest to the system. The roofs gutters have drainage holes that are all plugged except the hole closest to the system, which helps to divert the majority of the rain that falls on the roof through one hole. The water that comes through the gutter hole then travels through the plastic piping away from the roof. The plastic pipes are secured to a drain in the existing roof gutter in such a way as to allow for easy removal if it is needed in the future.

The water that is traveling through the plastic pipe then goes through a biosand filter that cleans the water for storage. From the filter the water is finally taken to a 55 gallon recycled food drum to be stored for later use. The drum is located 2ft of the ground on top of a foundation of recycled cinder blocks. The added elevation to the tank will allow a watering can to be easily filled from the spigot. The spigot is located at the bottom of the tank and can be locked using a combination lock around the knob. An overflow hole is located at the top of the tank so that extra water can be moved away from the tank through more plastic pipes.

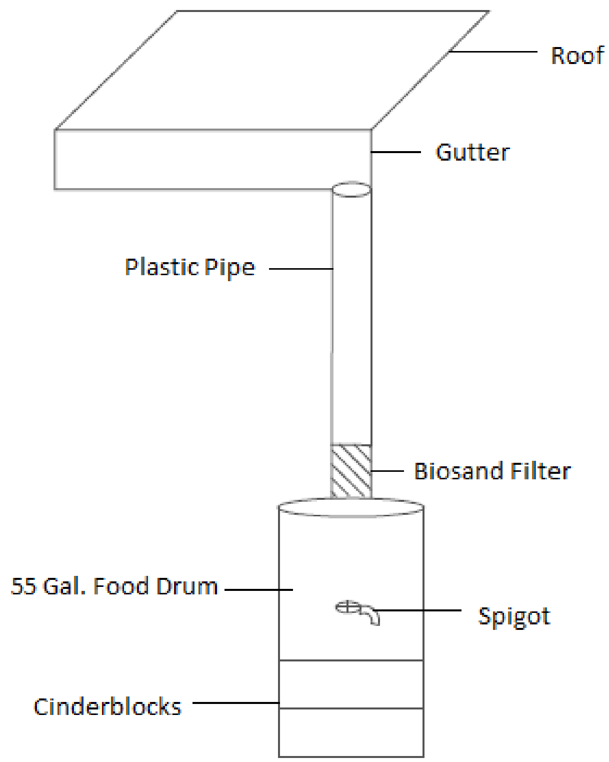



**Figure 13: The Not As Eco-System diagram created by the RainBeaus on 10/15/14**

### 3.3.7 The Tarp and Tank Wagon

The Tarp and Tank Wagon is a mobile water catchment system that uses wagon's bed as a foundation for the 55 gallon recycled food drum to rest upon. The wagon can be pulled around and displayed as a model of unbounded possibilities in harvesting rainwater. The drum situated upon the wagon has 2in PVC posts holding up and spreading out a tarp that collects rainwater. That water then collects in the middle of the tarp, due to the tarp's concavity, and goes through a mosquito proof mesh screen and into the drum for storage.

The drum has a spigot and an overflow hole. The spigot it located on the bottom of the drum and can be locked using a combination lock around the knob. The spigot is also located far enough away from the wagon bed so that a watering can can easily be filled up from the spigot. An overflow hole is located at the top of the drum and is connected to a 1in PVC pipe so that extra water can be directed away from the system. The system can be covered by an additional tarp when not in use and moved to a special location during especially windy weather to protect the system.

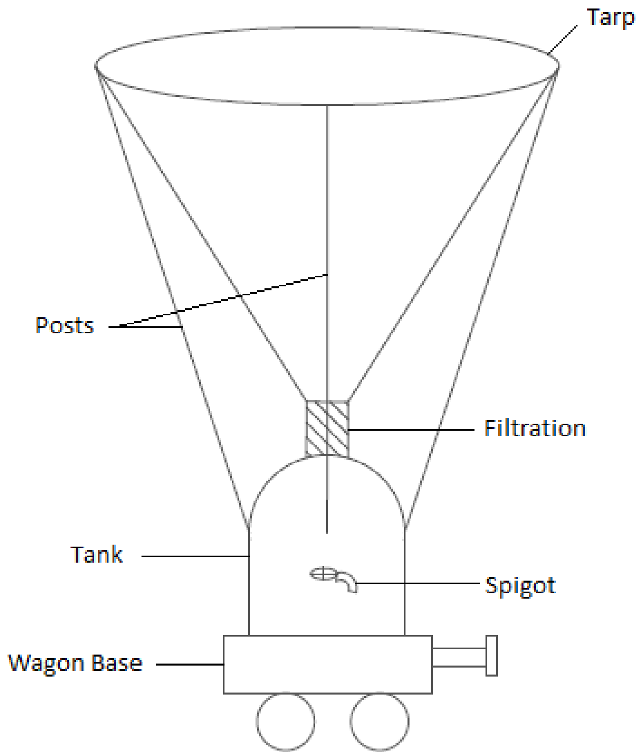



**Figure 14: The Tarp and Tank Wagon diagram created by the RainBeaus on 10/15/14**

### 3.3.8 The Catch ALL

The Catch ALL is a rainwater harvesting system that uses the full extent of the Redwood Coast Community Center's roofing in order to collect as much rainwater as possible. The system assumes costs are not a constraining factor in creating what would be a possible replacement of the community's current non-potable water supplies. Using the roof's current gutters and drainage systems, slightly modified with other piping and pumping, water will be collected and transported from both roofs to the garden and greenhouse area where the tanks will be stored. Once the water has reached its destination it will fall through a downspout, a first flush diversion system, screens, and a filter before collecting into a large 200 gal tank that will be purchased from a water storage tank manufacturer. This tank will be firmly secured upon a cemented foundation elevating the tank to allow use of the water through its own potential energy. This project design aims to collect the maximum amount of water possible from the building's roofing with minimal regard for the pricing of pumps and other expensive equipment. Such a system would collect so much water in this coastal region that much of it may need to be properly cleaned and used for more extensive purposes.

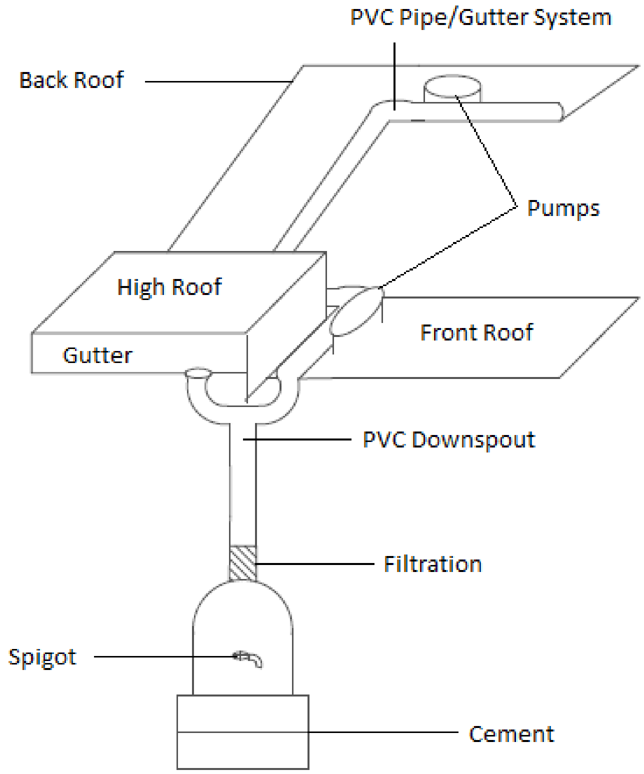



**Figure 15: The Catch ALL diagram created by the RainBeaus on 10/15/14**

# 4 Decision

## 4.1 Introduction

The decision section defines the criteria that were listed in Section 2, the Problem Analysis. The alternative solutions that were discussed in Section 3 are also listed. The decision process of choosing a solution is also discussed including the Delphi Matrix. Lastly the final decision is justified.

## 4.2 Criteria

The criteria from Section 2, the Problem Analysis is listed below and defined. The defined criteria will help make a final decision on which alternative solution will be picked by allowing the RainBeaus to rate each alternatives solution’s ability to fulfill the criteria.

- **Adaptability:** The capability for additional water storage tanks or drums to be added to the system at a later date if needed by a school official.
- **Easy to use for children:** The ability of children in grades K-8 to fill a watering can from the system without adult assistance.
- **Safety:** The system poses no risk to the health of both students and adults at the school.
- **Durability**: The ability of the system will work effectively even with wear and tear from use and the environment.
- **Cost:** All money that is spent both on materials for building the system and research and development.

- **Number of gallons stored:** The maximum quantity of rainwater that can be stored in the tank or drum for immediate use for watering plants.
- **Use of upcycled materials:** The percent of all materials used to build the system that have been previously used.
- **Aesthetics:** The system looks professional, safe, and intriguing to both children and adults.
- **Maintainability:** The ease of a school official to clean and repair the system when needed.
- **Educational:** The ability of the system to demonstrate principles of sustainability to K-8 students with the help of an instructor.
- **Building Time:** Time spent constructing the system from start to finish.

## 4.3 Solutions

The eight alternative solutions that are discussed in Section 3 are listed below and will be used in the decision process by the RainBeaus to find the best solution for Redwood Coast Montessori.

- The Seeing Sandbox
- The Sunken Sandbox
- The Filtration Station
- P.V.C (Pretty Very Cool)
- The Eco-System
- The Not As Eco-System
- The Tarp and Tank Wagon
- The Catch ALL

## 4.4 Decision Process

To determine the best solution is for Redwood Coast Montessori the criteria was weighed on a scale of one to ten, with ten being the most important criteria for the project, by the RainBeaus and the client. Then the eight alternative solutions were also weighed, on a scale of one to fifty with fifty being a system that best fits that criteria, for all of the criteria. This information was then used to create a Delphi Matrix, shown in Table 4, which uses the multiplied weights of the criteria and each solution weight to find the best overall solution. Three of the alternative solutions had very close scores, The Seeing Sandbox, P.V.C, and The Not As Eco-System, which were then presented to the client for a final decision.

**Table 4: The Delphi Matrix shows all eight of the alternative solutions and how well they meet the different criteria. The total sum at the bottom is used to determine the best system with the highest number being the best solution. Created by the RainBeaus.**

| Criteria | Weight (0-10 high) | Alternative Solutions (0 - 50 High) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Seeing Sandbox | Sunken Sanbox | Filtration Station | PVC System | Eco System | Not As Eco System | Tarp and Tank Wagon | The Catch All |
| Adaptability | 7 | 40 / 280 | 40 / 280 | 20 / 140 | 40 / 280 | 15 / 105 | 40 / 280 | 5 / 35 | 45 / 315 |
| Easy to use | 7 | 40 / 280 | 40 / 280 | 40 / 280 | 40 / 280 | 40 / 280 | 40 / 280 | 30 / 210 | 40 / 280 |
| Safety | 10 | 45 / 450 | 45 / 450 | 45 / 450 | 45 / 450 | 40 / 400 | 40 / 400 | 10 / 100 | 45 / 450 |
| Durability | 8 | 35 / 280 | 40 / 320 | 40 / 320 | 40 / 320 | 35 / 280 | 35 / 280 | 5 / 40 | 40 / 320 |
| Cost | 5 | 30 / 150 | 35 / 175 | 35 / 175 | 35 / 175 | 50 / 250 | 45 / 225 | 45 / 225 | 5 / 25 |
| Number of gallons stored | 3 | 25 / 75 | 25 / 75 | 40 / 120 | 25 / 75 | 40 / 120 | 25 / 75 | 10 / 30 | 50 / 150 |
| Use of upcycled | 5 | 35 / 175 | 35 / 175 | 30 / 150 | 25 / 125 | 50 / 250 | 40 / 200 | 25 / 125 | 20 / 100 |
| Aesthetics | 4 | 50 / 200 | 40 / 160 | 40 / 160 | 40 / 160 | 45 / 180 | 40 / 160 | 25 / 100 | 35 / 140 |
| Maintainability | 8 | 30 / 240 | 5 / 40 | 40 / 320 | 40 / 320 | 35 / 280 | 40 / 320 | 40 / 320 | 15 / 120 |
| Educational | 9 | 50 / 450 | 40 / 360 | 30 / 270 | 30 / 270 | 50 / 450 | 35 / 315 | 45 / 405 | 25 / 225 |
| Bulding time | 7 | 20 / 140 | 10 / 70 | 30 / 210 | 40 / 280 | 5 / 35 | 30 / 210 | 50 / 350 | 10 / 70 |
| | **Total:** | **2720** | **2385** | **2595** | **2735** | **2630** | **2745** | **1940** | **2195** |

## 4.5 Final Decision

The P.V.C system is the best solution for Redwood Coast Montessori because of the adaptability of the system's conveyance and storage components. The client preferred to avoid using the gutters of the school calling for the use of the tarp in the P.V.C system. The use of a pump and aquifer, like in The Seeing Sandbox, was also ruled out by the client because of the possibility of the pump breaking and the higher maintenance of the system. The use of a recycled food drum in the P.V.C system allows for easy addition of more drums and was appreciated by the client. The Delphi Matrix and client feedback led the RainBeaus to the final decision to use the P.V.C. design for Redwood Coast Montessori's rainwater catchment system.

# 5 Specifications

## 5.1 Introduction

The Specification section of the document describes the specifics of the chosen final solution, the P.V.C System, which will be implemented at Redwood Coast Montessori. Included in this description are detailed write-ups for each key component of the system as well as four diagrams illustrating these components and two overviews of the entire system both from an aerial perspective above the roof and from ground level. Also included in this section are: a cost analysis with respect to money spent on materials as well as time spent building and maintaining the system, instructions for recreating a similar rainwater harvesting system, and a write-up regarding the results of testing done on the system and its effects on the community of Manila and the Montessori school.

## 5.2 System Description

The system description both shows the final system and describes the individual parts of the system like the first flush diverter. This system is a variation on the original P.V.C system that was described in Section 3, the alternative solutions. Changes were made to the system to better fit the needs of the school along with necessary structural changes to make the system possible at the site. The completed P.V.C rainwater catchment system is shown below in Figure 16.

Figure 16: A picture of the competed P.V.C rainwater catchment system taken by the RainBeaus

The overall system consists of four main parts: the gutters, the first flush diverter, the barrels, and the foundation. This is shown below in Figure 17 with a diagram of the whole system and Figure 18 with an aerial view of the system.

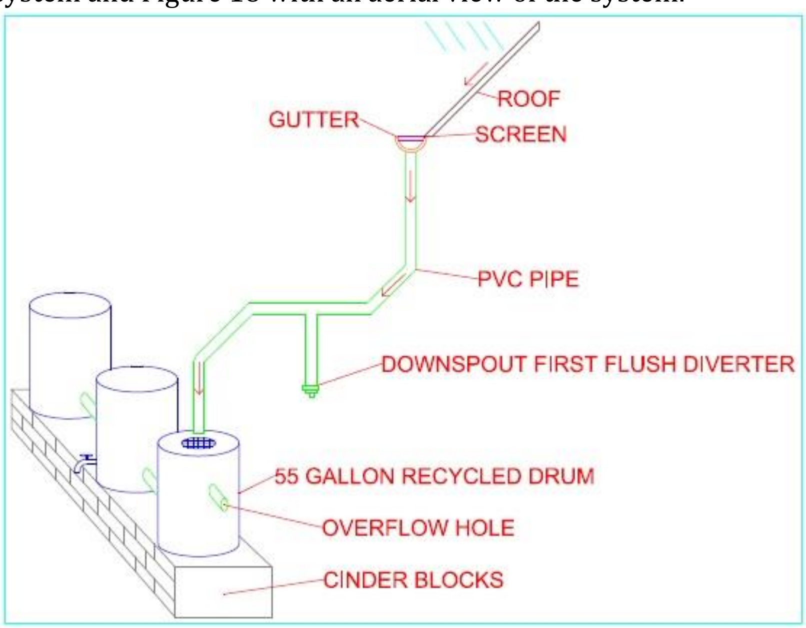



Figure 17: A CAD drawing of the entire system created by the RainBeaus on 11/17/14

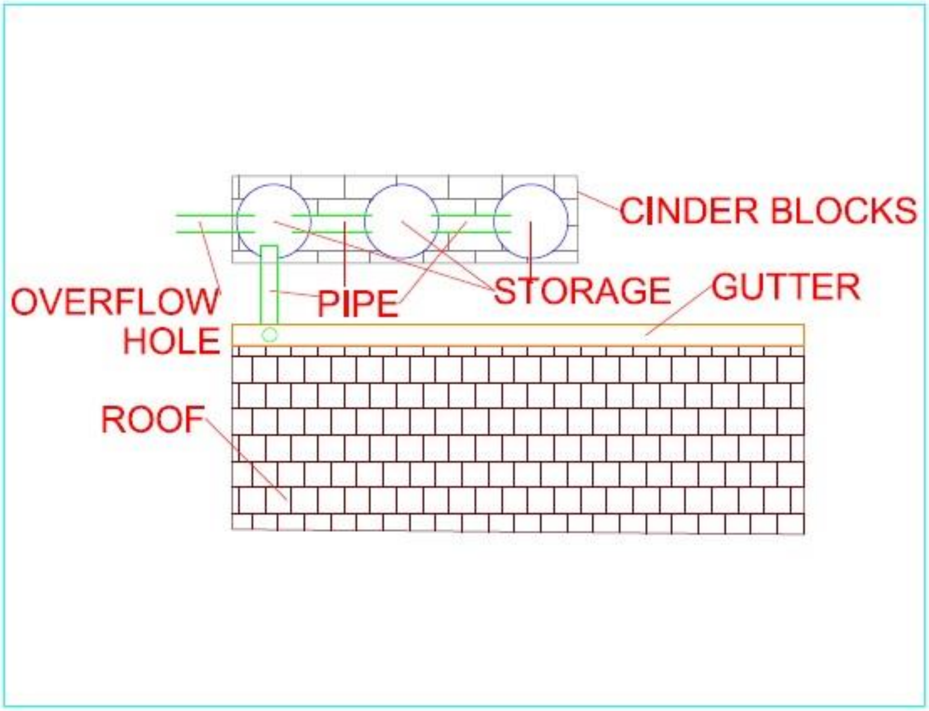



**Figure 18: A CAD drawing of the aerial view of the system created by the RainBeaus on 11/17/14**

### 5.2.1 The Gutters

The gutters are how the water is retrieved from the roof. The section of the roof closest to the system which has an approximate area of 35' x 19' has a single gutter connected to it. That section of gutter is covered with mesh to make sure that no leaves or other debris from the roof enters the system. From the gutter the water goes into a single hole in the gutter, which is connected to a PVC pipe that takes the water down from the roof.

### 5.2.2 First Flush Diverter

The water is then transported via the PVC pipe to a tee PVC connection where the water goes down into the first flush diverter. The first flush diverter is used to take the first about 10 minutes of rain, which is very dirty from the roof, and keep it from going into the barrels and being stored for use. The diverter works by the rain going down from the tee PVC connection into a separate 3" PVC pipe that collects the dirty water. Once the pipe is full the ball in the pipe floats to the top and covers the hole in the tee connection forcing the water to continue horizontally into the barrels. The first flush diverter also has an adjustable leak drip that slowly lets the water in the diverter out so that it does not have to be done manually after every rain. The first flush diverter is shown below in Figure 19.

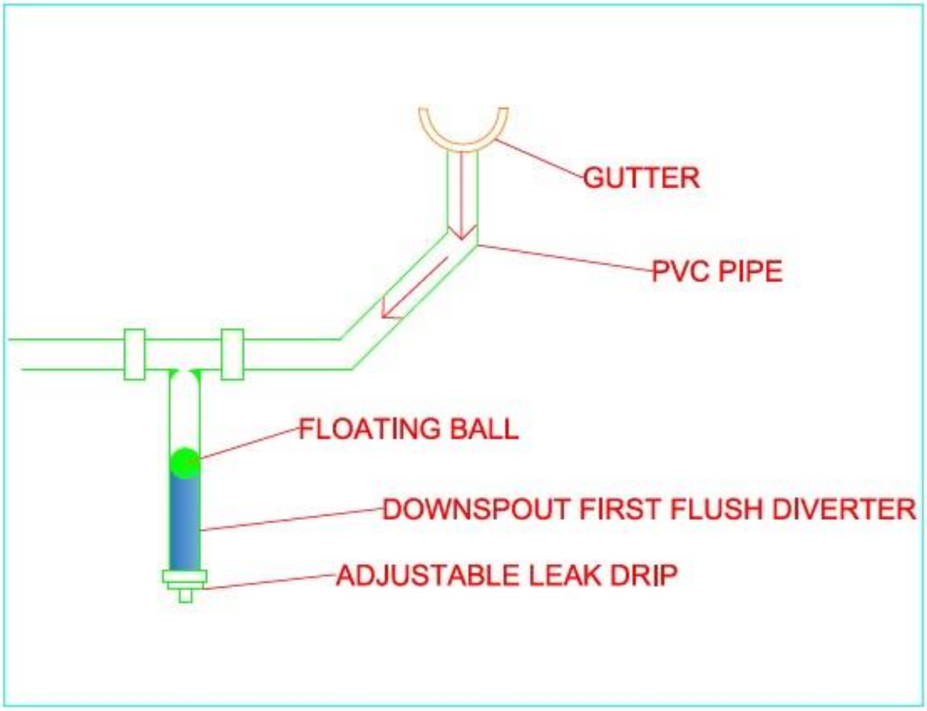



**Figure 19: A CAD drawing of the first flush diverter created by the RainBeaus on 11/17/14**

### 5.2.3 Barrels

The water that is not transported into the first flush diverter travels into a 55-gallon barrel via PVC pipe. A 4in diameter PVC pipe at the bottom of each barrel connects the first barrel to two other 55-gallon barrels. This connection allows the barrels to fill in parallel meaning that they fill from the bottom at the same rate. This helps prevent any water being left in a barrel for an extended amount of time, which helps to minimize maintenance. An overflow hole connected to 1in PVC is placed in the last barrel so that any excess water can be directed away from the system. A spigot is located on the middle barrel so that a watering can can be filled. The barrels configurations are shown in Figure 20 below with labels to show the different parts of the system.

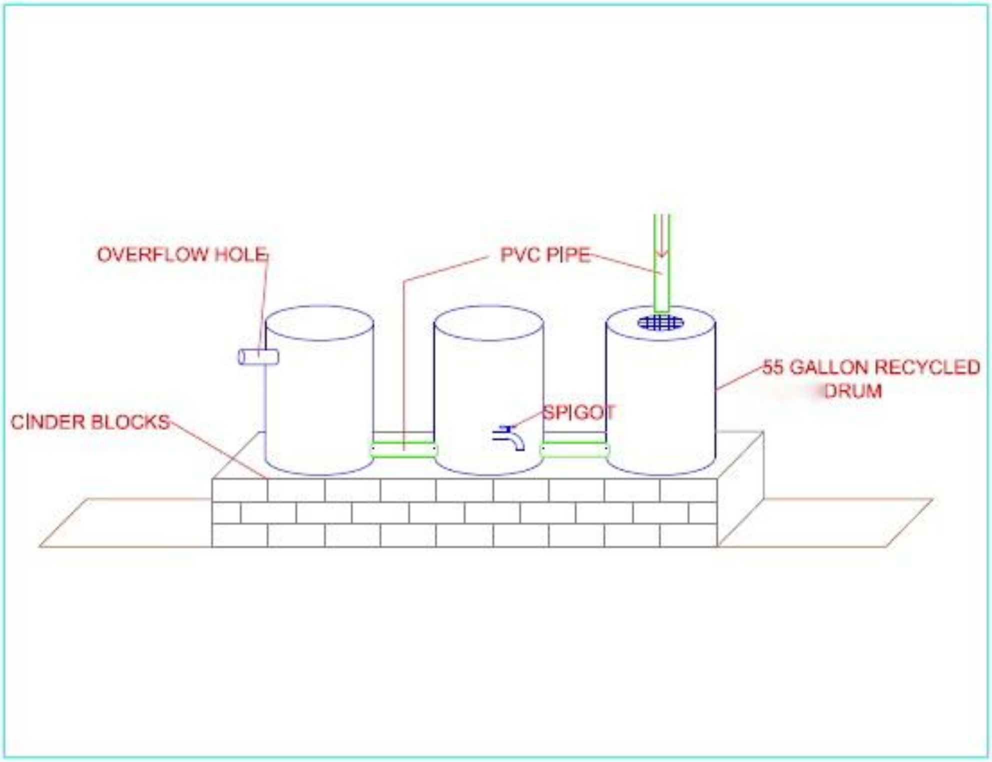



Figure 20: A CAD drawing a close up on the barrels created by the RainBeaus on 11/17/14

### 5.2.4 The Foundation

The foundation is the final part of the system and consists of two and a half feet of cinder blocks. The foundation can be seen above in Figure 20. The foundation of cinder blocks sits on leveled ground and allows a watering can to be placed under the spigot to be filled. It also adds height to the barrels so that the water pressure is high enough for the water to flow out of the spigot. It is very important for the foundation to be level so that all of the barrels fill in parallel.

## 5.3 Cost Analysis

The cost analysis of the final design, the P.V.C System described above, includes the dollar amount spent on materials for constructing the rainwater system, the time spent building the system, and the time expected to be spent maintaining proper operation of the system on a monthly basis.

### 5.3.1 Design Cost

The design cost is an analysis of the RainBeaus time spent on completing each step of the engineering design process beginning from the problem formulation and ending with the completed, working, and tested design as well as the finalization the documents and presentation materials. As a team the total time cost spent on the project was 183 hours, this is shown in Figure 21 below. The expected cost of replicating this design for a rainwater catchment system is 30 hours.

Total Hours: 239

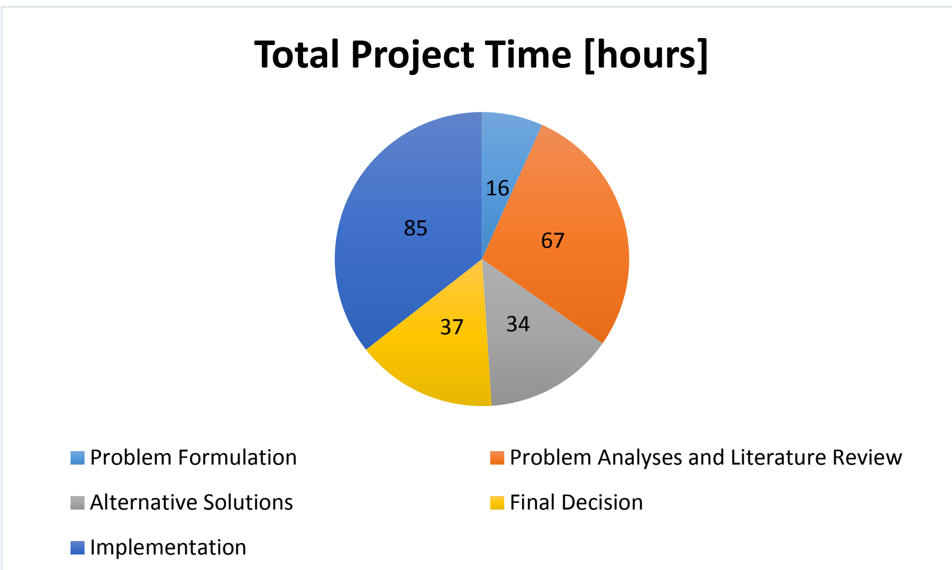



**Figure 21: A pie chart of the hours spent on the total project created by the RainBeaus on 12/6/14**

### 5.3.2 Implementation Cost

The cost of creating RainBeaus rainwater harvesting system, the P.V.C system, was $281.93, which includes expenses on materials and services needed in producing this system. These expenses are detailed in Table 5 and are simultaneously compared to the expected cost of producing the system without donations at retail cost. A total of $121.80 was saved due to donations and discounts.

Table 5: A table of the retail and actual costs of all materials used to create water catchment system

| Cost of Materials | | | |
|---|---|---|---|
| **Object** | **Quantity** | **Retail Price [$]** | **Our Amount [$]** |
| Rain barrels | 3 | 70.00 | 30.00 |
| PVC pipes | 3 | 21.00 | 5.00 |
| First flush diverter | 1 | 32.50 | 32.50 |
| 4 1/8" hole saw | 1 | 27.59 | 27.59 |
| Mosquito-proof mesh | 1 | 3.17 | 3.17 |
| UV-6800 adhesive | 1 | 8.99 | 8.99 |
| Caulk gun | 1 | 3.99 | 3.99 |
| Cinder blocks | 20 | 131.60 | 65.80 |
| 3/64" rubber sheet | 1 | 11.90 | 11.90 |
| 24" drum lids | 3 | 25.36 | 25.36 |
| Zipties | 66 | 7.12 | 7.12 |
| 3" PVC coupling | 3 | 6.49 | 6.49 |
| 3" PVC pipe | 1 | 18.65 | 18.65 |
| 45 degree PVC elbow | 1 | 5.80 | 5.80 |
| 90 degree PVC elbow | 1 | 8.50 | 8.50 |
| 3" x 10' PVC | 1 | 9.20 | 9.20 |
| Bend 1/8 PVC 3" Hub | 1 | 2.69 | 2.69 |
| Coupling 3" PVC | 2 | 3.58 | 3.58 |
| Bend 1/4 PVC 3" Hub | 1 | 5.60 | 5.60 |
| **TOTAL** | | **403.73** | **281.93** |

### 5.3.3 Maintenance Cost

The P.V.C system requires minimal maintenance to keep the system operating sufficiently as requested by the client at Redwood Coast Montessori. In order to keep water flowing properly into the system the screens above the water tank should be cleaned after every rain cycle and the first flush diverter should be cleared of water. Also, in order to maintain a clean water system unused water should be cleared from the storage tanks monthly. On average the total time spent monthly on maintaining this system should not exceed 40 minutes.

## 5.4 Instructions for Implementation and Use

The instructions for implementation help to outline how the rainwater catchment system was originally created by the RainBeaus along with how the system can be recreated by others. The system must be maintained by Redwood Coast Montessori regularly for the system to continue to work effectively. The use of the system is important for anyone who wants to recreate the system along with Redwood Coast Montessori.

### 5.4.1 Implementation

In order to build a recreation of the rainwater catchment system installed at Redwood Coast Montessori, it is first necessary to determine if the desired location receives sufficient rainfall. Manila, CA receives around 40 inches of rain per year, which is more than a sufficient amount to completely fill the storage unit for much of the year. For such a system to remain useful and functional, it must be implemented in a region that receives at least 20 inches of rainfall per year, though ideally more. The monthly-predicted rainfall for the region is outlined in the Literature Review, in Section 2, in the Climate for Arcata section.

Once an appropriate location has been found, the search for materials must be undertaken. To completely recreate this system, the following items are needed:

- Three 55 gallon HDPE (high-density polyethylene) barrels and accompanying lids
- 20 cinder blocks
- One 4 1/8” hole saw
- One first flush diverter
- Mosquito-proof mesh
- Pipe connecters
- Adhesive
- PVC piping
- One attachable spigot
- One drill
- One shovel
- One rake
- One roof (or other elevated area for capture)

All of these items can be found for well under $400.00, provided donations and gently-used materials are utilized instead of entirely new items. It is essential that the barrels are made of HDPE and not steel or any other metal, due to extensive studies reporting that metals corrode over time, contaminating stored water. Depending upon the intended use of stored rainwater, the condition and former use of an upcycled barrel can vary. If a collection system will only provide water for ornamental plants, using a refurbished barrel is a more feasible option. However, if stored water will be used for edible plants or for drinking water, either a new barrel or an almost new food grade barrel will be necessary.

To connect the barrels in series, four 4 1/8” holes must be punched in the lower portion of the barrels, allowing for the addition of connective PVC piping, enabling captured water to be equally distributed throughout the system. These pipes are connected by a silicon adhesive, which requires a minimum of four hours to dry completely. A spigot must also be attached to the central barrel at this point in the construction process. While the barrels are being constructed at a location offsite, the base must be assembled onsite. Before the base of 20 cinder blocks is set down, it is absolutely necessary to level the ground it will stand on. To do this, locate one rake and one square-edged shovel. It is also likely that the base area will need to be weeded to remove any further uneven regions. Once the ground has been adequately leveled, the cinder blocks can be arranged to form the base. This arrangement is illustrated in Figure 22 below.

Figure 22: A picture of the cinder block base configuration, taken by the RainBeaus

As soon as the cinder block base and connected barrels are both constructed, the barrels must be brought to the site and placed upon the level cinder block base. Transport of the system requires a truck and a number of strong individuals to lift the three connected barrels. Once transport is complete, attachment of the barrels to the region of capture (a roof with gutters) is the next step. PVC piping must first be cut to the appropriate lengths, dependent upon the height of the roof being used for capture. Once the desired length of piping has been achieved and any other downspouts have been blocked off, the piping can be attached to a single downspout. This piping will then be accordingly attached to the barrel, possibly using a PVC elbow. Another attaching pipe is also necessary in order to utilize the first flush diverter. The mosquito-proof mesh must be arranged in the roof gutters, minimizing further plant material and insect debris from entering into the storage tanks.

### 5.4.2 Maintenance

The system must be maintained on a bimonthly basis, focusing primarily upon the storage tanks and the first flush diverter. It may also be necessary to remove any debris that has been captured on the mesh attached to the gutters on the roof. Annually, it requires approximately one hour of maintenance work and likely no replacement parts. The lifespan of the system is mostly dependent upon location, as it will last longer in areas that have milder climates but are not exposed to extensive sunlight. Table 6 below shows suggested solutions to system problems.

Table 6: A table of solutions to system problems

| Troubleshooting | |
|---|---|
| **If** | **Then** |
| Water is not flowing into the barrels | Clear debris from gutters and ensure pipes are not blocked by debris |
| Water in barrels is dirty | Flush entire system with water and empty barrels for a fresh start |
| First-flush diverter is not emptying | Unscrew slow leak at bottom and clear away blockage |
| Water does not leave spigot | Remove barrel lids and clear debris that may be disrupting flow |

### 5.4.3 Use

The rainwater catchment system is simple to use. To use the system the knob on the spigot located on the barrel is turned till water starts to flow. A watering can is then places in the water flow until the can is filled and the spigot knob is tuned again till the flow of water stops. The watering can can then be used to water any type of ornamental plant located at Redwood Coast Montessori. The system's use is easy enough for any student at the school to use if they are able to turn the spigot knob, although supervision is suggested for young students so that no water is wasted.

## 5.5 Results

Now that the construction of the system is complete, a testing phase is necessary. First, make sure that the system actually stores rainwater and does not leak excessively. Ensure that there are no entry points for insects or small animals as decomposing organic matter will severely impact the water quality of the stored water. Next, make sure that there is enough water pressure for water to successfully leave the tank via the spigot. If not, add an additional level of cinder blocks. Once it is confirmed that the system does indeed distribute stored water effectively the system is ready for operation. Make sure that the water's use has been adequately specified on the tank to avoid accidental misuse.

The completed system at Redwood Coast Montessori is being used and has been largely successful thus far. It successfully captures rainwater and has both functional and educational value for students. Constructed with a combination of donated and new materials, it satisfies our desire to build a system with as many upcycled materials as possible. However, it also satisfies our most important specified criteria: safety. Achieving acceptable water quality levels for ornamental plants, it is labeled accordingly which will prevent any accidental misuse of stored water. We were successfully able to fill watering cans and water ornamental plants with the stored water from our system. The system is also able to withstand slight pushing on the various parts of the system, like the barrels and blocks, which means it should stand up well to wind.

# Appendix A: References

American Montessori Society. (2014). “Montessori Classrooms.” American Montessri Society, <http://amshq.org/Montessori-Education/Introduction-to-Montessori/Montessori-Classrooms> (Sep. 25, 2014).

B. Helmreich and H. Horn, Garching, Germany (2009). “Opportunities in rainwater harvesting.” Desalination, 248, 118-124

Blair, K. (2014). “What is a first-flush diverter?” How to Build a Simple Rainwater Collection System, <http://rainbank.info/tag/first-flush-diverter/> (September, 28, 2014).

Child Development Institute. (2013). “Stages of Intellectual Development in Children and Teenagers.” Child Development Institute, <http://childdevelopmentinfo.com/child-development/piaget/> (Sep.25, 2014).

Eccles, J. (1999). “Development of Children Ages 6 to 14.” The Future of Children, 9, 30-41.

Gould, J., Nissen-Petersen, E. (1999). “Rainwater Catchment Systems for Domestic Supply: Design, Construction, and Implementation.” London: Intermediate Technology Publications, Ann Arbor, Michigan, 1-135

Hart, C., and White, D. (2006). "Water Quality and Construction Materials in Rainwater Catchments Across Alaska." J. Env. Eng. & Sci., 5, S19-S25.

Inspectapedia. (2014). “Faucets, Sill-cocks, Hose Bibbs & hose hook-ups.” Inspecapedia, <http://inspectapedia.com/plumbing/Faucets_Outdoor.php> (Sep. 28, 2014).

Jensen, M. (2008). “Feasibility of Rainwater Harvesting for Urban Water Management in Salt Lake City”. M.S. thesis, University of Utah., Salt Lake City, Utah

Macomber, P. (2010). “Guidelines on Rainwater Catchment Systems for Hawaii.” College of Tropical Agriculture and Human Resources, University of Hawaii at Manoa, Honolulu, HI.

Montessori. (2014). “Teaching Montessori.” Montessori, <http://www.montessori.edu/info.html> (Sep. 25, 2014).

National Weather Service. (2014). “The Climate of Eureka California.” National Weather Service, <http://www.wrh.noaa.gov/eka/climate/summary.php> (Sep. 28, 2014).

North Coast Laboratories. (2013). “About North Coast Labs.” North Coast Laboratories Ltd, <http://www.northcoastlabs.com/> (Sep. 31, 2014).

Opus (2014). “Material PVC Pipe.” Opus: Material: PVC Pipe, <http://opus.mcerf.org/material.aspx?id=5617435305915729269> (Oct. 30, 2014)

Redwood Coast Montessori. (2014). “Redwood Coast Montessori.” Redwood Coast Montessori, <http://www.redwoodcoastmontessori.org/> (Sep. 30, 2014).

Texas Commission on Environmental Quality (2007). “Harvesting, Storing, and Treating Rainwater for Domestic Indoor Use.”, TCEQ, Austin, TX 78711.

Texas A&M Agrilife Extension (2014). “Tank Material.” Rainwater Harvesting, <http://rainwaterharvesting.tamu.edu/tank-material/> (Sep. 25, 2014).

The Diggers Club (2014). “How much water does the garden need?” Being Self-Sufficient, <http://www.diggers.com.au/media/114986/how_much_water_32-33__low_res_.pdf> (Sep. 28, 2014)

Veggie Harvest (2008-2014). “Watering your garden.” Veggie Harvest, <http://veggieharvest.com/info/irrigation.html> (Sep. 28, 2014).

Weatherbase. (2014). “Arcata, California.” Weatherbase, <http://www.weatherbase.com/weather/weather.php3?s=64537&refer=&units=us > (Sep. 28, 2014).

Western Australian Agriculture Authority, Australia (2006). “Water quality in home gardens.” Gardennote, 194

Woodson et al. (2014). “ Rainwater Harvesting” Catchment Area, <http://rainwaterharvesting.tamu.edu/catchment-area/> (Dec. 2, 2014).

## Appendix B: Brainstorming Notes

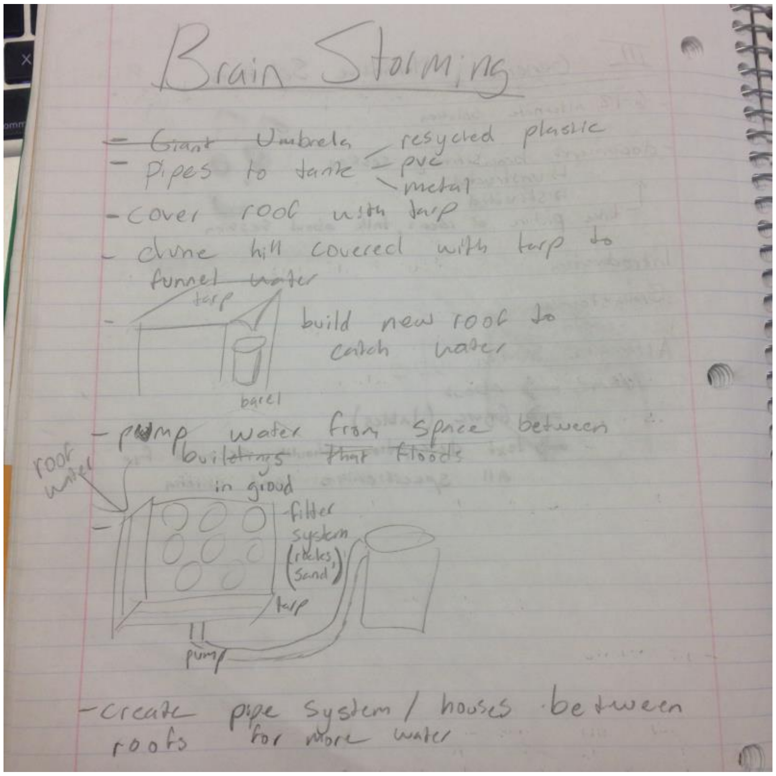



Figure 23: A picture of the fist page of brainstorming notes from the first session, created by the RainBeaus

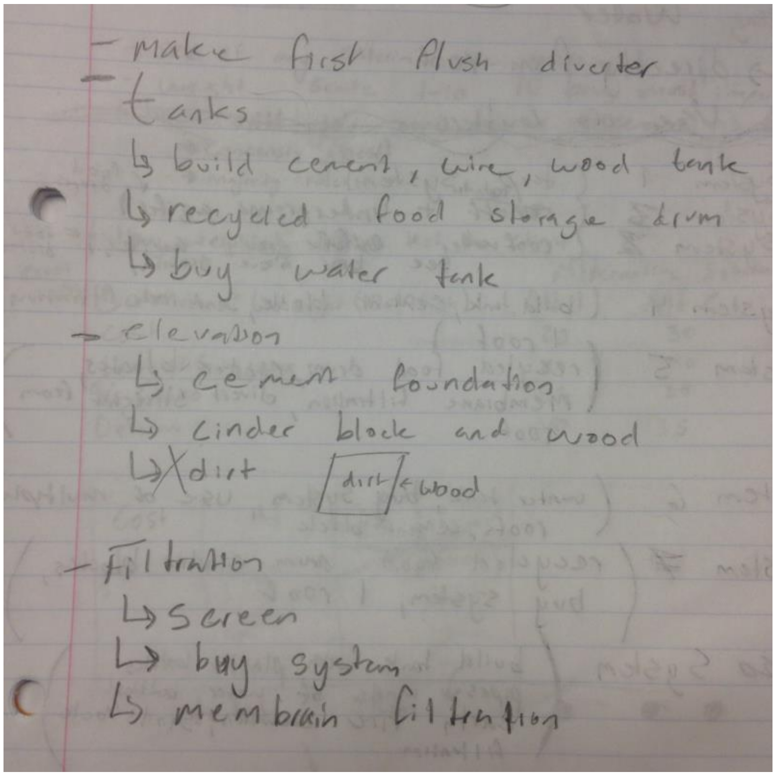



**Figure 24: A picture of the second page of brainstorming notes from the first session, created by the RainBeaus**

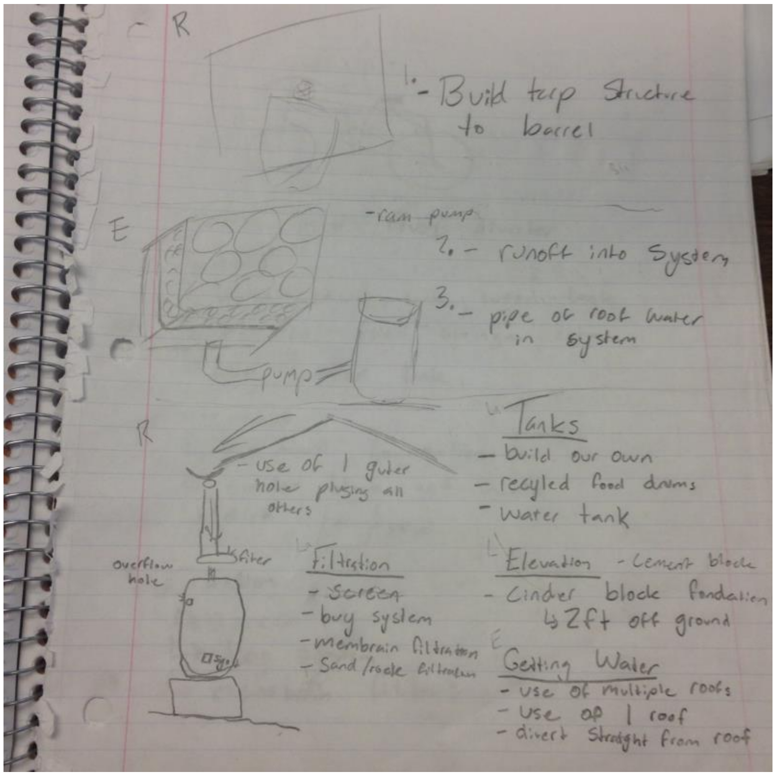
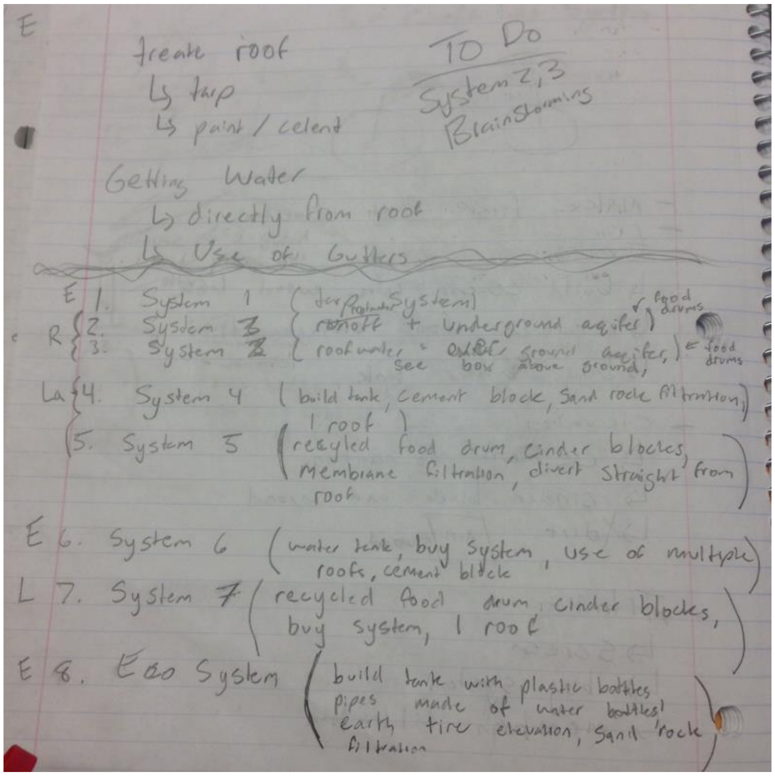



Figure 25 : A picture of the third page of brainstorming notes from the first session, created by the RainBeaus



E

treate roof
↳ tarp
↳ paint / celent

TO DO
System 2,3
Brainstorming

Getting Water
↳ directly from roof
↳ Use of Gutters

E 1. System 1 (tarp System)
R { 2. System 3 (runoff + underground aquifer) ✓, food drums
{ 3. System 2 (roof water, ... ground aquifer, see box above ground,) E food drums
La { 4. System 4 (build tank, cement block, sand rock filtration, 1 roof)
{ 5. System 5 (recyled food drum, cinder blocks, Membrane filtration, divert straight from roof)
E 6. System 6 (water tank, buy System, use of multiple roofs, cement block)
L 7. System 7 (recycled food drum cinder blocks, buy system, 1 roof)
E 8. Eco System (build tank with plastic bottles pipes made of water bottles, earth tire elevation, sand rock filtration)