The Black Hole

Rainwater Catchment System

Engineering 215: Intro to Design Fall 2016

Sacred Consulting:

Jenna Davey

Karen Duarte

Richard Thompson

Caleb Wegener

Humboldt State University

The Sanctuary

Table of Contents

1 Problem Formulation

1.1 Introduction

For the Fall 2016 class, Engineering 215: Intro To Design, we have a client in the community for whom we are designing a solution. For the semester-long project, our team, Sacred Consulting has been given the responsibility of designing and engineering a solution to a water issue that is facing the client. Our client, The Sanctuary, is a local non-profit who has been a part of the community since 2013 with a focus on sustainability and sharing resources within the community. The Sanctuary is home to concerts, art exhibits, workshops, and a variety of other events. With a large garden on site, there are many uses for water aside from drinking and cooking. Rainwater catchment is considered to be a great way to be more sustainable and reduce dependence upon public utilities. This is because the water can be stored until it is needed instead of letting this water run into the street, through the sewer, or even oversaturate the ground on its way to the bay. Sacred Consulting will be designing a rainwater catchment system for the client, which will provide a sustainable, efficient, and functional way to reduce water consumption from the tap.

Section One of the design process contains the formulation of the problem, as well as the objective of the design. The problem is defined in the following objective section, and then represented by a black box model, shown in Figure 1-1.

1.2 Objective

The objective of this project is to design a solution to solve a problem of unused rainwater for our client. Our client lacks an efficient and sustainable system to catch, store, and deliver rainwater to the garden. The Sanctuary wants a way to use less water for watering their plants so that they can have less of an impact on the environment. The solution will provide for the needs of The Sanctuary by providing a fully functional, efficient and sustainable method for collecting, storing, and delivering non-potable water collected from rainfall for garden usage on site.

1.3 Black Box Model

The black box model, shown below in *Figure 1-1*, defines the state of the world before and after the implementation of the rainwater catchment system.

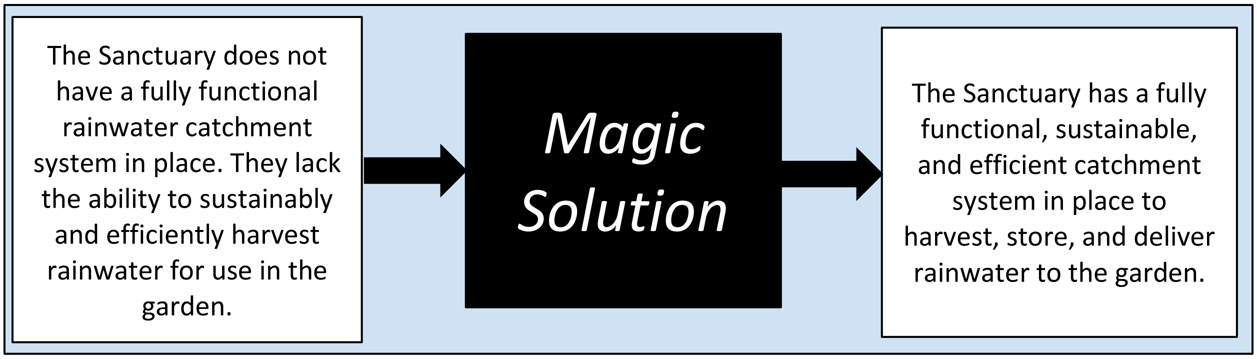

Figure 1-1 The Black box model showing what the solutions will do.

2 Problem Analysis and Literature Review

2.1 Introduction

In this section, all the aspects of the client criteria are examined. This is to form a proper framework with which to examine design ideas so that the best option can be chosen. The specifications, considerations, criteria and constraints of the client are looked at here along with the usage and production volume.

2.2 Specifications and Qualifications

2.2.1 Introduction

Criteria and constraints are a set of useful guidelines to refer to when deciding which design best fits the needs of the targeted audience.

2.2.1.1 Specifications

The team wants the designed system to meet certain needs and to avoid certain pitfalls so a set of qualifiers has been identified to help guide the team's decision making process. The designed system must collect excess rainwater from the area on top of the house next to The Sanctuary. There are gutters, which are pieces of metal lining the edge of the house to keep the water from dripping off of the roof during a storm. All of this water is channeled into a pipe, or gutter, which is running down the southwest corner of the house. The designed system collects, stores, and transports the collected rainwater from the gutter coming from the roof to the garden or buckets for other non-potable uses. The designed system makes it easy to access the water. The system does not stand out as an ugly implementation at the site, and it is safe, inexpensive, low maintenance, and it located at The Sanctuary where the client requested the system to be placed.

2.2.1.2 Considerations

The facts that must be taken into consideration before designing the system are as follows:

- The client has a community space and the rainwater catchment system will be used by many different people and may have people walking near the system. More people during events.
- The client has two pieces of pond liner, some PVC pipe and other materials for use on the project and would prefer to purchase the least amount of new materials possible for the system.
- The client wants the system to be, in addition to the duck pond in front of the house, a safe place for ducks and possibly fish.

2.2.1.3 Criteria and Constraints

Criteria and constraints are a set of useful guidelines to refer to when deciding which design best fits the needs of the targeted audience. The criteria and constraints used to determine a solution are shown below, in *Table 2-1.*

Criteria	Constraints
Costs	Less than $400.
Aesthetics	Look as good/better than the surrounding structures.
Usefulness	Provide at least 25% of the water for the garden and outdoor uses.
Accessibility	Must not block walk path. Area must allow enough room to safely travel.
Maintenance	Must require less than 1 hour maintenance per week.
Sustainability	Lowest embedded energy for each item in system.
Sizing	Water storage must match the amount of water needed for 25% of garden and outdoor use.

Table 2-1 Criteria and Constraints.

2.2.2 Usage and Production Volume

2.2.2.1 Introduction

In this section the quantity of items produced will be discussed as long as the length of time the system will be in operation.

2.2.2.2 Usage

The system will be in constant use. The system will collect and store water from the gutters on the north side of the large building, "The Sanctuary," during periods of rain. The system can expect to receive around 14,000 gallons of water per year with much of this water being collected November-February and much of the usage being the other months of the year (based on 600 square foot area). The water will then be applied to the garden and used for other non-potable uses. The system should be expected to last for 10 years with normal usage.

2.2.2.3 Production Volume

There will be one system produced and installed at The Sanctuary, 1301 J Street, Arcata, CA 95521. However, this system should be able to be reproduced as many times as needed using this design blueprint.

2.3 Literature Review

2.3.1 Introduction

In this section, all aspects of the research done by Sacred Consulting are examined as it pertains to the project. Through the reading of many research resources, a thorough look at many different types of rainwater catchment system has been taken and the following information will help to formulate a design solution. Each component of a rainwater catchment system is discussed as well as its impact on this project. This information is presented in the following sections.

2.3.2 Climate Rainfall

Arcata has very high humidity on average due to its coastal climate. The weather is temperate during the days with cooler nights while never quite freezing. It ranges from high 50s °F to the mid-70s °F in the summer. Winter months are rainier and cooler than the summer months where temperatures in the 40's can be experienced. The average temperature is 53 °F.

The amount of rainfall in Arcata, CA is approximately 39 inches per year. The number of days with measurable precipitation (over .01 inch) is 120 days. December and January are the months with the most precipitation. December has an average rain fall on 8.44 inches per year, where January has an average of 8.23 inches per year. Almost half of

the year's rainfall is accumulated between the months of December and January (WaterAid 2013) (Wikipedia 2016) (Weather DB).

2.3.3 Rainwater

Rainwater is slightly acidic but can be used for domestic usage. It has a pH of about 5.6 because of molecules that are in the air such as carbon dioxide, sulfur dioxide, lead, and other volatile organic compounds. As rain falls, it accumulates contaminants in the air before it reaches the ground. Pathogens can also become present in rainwater. Due to this, rainwater near known contaminated sites should be avoided (About.com) (CityStats) (Dupont 2013).

2.3.4 Laws

Laws affect many aspects of our lives. Water affects every organism on this planet and in some places laws have been enacted where the collection of rainwater is a criminal act. Since 2012, California citizens are allowed to keep rainwater catchment systems on their property (California Assembly 2012). Previously, a permit would need to be obtained (Davis and Slater, 2013). The *Assembly Bill 1750* (2012) enacted the *Rainwater Capture Act of 2012*. This law makes it possible to install, maintain, and use rainwater collection systems "if the system is used exclusively for landscape irrigation."

2.3.5 Client Criteria

An interview conducted on September 23, 2016 revealed that the client would like water storage by means of a pond to be constructed on their property was the most apt conclusion. This differed from the usual system of rainwater catchment, which most often uses barrels. However, they determined that the pond would be more aesthetically pleasing.

2.3.6 Location of the System

There are three different structures associated with the Sanctuary, all of which the rainwater catchment system may collect water from. One location is the site of The Sanctuary non-profit organization. The other two buildings are located on either side of the Sanctuary. All three structures have a working rainwater gutter collection system. It is possible to place a system of barrels underneath any of these rainwater-collecting gutters. The location of the pond is between the retaining wall on the north side of The Sanctuary and the yellow house located there. The client wants to place the pond between the house and the wall along the walking path.

Figure 2: A "Before Picture" of the selected location of pond placement.

2.3.7 Available Materials

The client has several materials already in their possession. They are listed in *Table 2-2*.

Available Materials
An existing gutter system on all three structures.
Rainwater catchment barrels already in use, which are able to be added onto.
Three (3) 55-gallon barrels.
An assortment of PVC piping.
Two pieces of pond liner, one measuring 15' x 15', the other 9' x 8'.
An assortment of plumbing connections.

Table 2-2: Table describing the available materials.

Having these items ready for use will decrease the amount of monetary expenditure and embedded energy attached to materials used to design the system.

2.3.8 Collateral Damage

Collateral Damage could be any unforeseen incident that might occur due to the installation of this design. Water can cause quite a bit of trouble especially if a large quantity of it is released at the wrong place or at the wrong time. If the storage system overflows there is a chance the water might damage surrounding structures since it is near two buildings and the site is also near to a walkway. Sacred Consulting desires that utmost importance be placed on structural stability and safety of the area around the site.

2.3.9 Dangerous Rain Water Damage

In addition to concern about the water leaving the system unintentionally, the quality of the water running into the system is a concern. It would be desirable to maintain the quality of the water running into the system and keep that water clean for the duration of its storage so that the water is of utmost use in the garden and for other uses around The Sanctuary.

Rainwater can be dangerous as it picks up oil, chemicals, sediment, bacteria and other pollutants, carrying them to an unknown destination. Runoff is actually the cause of 70% of pollution (Ritcher 2008).

2.3.10 Contamination Before the Storage System

Contamination can happen in multiple ways. One is way is by the surroundings and what is on the roof area. It also depends on what the roof material is made out of. Animals and tiny dirt particles eventually wind up on the roof (Roof and Gutters, 2016).

2.3.11 Contamination in the Storage System (The Pond)

Once the storage system is contaminated it can become a problem. Bacteria can start to grow and affect aquatic life. Algae can start to grow with the right temperature and nutrients such as nitrogen and phosphorous. Algae can then increase the BOD in the pond affecting and/or eventually killing water life or animals. Soil and dirt that flow into the storage system can increase the turbidity of the water that increases the temperature of the water, contributing the growth of algae; becoming toxic to the aquatic life. (WaterTreatment.org 2016)

2.3.12 Types of Rainwater Catchment Systems

2.3.12.1 Gravity Fed System/Storage

2.3.12.1.1 Introduction

A gravity fed catchment system is a system that can be easily accessed by the person, and does not require for one to pump the water out. Gravity can be very helpful when designing a system for water. The Sanctuary's property is on sloping ground, and because of this a good deal of information is needed about layout. Without using pumps we must plan carefully to keep water from falling below the level where it is needed for use. For placement of the holding area and system we need to consider several factors: location of the house, location of the garden, wind direction, sun angles, and accessibility.

2.3.12.1.2 Advantages

Rainwater is chlorine free. No labor is done to access the water stored by the system. It is easily accessed without it being necessary to pump. Using the force of gravity, water is transported through the pipes to its endpoint. Automatic Systems can be supplemented to it. Using a gravity fed system makes it inexpensive to move and transport water. A gravity system can be constructed to implement a pond. Gravity is reliable. Using gravity, energy can be produced as the water finds its way to lower elevation. There is no need for external energy source because the system itself creates a renewable energy source (WaterAid 2013)(Henke)(Dupont 2013) (Polenghi-gross 2014).

- Inexpensive
- Easy to add other systems to it (filtration, heat system)
- Reduces water bill
- Helps to reduce stormwater runoff
- Can serve as a backup system, water can be accessed at any time (Appropedia 2016) (Dupont 2013).

2.3.12.1.3 Disadvantages

One of the disadvantages of a gravity fed System would be the cost of the construction for it since it involves underground digging and pipes.

- Requires construction on ground area versus barrels
- Requires roof area
- Material of the roof and surrounding area of the roof can contaminate the rainwater

- Gutters will be required to be cleaned
- Unpredictable Rainfall (Appropedia 2016)

One of the disadvantages of a gravity fed System would be the cost of the construction for it since it involves underground digging and pipes.

1. Requires construction on ground area vs. barrels
2. Requires roof area
3. Material of the roof and surrounding area of the roof can contaminate the rainwater
4. Gutters will be required to be cleaned
5. Unpredictable Rainfall

(Appropedia 2016)

2.3.12.2 Rain Barrel System

Perhaps the most commonly used method of rainwater harvesting is by employing the use of a rain barrel. Rain barrels are placed directly under the downspout of a gutter, which collects rainwater that is falling off a roof or other structure. Cheap barrels include trash cans, 55-gallon drums, and any small tank that can be easily installed. Occasionally, a series of these barrels may be installed together and connected allowing collected water to flow from barrel to barrel, filling them simultaneously (Rain Barrel Guide 2010).

2.3.12.3 "Dry System"

Dry systems describe the use of a much larger storage tank than the traditional rain barrel system, though still similar in design. This larger tank may still be inexpensive to implement, and provides water for much longer than rain barrel systems (Maxwell-Gaines and West 2004-2016).

2.3.12.4 "Wet System"

Wet systems, like dry systems, use a much larger tank to store water. However, with this system, the tank is placed much farther from the house or structure that is collecting water. Firstly, this allows an even greater sized tank to be used, as it is not being obstructed by the house or anything else. Secondly, it allows a greater volume of water to be collected. The purpose of wet systems is to collect water from a number of different downspouts, rather than being placed under just one. The water from these spouts are piped underground to the tank, where the water than travels up and into the tank. Unfortunately, due to the underground aspect of this system, it can be costly, and at the very least will be pricier and require more effort than the previously stated systems (Maxwell-Gaines and West 2004-2016).

2.3.13 Cleaning

2.3.13.1 Gutters

The first step to keeping a rainwater catchment system clean is to keep the inflowing water clean. This requires manual cleaning, so as to prevent clogs, but can also be helped by installing mesh filters to keep out debris. These filters may be placed at the entrance to the downspout, so as to keep objects from ever entering the system. Larger mesh filters may be placed on the tops of the gutters themselves, to keep out leaves and other bigger objects, though these are not necessary, and may even make manual cleaning harder (Padmanabhan 2015).

2.3.13.2 The "First Flush" Method

When an area experiences an extended period of time with little to no rainfall, dust and debris including pollutants and bird droppings collects on the roofs of households, and stays there unless manually cleaned, or washed off by rain. When rain does come, this dirt is not safe to have washed into rain water barrels or tanks, especially if being used to drink or cook with. To counteract this, a "first flush" method may be employed, though it is not necessary (Pushard 2013).

This method uses an addition to a downspout, which diverts the first rush of rain water into a separate, much smaller tank, to be manually disposed of at a later time. These systems can be hand built, or bought and installed. One type of first flush system that can be bought is placed between the downspout and a pipe leading to the entrance of the storage tank. It is typically in a "T" shape, constructed of the same materials as the downspout. As water begins to flow, it is first diverted from the downspout to the first flush system, rather than onto the pipe that leads to the tank. As water fills the small space of the system, a float placed inside climbs to the top of the system with the rising levels of water. Eventually, when the system is filled, the "first flush" is considered done. When this happens, the float reaches the top of the system, and seals the entrance, allowing the water to then bypass the first flush, and continue directly to the storage tank (Pushard 2013).

In a case study done in South Africa in 2012, it was concluded that first flush filters generally rid the system of microorganisms, as well as larger particles, which make the water much safer for domestic use (Gordon et al. 2012).

2.3.13.3 Preventing Algae

The best way to prevent algae growth is to use a non-transparent storage tank, as sunlight permits algae to grow and thrive (Kinkade-Levario 2007). If a see-through tank is already in use, or is the only option to use, an addition of chlorine will prevent algal growth (Maxwell-Gaines and West 2004-2016).

2.3.14 Costs

If the traditional rain barrel system is employed, then all that is needed to be bought is a barrel, if not already available a 55-gallon drum runs for about $70, though prices may differ for different products (Uline 2016).

2.3.15 Materials

2.3.15.1 Metal

Metal pipes and fittings can often corrode in the right conditions and surrounded with the right material. This could cause collateral damage that might be harmful to the environment around that metal.

2.3.15.1.1 Galvanized Steel

This type of steel is made by completely immersing the metal in molten zinc after the cleaning (WHO 2006), or by a process called electrogalvanizing where the metal is immersed in a solution of zinc sulfate or cyanide. Immersion creates a pure zinc coating on the steel (gsa.gov 2016). There can be some corrosion problems with this material, more so than other materials (WHO 2006) (gsa.gov 2016).

2.3.15.1.2 Copper

Out of the 3 thicknesses of pipe the “L grade” of pipe would be the one used for outdoor plumbing. This metal has a long lifespan and is very good at holding connection to valves. It can fail however if the water inside has a pH of 6.5 of less (CDC 2009). When this metal is out in the elements it will change colors and gains a protective coating. However, this coating is actually natural corrosion, but will protect the pipe from further corrosion, and therefore this protective patina makes copper corrosion-resistant.

Characteristics of Copper:

- Durable
- Corrosion-resistant
- Strong
- Ductile: Can be drawn or "stretched"
- Malleable: Can be hammered or rolled into sheets without breaking (gsa.gov 2016).

2.3.15.2 Non-Metal

Polybutylene is a type of non-metal that was used in the past but is no longer used due to being banned because of problems with leaks at joints resulting in very bad water damage in houses (WHO 2006).

2.3.15.2.1 Polyethylene (PE)

There are 3 different types; high, medium and low density. The higher the density, the lower the flexibility, and usually the higher the cost (WHO 2006).

2.3.15.2.2 PVC

This is a thermoplastic that is created through the process of polymerization using vinyl chloride. Specific to this piping is the sizes of the diameter of the pipe, being .25 in. to 12 in. in diameter (WHO 2006). The positives to this material are its cost, good resistance to alkali and acidic conditions, fire and good UV resistance. Although, some of its disadvantages are that it requires modification, is difficult to milt and can become weak enough to crack in temperatures below 50℃ (AZoM 2001).

2.3.15.2.3 Concrete

When concrete is mixed, the biggest determinant of how strong it will be is the ratio of the water that is used compared to the amount of cement. Caution must be used though in order to not use too little water or else all of the cement will not be hydrated and then will not create concrete (ce.memphis 2016). This material tends to be more resistant to corrosion, but is also damaged much easier than its metal counterparts (CDC 2013). To solve this problem of getting damaged additional supports are often put inside concrete structures (ce.memphis 2016).

2.3.15.3 Roofing

Most modern roofs are built out of either asbestos, aluminum, concrete, corrugated plastic and wood. The asbestos's biggest con is that it creates water with the highest pH out of these materials. Lastly, asbestos, concrete and corrugated plastic roofs have some bacterial contamination in the water runoff. However, all of these materials are safe according to WHO (world health organization) recommendations (Olaoye, Olaniyan 2012). The possible area of the system, available roof area, which could be used for rainfall collection is 5000 square feet. This area consists of the clients building, 2500 square feet, the client's house, 1500 square feet as well as the neighboring house, 1000 square feet (pequals.com 2016).

2.3.15.4 Plumbing

2.3.15.4.1 Intro

Plumbing is about creating a system by connecting pipes together with fittings, these are like the glue of the plumbing puzzle. The most common materials used to make all of these type of fitting are; brass, copper, galvanized or stainless steel and PVC.

2.3.15.4.2 Fittings

Plumbing is about how creating a system, usually for water to flow, by connecting pipes together with fittings, these are like the glue of the plumbing puzzle. The most common materials used to make all of these type of fitting are; brass, copper, galvanized or stainless steel and PVC (plumbingsupply.com 2016).

2.3.15.4.3 Adapters

One of the most basic fittings, this allows for changing the connection type or simple just to extend the pipe a bit farther (plumbingsupply.com 2016).

2.3.15.4.4 Bushings

This type of fitting is an adapter that is used to join two pipes of different sizes usually by reducing a larger fitting down to a smaller pipe. Most of the times bushings are threaded both inside and out, and usually don’t take up very much space as opposed to a coupling or union, which do the same task (plumbingsupply.com 2016).

2.3.15.4.5 Caps & Plugs

Caps are exactly what the name suggests, a way to cap, or stop the flow in, the pipe. In order to achieve this goal these caps or plugs need to be glued or soldered onto or into the pipe (plumbingsupply.com 2016).

2.3.15.4.6 Couplings

A coupling is used when a pipe needs to be extended or changed to a different pipe size. In the case of the latter the coupling would be called a reducing coupling or a bell reducer. The majority of couplings contain threads on the inside when threads are present. When threads are absent then the coupling must either be soldered or glued to the pipe (plumbingsupply.com 2016).

2.3.15.4.7 Elbows

It is common to run into a problem where a pipe needs to be turned around a corner or for some other reason. An elbow is used to connect two pipes at an angle, usually 90 or 45 but any angle can be made. These fittings can be threaded or sweated, and are one of the most crucial fittings in most plumbing cases (plumbingsupply.com 2016).

2.3.15.4.8 Flanges

Flanges accomplish the task of connecting pipes that are threaded or not. In the case of attaching to a non-threaded pipe the flange will be welded or bolted together. These fittings are normally found in residential systems, more specifically in toilet plumbing (plumbingsupply.com 2016).

2.3.15.4.9 Nipples

These fittings are actually just short pieces of pipe, but with male threads at each end, and are used to connect straight pipe runs (plumbingsupply.com 2016).

2.3.15.4.10 Crosses

Adding another branch on the opposite side from the stem of the T makes a cross, with all the other characteristics of a T as well (plumbingsupply.com 2016).

2.3.15.4.11 Unions

The common alternative to couplings is a union and is used for practicality or convenience. Unions are more convenient because they don't require threads and can just be glued and slipped onto the pipe (plumbingsupply.com 2016).

2.3.15.4.12 Tees (T)

This fitting is required when more than one branch has to be connected. As the name suggests it looks like the capital letter T and is usually threaded on the insides of each of the branches of the T (plumbingsupply.com 2016).

Figure 3: This is the T-fitting that was used in the system's First Flush Water Diverter.

2.3.15.4.13 Saddle Tees

Another variation on the T, this is usually only a PVC fitting, and is the top half of a pipe with one fitted attachment on the top to create the T (plumbingsupply.com 2016).

2.3.15.4.14 "Y"'s

Primarily found as a drainage fitting, this usually PVC pipe consists of a straight component and then a branch at a 45o so that the flow is kept smooth. This fitting can help fix buildup of various kinds when used instead of a T (plumbingsupply.com 2016).

2.3.16 Storage Area

Once the storage system is contaminated it can become a problem. Bacteria can start to grow and affect aquatic life. Algae can start to grow with the right temperature and nutrients such as nitrogen and phosphorous. Algae can then increase the BOD in the pond affecting and/or eventually killing water life or animals. Soil and dirt that flow into the storage system can increase the turbidity of the water that increases the temperature of the water, contributing the growth of algae; becoming toxic to the aquatic life (WaterTreatment.org 2016).

2.3.17 Calculating Storage Needs

One of the first steps when looking at storage volume is to calculate the maximum amount of water that can be stored and also the usage that can be expected to leave the reservoir or holding area on any given day. Arcata receives around 40 inches of rain a year on average. Much of Arcata's rain comes in December and January. They both average over 8 inches per month. A square foot of horizontal roof surface receives 0.625 gallons of water with each inch of rain. This gives a framework for making some calculations on volume of water coming in.

One of the first steps when looking at storage areas, is to calculate the maximum amount of water that can be stored and also the usage that can be expected to leave the reservoir or holding area on any given day. Arcata receives around 40 inches of rain a year on average. Much of Arcata's rain comes in December and January. They both average over 8 inches per month. A square foot of horizontal roof surface receives 0.625 gallons of water with each inch of rain. This gives a framework for making some calculations on volume of water coming in (WaterAid 2013) (Weather DB).

2.3.18 Maintenance

All of the reservoirs in a rainwater catchment system require maintenance. Some more than others, so a carefully chosen design is key if a requirement is that the system functions for a long time with minimal maintenance costs, both in time and replacement parts. The things to consider when looking at long-term maintenance are:

1. Cleanliness of incoming water
2. Circulation of water through system
3. Light exposure
4. Method of water entry/exit

A carefully designed system should be able to be cleaned every 2-3 years but there are many factors that need to be considered. The gutter will need cleaned every season or

more often depending on the trees and overhead objects present. The best way to clean a system is to prevent it from getting dirty. This includes extensive planning and preventative steps to keep stuff from getting into the water.

2.3.19 Combinations

2.3.19.1 Permaculture

"Nothing in nature does just one thing. This multipurposeness—where in each interconnected piece plays many roles is another quality that distinguishes an ecologically designed garden from others." (Hemenway, 2009) It is best to design a system that meets multiple needs. Addresses multiple things that were lacking before. By doing this we are copying nature and how it makes sure all bases are covered when forests are grown. Everything in the forest helps its neighbor and supports the needs of the other living species in the local ecology.

2.3.19.2 Swales

There are many ways to combine a rainwater catchment system with existing barrels and catchment gutters at a site. Many systems have been combined with existing garden features so that the runoff from the collection reservoirs will filter into swales, which are big humps of ground designed to catch water from running away. These will keep an open system from losing water that may overflow during heavy rainfall and can help the ground to absorb more water. This improves the moisture content for the subsurface and can greatly benefit plants and organisms that live downhill.

2.3.20 Multiple Holding Areas

It is necessary to look at which geographic areas of the property are using water to best design the system. It is possible to have multiple holding reservoirs so that water is available at multiple spots instead of one single location. The overflow from one reservoir can feed into another larger one. Manual controls can be used to bring water from one body to another to keep a more constant level in the second holding area. This is useful when using a pond as a holding area and didn't want fish or plants to be stressed from low water levels that can result in dry periods.

A benefit of having multiple areas is the fact that pumps or much elevation is needed to pipe water may limit the ability to properly pressurize hoses and get the water from a storage location to where it is needed. Having multiple storage locations which are linked into a bigger system can save time and headache when trying to get water from point A to point B.

2.3.20.1 Pros of Multiple Holding Areas

The fact that pumps or much elevation is needed to pipe water may limit the ability to properly pressurize hoses and get the water from a storage location to where it is needed. Having multiple storage locations which are linked into a bigger system can save time and headache when trying to get water from point A to point B.

2.3.21 Add-ons to Rainwater Catchment Systems

It is also possible to add in other water features such as a solar shower with some of the water coming off of the house for those hot summer days (Schulz 2016). Cooler climate can take advantage of this cold water for other uses. It is also very easy to add spots for aquatic plants along the way so as to keep the system functioning for multiple beneficial uses.

2.3.22 Wind and Sun

We do not want to put the holding area directly uphill from any structures in case of a holding area failure. We want the water to be able to make its way to the holding area with little or no energy expended for pumping. Using the overflow from the holding area to run into areas where plants can use this water would be best. So thinking about where the garden is will help with the planning. If this water is in direct sun all day and/or exposed to a lot of wind, we will lose more water to evaporation than if we can protect this water holding area using existing features on-site.

2.3.23 Carbon Emission Budget

A carbon emission budget is a framework for which to track the amount of carbon emissions are produced by a certain product, system, or even population of people. With global warming becoming a huge issue all around the world more attention is being paid to this and it is important to examine each project through this lens.

2.3.24 Rainwater Compared to Municipal Water

During studies of different rainwater catchment systems, it was found that a rainwater catchment system has been estimated to save 30% on the amount of water needed from outside source. However, the materials used and maintenance of the system can cause a deficit when carbon emission budgeting is looked at. The addition of a rainwater catchment system can actually cost us more in carbon emissions than just getting that water from a municipal source depending on how these systems are implemented and maintained (Macomber 2001).

3 Alternative Solutions

3.1 Introduction

The purpose of presenting alternatives to the client is to find the solution which best satisfies the needs and desires of the client. In order to come up with sufficient quantity and quality of ideas, a brainstorming session was held where team members shared thoughts on the design while keeping our criteria and considerations in mind. The group formulated ideas and was able to synthesize some excellent designs out of the brainstorming session. After the brainstorming, each possible design was drawn out and examined in detail. Our brainstorming process and the eight best alternative solutions are detailed in the following sections.

3.2 Brainstorming

Before brainstorming, rules were established so as to not impede the creative process. All given ideas were accepted without criticism, and listed on one piece of paper. After brainstorming for half an hour, this long list of ideas was condensed into eight individual solutions. Documentation of the brainstorming session can be found in *Appendix 6-3.*

3.3 Alternative solutions

As stated before, the brainstorming session ended with the team choosing eight individual alternative solutions. The solutions that best met the criteria and considerations of the client were:

1. Pond without a Cover
2. Cistern with Secondary Storage
3. Water Tower and Beautiful Pond.
4. Water Tower over a Cistern.
5. Pond with Secondary Storage
6. Existing Circle System
7. Cistern without Secondary
8. Pond with Lid

3.3.1 Pond without a Cover

The Pond without Cover, seen in *Figure 4* below, is one of the simplest solutions. With this solution, rainwater collected in the gutter is run directly into a pond, which is situated in between the north wall of the house and the wooden fence that separates the property from the Sanctuary. The pond is built using the provided liner that the Sanctuary already owns, the sizing of which is 15’ x 15’ and 9’ x 8’. The pond has an aerator that prevents the water from becoming too dirty. Another method of keeping

the pond clean is placing a fence around it, in hopes of keeping ducks out. Inside the pond are water plants and fish, which also act as mosquito prevention. On the other end of the pond is an overflow tube, which is place to prevent flooding in case of a heavy rain that cannot all be contained by the pond.

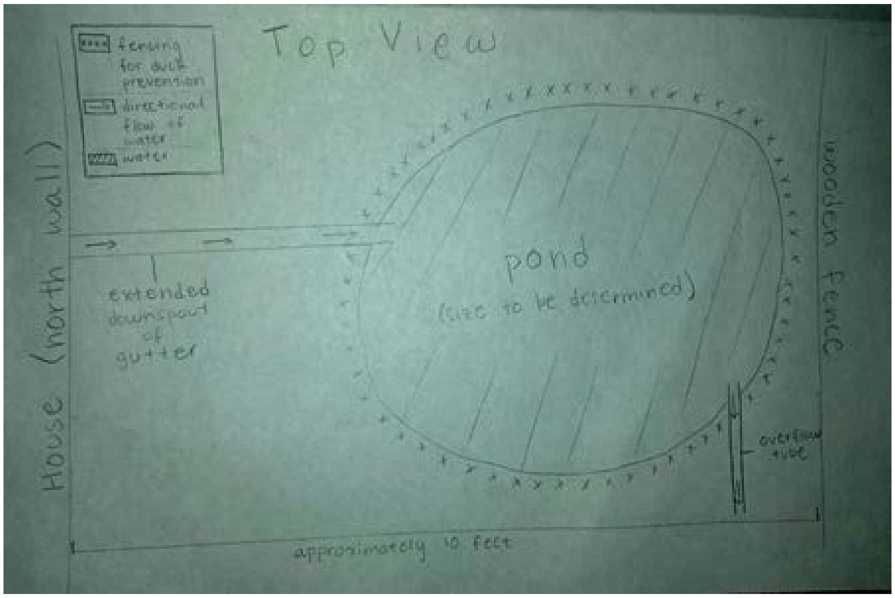

Figure 4: This drawing represents an example Pond without Cover.

3.3.2 Cistern with Secondary Storage

The Cistern with Secondary Storage is a solution that receives its water directly from the gutter. The water from the gutter first fills a rain barrel, or possibly a series of rain barrels. This is the “secondary storage,” or the smaller storage. After filling this rain barrel, water than flows underground to a much larger cistern. This cistern is situated underground in between the north wall of the property and the wooden fence. As water fills the cistern, it is able to be pumped up into a water spigot, which can be connected to a hose and used to water the garden. The main form of storage in the solution is definitely the underground cistern, which can hold a large volume of water.

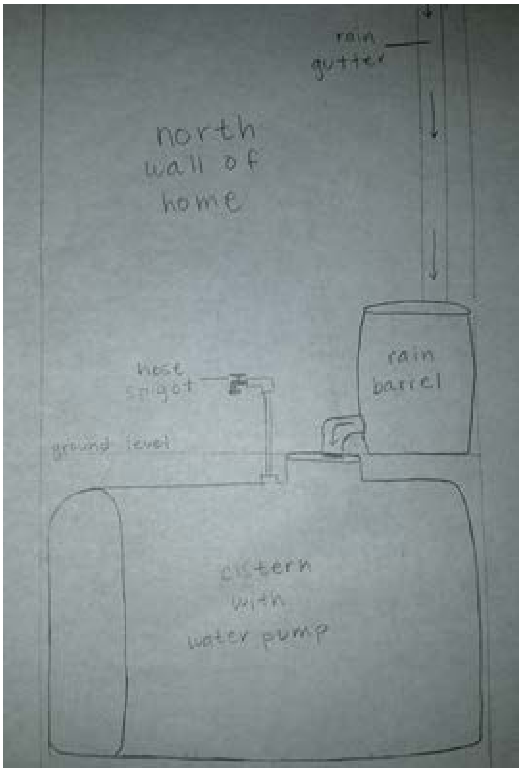

Figure 5: Example of underground Cistern with Secondary Storage; in this case, a barrel.

3.3.3 Water Tower and Beautiful Pond

This design utilizes a water tower holding tank near the street between the Sanctuary and the house to the north. This design allows for higher water pressure for all applications down the line. When this tank is full water can flow to the two-chamber pond where fish and plants can benefit. The pond doubles as the primary storage unit. Water can also bypass the pond and flow directly to the garden or through a hose with reasonable pressure do to change of elevation. This design also grandfathers in the old rain barrel on the northwest corner of the house. The only modification is to run the overflow for this directly into a junction box where the other gutter releases water on the southwest corner of the house and then into the pond/primary storage. The overflow from the old tank can be controlled by manually releasing water through the line but the overflow in case of overfill will automatically run into the line. The junction box will have a filter and all downspouts will be fitted with screens if not already in place.

The inflow to the pond will undergo aeration and there will be an aerator in the pond to maintain dissolved oxygen levels. Lastly, the main overflow of the system will run into a series of three holes placed in the garden and filled with rocks, phone books, broken

ceramics, or other material to help water to absorb and leech water into the ground reducing the amount of surface water runoff.

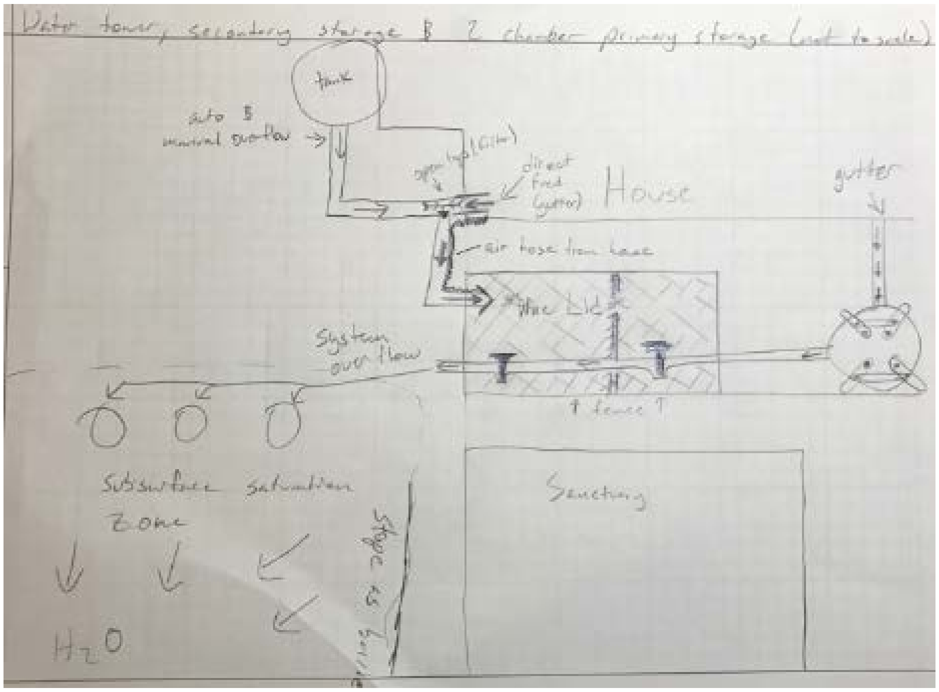

Figure 6: This diagram illustrates a pond being sourced from a water tower, located on the roof, and a storage tank that already exists on the property.

3.3.4 Water Tower over Cistern

This design is simple and self-contained. It does not take up much space and keeps the water free from contamination. Water runs directly from the gutters into a raised tank built on standard 4-leg stool. This tank is the secondary storage but water may be pulled from this tank more often when it is full because of the added convenience of being able to open a tap instead of pulling/pumping water out of the underground cistern. The cistern is located directly below the water tower. The overflow from the water tower drops straight down into the primary storage, the cistern. The cistern is covered with a concrete or other sturdy top to prevent anything from falling into the water source. There will be a lit on the top as well as a pump or small bucket/pulley system in place to aid in recovering water from the cistern. This design will utilize inline filters which can be cleaned and replaced as well as screens fitted on all gutters. Each tank will require aeration so that the DO levels do not plummet.

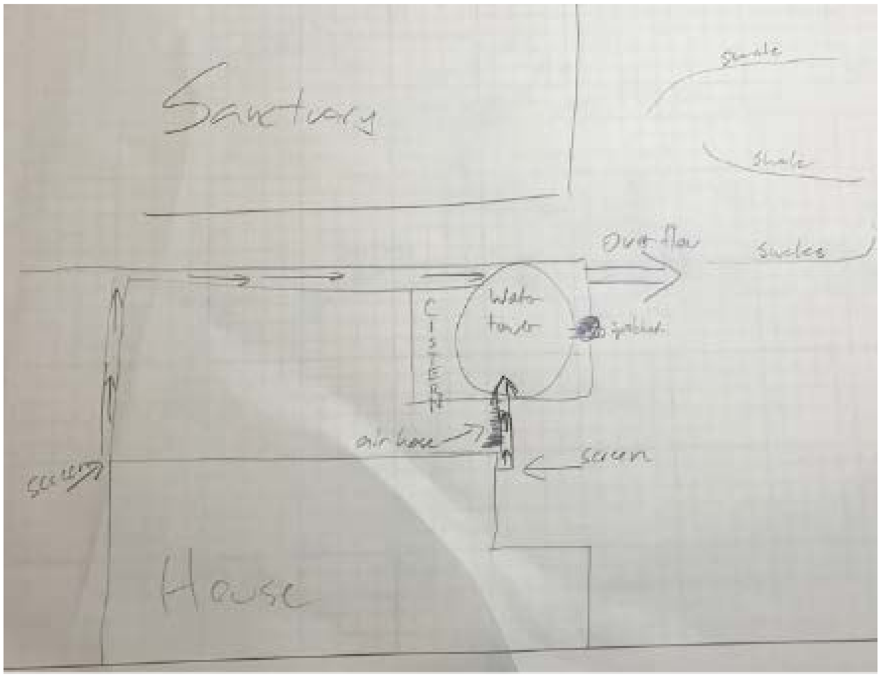

Figure 7: In this alternate solution, both downspouts on the property are being used to supply water to a water tower and a cistern.

3.3.5 Pond with Secondary Storage

This solution involves a pond as the primary storage system for the rainwater collected from the 2 drains coming off from the client's personal house. Directly from the gutters, the rainwater would go into a secondary storage collection unit. There are two options on where to locate this secondary storage site, and they are on either end of the pond length-wise. These secondary tanks would be the place where some type of natural filter would be constructed. On the west side of the pond there is an option on this solution to have a section covered so that the space can be utilized to store the existing items.

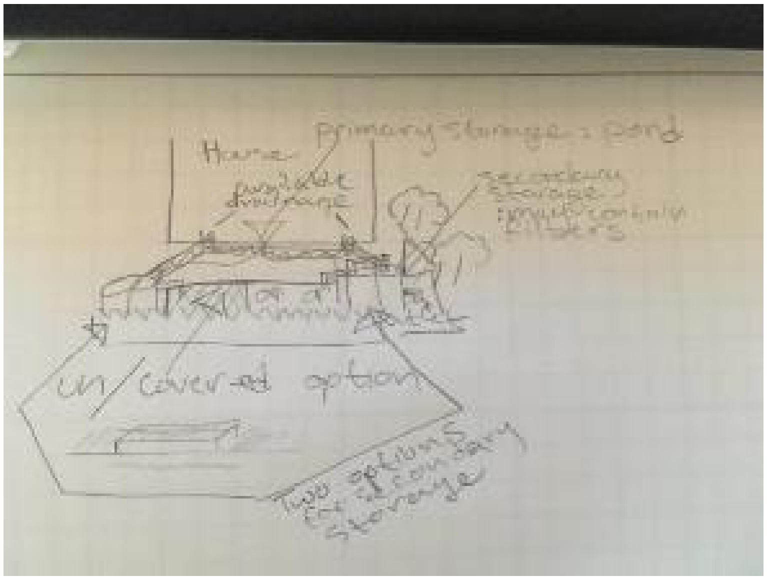

Figure 8: A sketch of an uncovered pond complete with secondary storage.

3.3.6 Existing Circle System

The Existing Circle System is a possible solution to the rainwater collection problem at The Sanctuary. It utilizes their existing pond and rainwater catchment system. First, the existing storage would need to be removed and replaced onto a level surface. After that the available water from the gutters would need to be diverted into the existing storage or placed near the existing tank. Then the water from the end of the existing pond/aquaponics system would flow to the new primary storage pond, which is located beside the house. This pond would have a small secondary storage tank in order to control filtration of incoming water using a natural sediment filter.

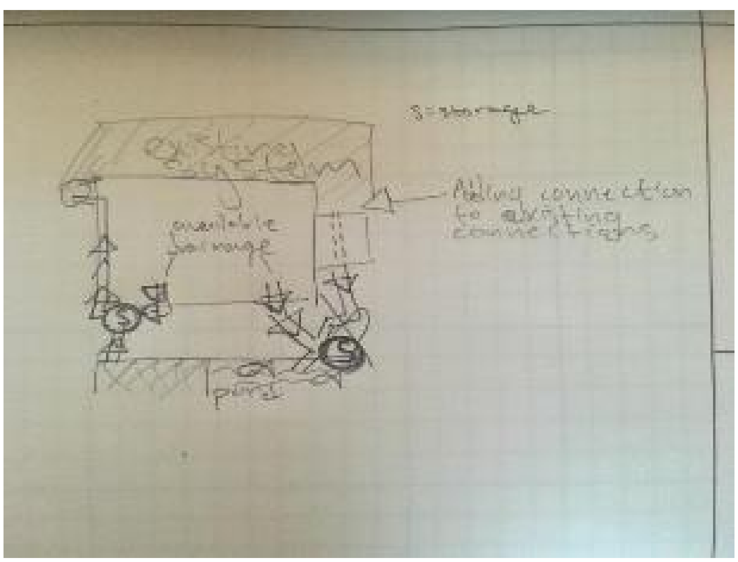

Figure 9: This is an example of how the existing pond can be integrated into the new rainwater catchment system.

3.3.7 Cistern Without Secondary Storage

The Cistern without Secondary Storage is a gravity fed cistern placed underground approximately 5 feet away from the house and behind the sanctuary. This system requires a filtration system and a pumping system to get the water to ground level again after storage. This design also calls for added digging which should be considered when looking at this design. The rainwater would travel through the gutters, down into underground piping, entering a filtration system before continuing into the cistern to be stored. In order to get water out of the storage a pump or siphon system would need to be installed.

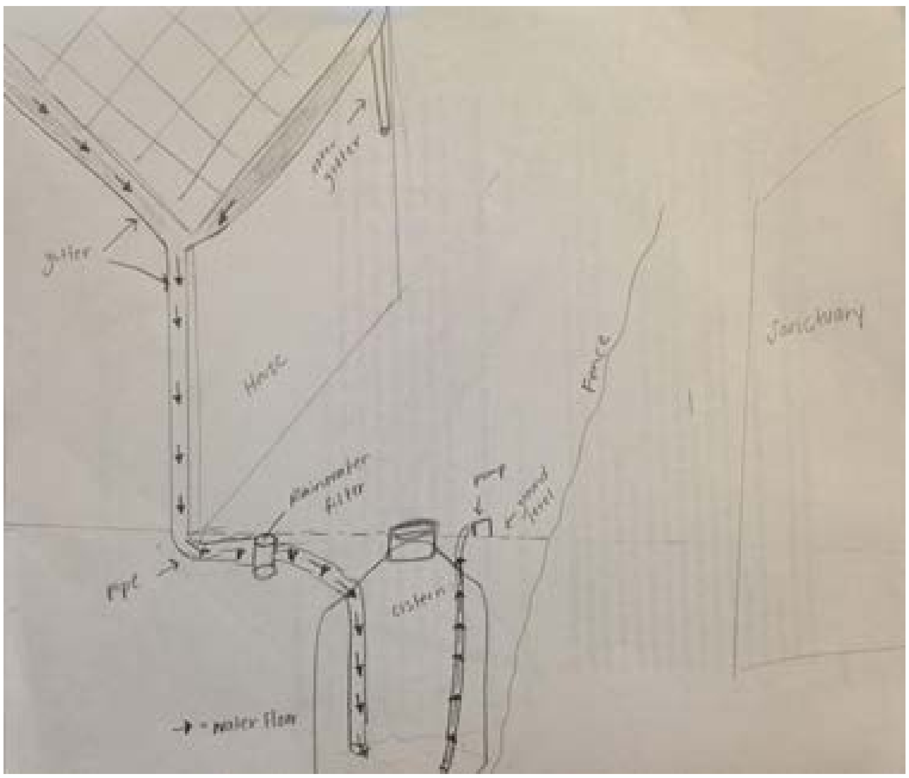

Figure 10: This picture shows how the water would flow in a system with only a cistern.

3.3.8 Pond with a Lid

The Pond with a Lid is a gravity fed pond with a lid. The pond would be built underground. This pond would be located several feet away from the house and against the fence located on the north side of the sanctuary. The rainwater would directly go into the pond without any filtration systems except for screens on the gutters. The gutters on the house would be used to direct the rainwater down the back of the house into underground piping. There the rainwater would travel about 9 feet into the area of the pond. The pond will contain an overflow will flow directly into subsurface wells where the water can leach into the ground. These subsurface wells are nothing more than giant holes in the ground that help the earth to absorb water instead of having that

water run along the top of the soil causing erosion and a multitude of other problems. The purpose of the overflow is to prevent water from building up in the system and flooding the surrounding areas where structures or the system itself could be in danger.

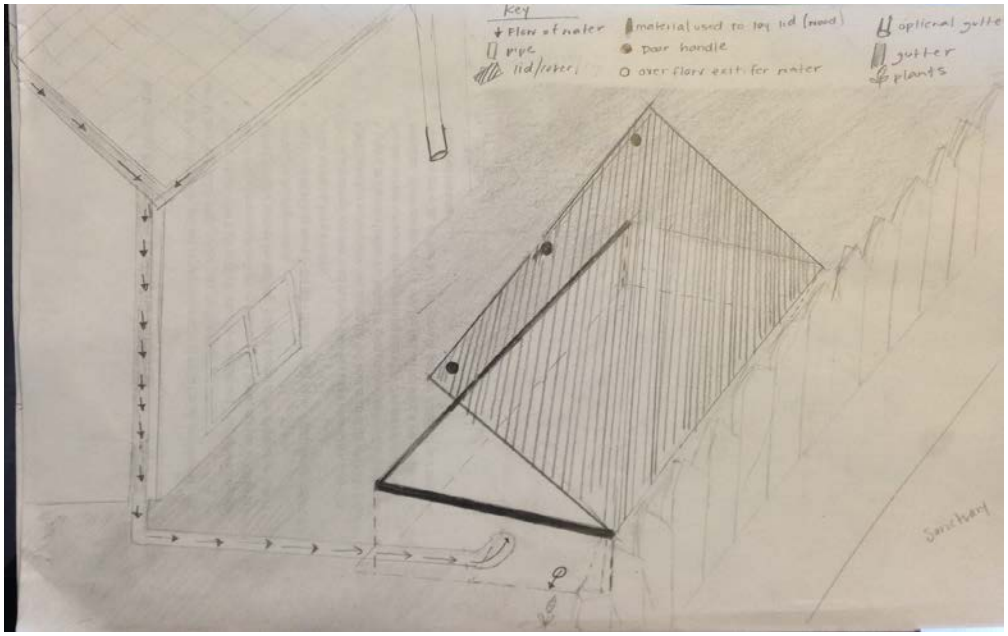

Figure 11: This pond is supplied with a lid that can be removed, or used as a base for an extra storage option.

4 Decision Making Process

4.1 Introduction

Section 4 of this process will contain details about the process used to decide which of the alternative solutions, described in the previous section, best meets the client's list of criteria.

4.2 Criteria Definition

The following criteria defined below are the same as those listed in Section 2.

Cost: the total money spent on supplies, the total hours of each team member combined for both the design and implementation processes.

Usefulness: the amount of water that can be provided to the garden.

Aesthetics: blend into or enhance the surrounding environment with the existing theme.

Accessibility: how much space is left to walk through the area.

Maintenance: the experience and time that it takes to properly maintain the system.

4.3 Solutions

Listed below are the alternative solutions that were detailed previously in Section 3.

1. Pond without a Cover
2. Cistern with Secondary Storage
3. Water tower over a cistern.
4. Water tower and beautiful pond.
5. Pond with secondary storage
6. Existing circle system
7. Cistern without Secondary Storage
8. Pond with a Lid

4.4 Decision Process

The technique that was used in the final decision making process was called a Delphi Matrix shown in **Error! Reference source not found.**. It is a table that takes each criteria, with its weights shown in **Error! Reference source not found.** below, multiplied by a score of how well each alternative solution meets the criteria and constraints.

Table 3: Criteria weighted on the client's needs.

Criteria	Weight
Maintenance	8
Cost	8
Usefulness	8
Aesthetics	7
Accessibility	5

4.5 Final Decision

The Delphi matrix shown below assisted in narrowing the alternative solutions based on their total ranking. The final decision, “The Black Hole”, was a combination of some of the elements from the top 3 ranked alternative solutions.

Table 4: The Delphi Matrix is calculating by multiplying the weight of the criteria with how well it meets the constraint.

Criterion:	weighted 1-10	Pond w/o cover	Cistern w/secondary	tower w/pond	tower over cistern	pond w/secondary	circle	cistern w/o secondary	pond w/cover
	Alternative Solutions								
Aesthetics	7	9	3	9	4	8	8	1	5
		63	21	63	28	56	56	7	35
Cost	8	9	6	7	4	7	7	7	8
		72	48	56	32	56	56	56	64
Usefulness	8	8	4	9	5	8	7	3	6
		64	32	72	40	64	56	24	48
Accessibility	5	5	8	4	7	4	5	10	7
		25	40	20	35	20	25	50	35
Maintanence	8	4	8	4	8	6	4	9	7
		32	64	32	64	48	32	72	56
	TOTAL	256	205	243	199	244	225	209	238

5 Specification

5.1 Introduction

Section 5 contains a detailed description of the final design solution chosen by the process described in Section 4. In order to assist with full understanding of the final design an overview of the system, as well as a detailed description of each component and how to maintain the system. Estimates on material costs and hours of labor on designing and implementing the final design. Also included is a detailed description of how to recreate this design, and the results of the system.

5.2 Description of Solution

The final design is an estimated 800 gallons of total storage. All of the pipes and fittings in this system are standard schedule 40 black PVC. These pipes send water from the existing gutters into the first flush diverter before it is housed in the secondary storage, a 55-gallon drum, and the primary storage, a 700 gallon pond. After the rainwater fills up the pond it goes into the overflow drain.

5.2.1 Overview

The solution decided upon by the client, The Sanctuary, and the team/aforementioned firm, Sacred Consulting is compact and useful. It keeps the water close to the site where it exits the gutters from the roof of the house and makes this water available for use for anyone passing by or anywhere on site through siphoning with a garden hose. This design makes the maximum use of the materials donated to the project by the client. The pond is the primary storage of the system holding between 900-1000 gallons of water. The system also has a second holding area with 55-gallon capacity.

With all this water, so many moving parts, and a garden needing water during the hot summer months, there are many aspects to what seems like a simple concept to begin with. These following sections will follow the rainwater as it falls onto the roof of the house and discuss each step as it flows through the rainwater catchment system.

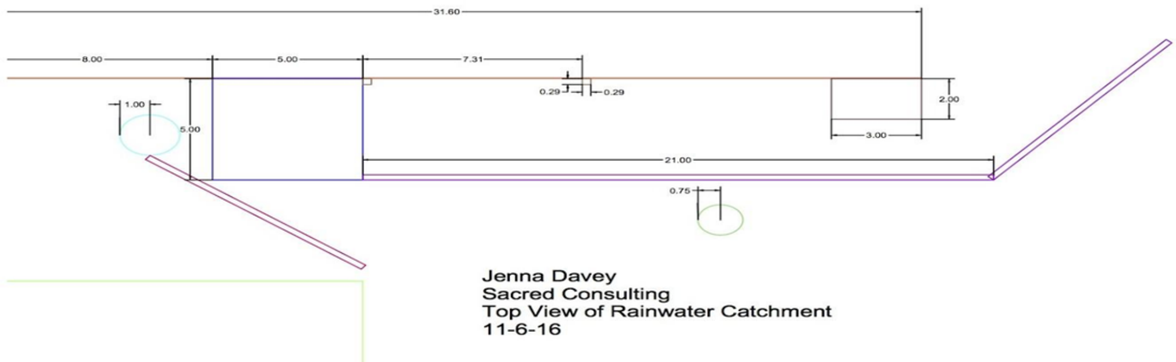

Figure 12: This diagram, drawn in a program called Auto CAD, represents the system shown from above, with dimensions.

5.2.2 Collection of Rainwater

The one and only source for water into the rainwater collection system is through one gutter downspout. This downspout is estimated to provide water runoff from 370 square feet providing the rainwater catchment system with around 8500 gallons of annual water runoff. This water runs out of the downspout and then hits a metal screen at a 45-degree angle that deflects the leaves and organic matter onto the ground while allowing the water to flow into the rainwater catchment system. After going through the leaf filter the water turns nearly 90 degrees where it prepares to enter the “First Flush Zone”.

5.2.3 The First Flush Water Diverter

This diverter is made out of a repurposed 20-gallon barrel with two threaded holes on the top, one of which is filled with a cap. The second hole is fitted with threaded PVC, which has a rubber couple fitting in order to allow for removal of the barrel. Attached to this couple is a T fitting that allows water to come in from the gutter, and then out and onto the next component after the diverter fills all the way to the top. At the base of this barrel is a valve that allows water to flow out. This valve allows the diverter to empty itself after every rain.


Figure 13: The system's First Flush Diverter, placed on the side of the house.

5.2.4 Secondary Storage

Secondary storage can be a confusing name since the water is stored in the secondary before advancing into the primary storage. The secondary storage for the solution is a standard sized 55 gallon PVC barrel. It stands about 3 feet tall and is 22.5 inches in diameter. The barrel was donated and also includes a white lid that will be utilized to keep the storage area clean and free from debris. The water will fall into the storage by means of a pressurized drainpipe coming from the side of the house and the first flush diverter. When the water nears the top of the tank, the water level will encounter a level pipe going through the side of the tank allowing the water to flow out when storage capacity is reached. As the water falls into the secondary storage it will fall through a wire strainer attached to the lid. This makes cleaning the strainer a breeze and is also readily apparent when it needs to be emptied as well as ensuring that no large pieces of organic matter reach the secondary or primary storage by means of the inflowing water.

Cleaning the secondary storage will be easy because the lid can be removed and the entire barrel can be moved to a different location where bleach or other natural cleaners can be applied. All the components can be easily moved and then placed back securely after maintenance has been performed.

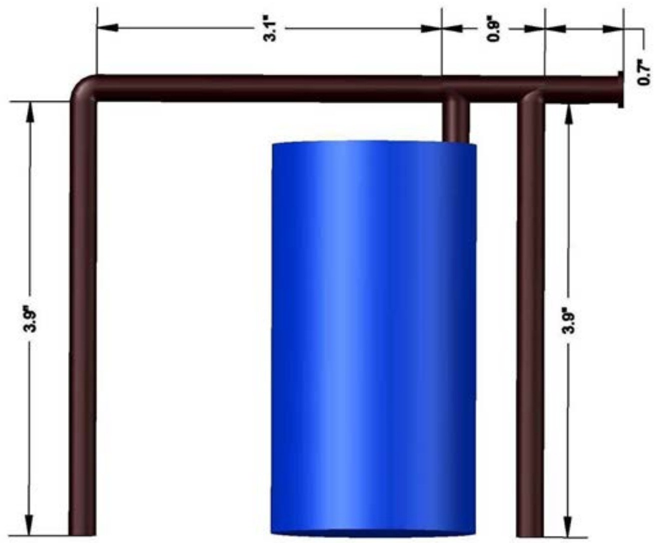

Figure 14: This Auto CAD drawing represents the secondary storage used in the system, dimensions shown in feet.

5.2.5 Primary storage (The Pond)

The primary storage for this solution is a 5’x7’ pond that is 5’ deep with sloping sides. This pond is lined with two large pieces of scrap carped as well as a 15’x15’ recycled pond liner, and can hold up to 700 gallons of water before it fills up. There is a large wooden pallet that covers the pond with a removable 2’x2’ panel for access to the water. At the lowest point of the pond a small pipe, the only non 2 inch pipe in the system, with pond liner wrapped around it is fitted in a drainage pipe. This larger drainage pipe is 20’ long and is buried 15’ with dirt and the rest with fabric and rocks.

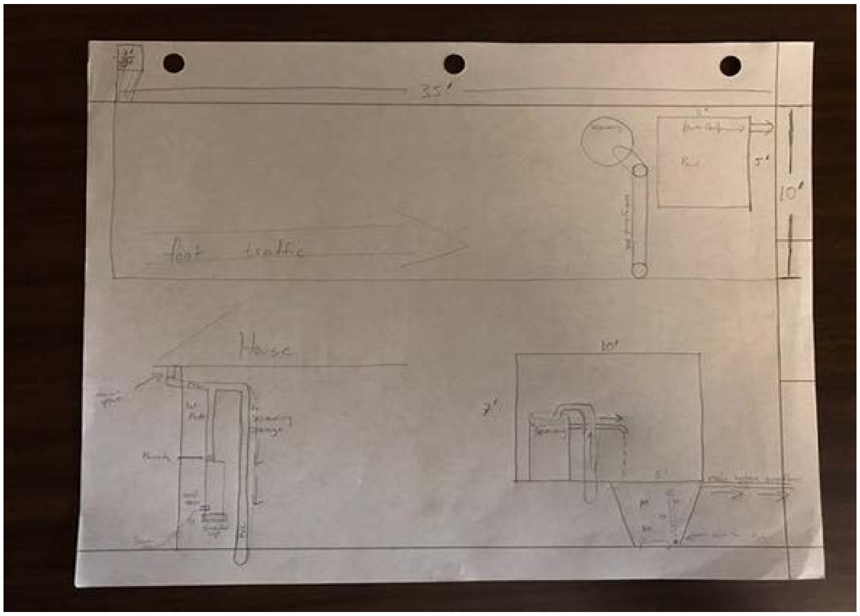

Figure 15: This drawing illustrates different viewpoints of the implemented system.

5.2.6 Pipes

Several different types of pipes were implemented in the system. The first piping that transports the collected rainwater is the present gutter system. After being filtered of big debris such as leaves, the water reaches the first flush diverter, which is made out of PVC and whose dimensions are stated above.

After filling the first flush system, water is piped through 3 inch PVC which acts as a downspout would, allowing gravity to bring the water to ground level. From here, PVC is ran underground, in a diagonal direction from the house to the secondary storage: a distance of about 9 feet. The reasoning for underground piping is so that no visible pipes are in the way, as the area where the system is located is a main walkway on the property. After running underground, the 3 inch PVC pipe will come up at a 90 degree angle and empty into the secondary storage. Because all underground pipes are sealed, the pressure that results from the height of the gutter will allow water to flow uphill, so long as the height of the PVC does not exceed the height of the gutter.

The overflow from the secondary storage will fill the primary storage, or the pond, by way of more 3 inch PVC pipe.

The final step of the whole system is the overflow pipe, which runs from the pond to another part of the property, so as to not cause structural damage from corrosion from the running water. This overflow pipe will also be made from 3 inch PVC and be run underground. The entrance to this pipe will be at the edge of the pond, very near ground level. This way, if the water level in the pond gets too high, it will be diverted to the overflow tube, always leaving a 3 to 4 inch space at the top. After entering this overflow pipe, water will flow downhill for a total of 21 feet away from the pond. It will then flow into a corrugated tube that is connected to the PVC, which will continue for about another 9 feet, where it will then empty the water into the ground.

5.2.7 Fittings

Several PVC pipe fittings to join together cut pieces of pipes and to connect the tanks to the overflow drains. A San Tee is a piece similar to the traditional tee fitting but is carved out to cause the water to prefer to flow in one direction. This piece will be used at the top of the first flush water diverter to keep the dirty water separate from the clean water which is continuing on further through the system.

PVC faucets will be used to control the flow of water out of our secondary storage. This faucet is here so that someone can have access to this stored water if they want to fill a bucket or other container with the rainwater.

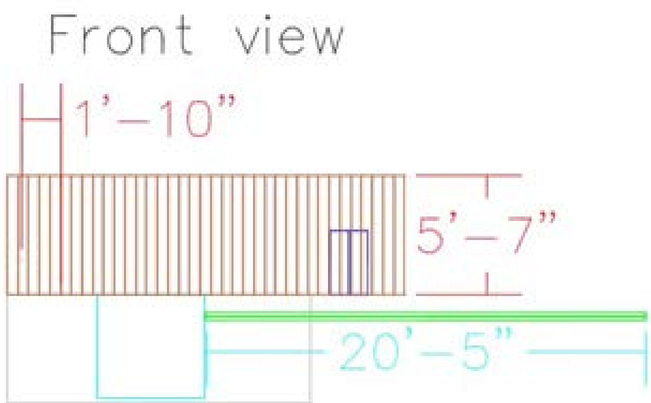

Figure 16: This Auto CAD shows the dimensions of the system with the secondary storage, as viewed from the front.

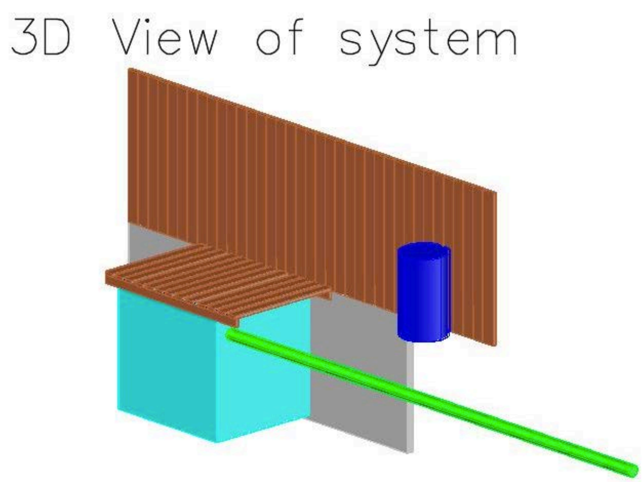

Figure 17: This is a 3D representation of the system, viewed from an angled viewpoint.

5.3 Cost

5.3.1 Design Cost

A total of 355.5 hours were dedicated to designing the system. About 214.5 hours have been spent on implementation and installation of the design solution. This time was split between our team members.

This time included digging the 7’x6’x5’ area for the pond, as well as the two trenches needed for underground piping.

5.3.2 Materials Costs

Due to many items being donated the total cost for the materials was $85.88. A detailed list of all of the materials that were purchased as we as donated can be found below in Table 5.

Table 5: List of expenses. Many materials were donated.

Item	Qty.	Cost (ea)
15' x 15' Black Pond Liner	1	donated
2" Black ABS Pipe	13 ft.	donated
3" Black Corrugated Drain Pipe	32 ft.	donated
55 gallon Blue PVC barrel w/ White Lid	1	donated
3” Black Corrugated Drain Elbow Fitting	1	donated
1/2" plastic tubing	20 ft.	donated
3" Black ABS Pipe	179”	donated
ABS Adhesive		donated
ABS Primer		donated
3" ABS Tee Fitting	3	$7.99
3" ABS 90° Elbow Fitting	4	$6.99
2” Adapter	1	$1.99
3” to 2” Couple Flex Fitting	2	$7.99
3” ABS 90° Elbow Fitting	2	$7.99
Total (before tax)		$85.88

5.3.3 Maintenance Cost

Every year the system needs a complete cleaning and winterization. This annual cleaning should be performed in the fall of the year before the rains start. This allows the system to be as clean as possible before filling with water. If the entire system needs to be cleaned and the pond is full of water, that water must be emptied so that the pond liner can be removed to be cleaned. While the total cleaning time can vary, cleaning the pond liner should only take one hour if all the water has been removed.

The other task that will need to be completed is the emptying and cleaning of the first flush water diverter and the secondary tank. Occasionally, this first flush diverter will become clogged with debris and sediment. Time needed to empty and clean the first flush water diverter and secondary storage is estimated to take less than one half of an hour. This maintenance is recommended to be performed once a month.

In total the system should require under 7 hours of maintenance per year.

Table 6: This Table describes the labor hours associated with maintaining the system.

Task	Cost per month (in hrs)
Cleaning of first flush diverter and secondary storage	1/2
Cleaning of pond liner	1/4

5.4 Instructions for Implementation and Use of Model

The first step in the creation of this rainwater catchment system is start digging a 7’x6’x5’ hole. A shallow trench extending from the side of pond with the lowest walls and heading downhill is necessary for the overflow drain. Any other necessary trenches can be dug at this time.

Figure 18: A team member demonstrating how deep the hole is.

Before installing the secondary storage tank and the first flush diverter these units will need to be fitted with their respective outlet fittings. For the first flush diverter this will be a very small drain placed about one third of the way up the barrel. This allows the

sediment to fall to the bottom of the tank without clogging the drain while allowing the other two thirds of the water to slowly drain between periods of inflowing water.

After digging, it is necessary to create a secure foundation where the secondary storage will be placed as well as one for the first flush diverter as these items will be very heavy once filled with water. It is suggested to put some type of concrete or very solid base under these storage units. Having a secure foundation for these items means less chance that they will settle uneven as time passes.

After creating the foundations for the secondary storage tank as well as the tank for the first flush diverter, these items are installed. At this time the pond liner can also be placed into the hole.

Figure 19: Before placing the pond liner, carpet was put down to protect from damage.

Next, the pipes which will be used to link the gutters to the rainwater catchment system need to be "dry-fitted." This is accomplished by starting where the current gutter system ends and cutting each pipe carefully section by section until all the pieces are connected in a way which reflects the design blueprints. After "dry-fitting" all the pipes, a permanent marker is used to number each connection and also mark a line to use for lining up the angles on each of the connections.

When you are certain that each connection has been properly calculated and marked you may begin priming and gluing the pipes together being careful to only glue the sections that can be installed as once piece because all of the connections will now be permanently in place. After gluing, place the sections into the trenches. By carefully

marking each connection, the pipes are able to be glued and then fit into place using large sections instead of gluing every connection in place and having to deal with limited workspace.

After connecting all the inflowing water pipes, the overflow drain will need to be placed through the pond liner and secured in place. After connecting all the sections of the system together, the pipes are secured using whatever hardware the blueprints demand.

Figure 20: A picture showing the finalized system, complete with a cover.

5.5 Use

In order to use the water in the secondary storage the spigot will need to be opened, either with a hose attachment or not. This will also help flush the system and assist with maintenance. The first flush can also be detached by unscrewing the bucket from the PVC fitting. Cleaning consists of emptying the bucket of debris and then re-attaching.

5.6 Results

The solution approved by the client and proposed by Sacred Consulting fully meets the criteria and constraints of the project. The solution is a complete success and functions as it was designed. There are many years of expected use from this system and it is hoped that other will be inspired by the success experienced here.

A sufficient amount of rainwater is collected to fill both of the storage tanks and provide the garden with supplemental water during times with little rainfall.

The system fulfills its purpose of collecting and storing rainwater in a pond for use in the garden. Testing was performed several times in order to deliver a fully functioning system to the client. The system was presented free of clogging when the rainwater was carrying a minimal amount of sediment from the surrounding environment. During the implementation stage, an issue was brought to the team while digging a trench to lay a PVC pipe connecting the first flush to the secondary storage. The issue being another pipe in the way. Previously, a French drain had been installed and finding it was unexpected. In the end, the new PVC pipe lies above the French drain. Since this pipe will be pressurized by gravity there is no need to worry about the slight uphill slope the water will encounter here.

Sacred Consulting had to reevaluate the ponds dimensions when the client suspected there would be a problem with slope of the pond's walls being too steep. This was not a major issue and was quickly resolved by more digging on the sides and making the shape of the pond more rounded.

The design has an overflow pipe exiting the primary storage pond to allow excess water to drain when the pond reaches capacity. This prevents any water damage the structure of the pond or surrounding structures due to water damage. The overflow pipe is 20 feet long and then opens into a 6 ft. pipe with holes for drainage. It was discovered that the compost team would need to be utilizing the space over where the overflow drain was to be dug. This caused some shuffling of the schedule to allow this trench to be dug first and foremost allowing the other team to progress on schedule and also allowing the pipe to be installed without having to work around another team/project.

6 Appendices

6.1 References

“2.1 Roof and Gutters: Safe Materials Continued.” (2016). Roof, Gutter materials selection, consequences continued, <http://www.thecenterforrainwaterharvesting.org/2_roof_gutters3.htm> (Sep. 26, 2016).

“Arcata (California).” (2016). Arcata, California (CA) climate and weather, <http://city-stats.org/ca/arcata/climate/arcata-climate-data> (Sep. 27, 2016).

“Arcata, California Average Rainfall.” (2016). Weather DB, <https://rainfall.weatherdb.com/l/1075/arcata-california> (Sep. 26, 2016).

“Arcata, California Climate.” Arcata, California Climate, <http://www.bestplaces.net/climate/city/california/arcata> (Sep. 26, 2016).

“Gravity Fed Water System.” Gravity Fed Water System, <http://www.tapstore.com/gravity-fed-water-system> (Sep. 29, 2016).

Living the Country Life, <http://www.livingthecountrylife.com/homes-acreages/ponds/pond-gravity-control-watering-system/> (Sep. 25, 2016).

Dupont, P. (2013). “Rainwater.” Your Home, <http://www.yourhome.gov.au/water/rainwater> (Sep. 27, 2016).

“Is It Okay To Drink Rain Water?” About.com Education, <http://chemistry.about.com/od/waterchemistry/fl/can-you-drink-rain-water.htm> (Sep. 27, 2016).

Luthens, T. (2013). “Rain water to fill pond.” Rainwater to fill pond , <https://permies.com/t/18183/ponds/rain-water-fill-pond> (Sep. 26, 2016).

“Pond Water Contaminants.” Water Treatment, <http://www.water-treatment.org.uk/pond_water_contaminants.html> (Sep. 27, 2016).

Pushard, D. “Rainwater - Purification and Filtration.” Rainwater - Purification and Filtration, <http://www.harvesth2o.com/filtration_purification.shtml> (Sep. 27, 2016).

Richter, A. (2008). “There are four components of a rainwater recapture system: capture, conveyance, holding and distribution.” Harvesting Rainwater, <http://igin.com/article-765-there-are-four-components-of-a-rainwater-recapture-system-capture-conveyance-holding-and-distribution.html> (Sep. 25, 2016).

“Rainwater Catchment System.” (2012). - Appropedia: The sustainability wiki, <http://www.appropedia.org/rainwater_catchment_system> (Sep. 26, 2016).

“Gravity-fed schemes” (2013). Water Aid, <https://www.google.com/url?sa=t&rct=j&q-=&esrc=s&source=web&cd=1&ved=0ahUKEwj1kvK4jrTPAhWCNiYKHZxtBwMQFggeMAA&url=http%3A%2F%2Fwww.wateraid.org%2F~%2Fmedia%2FPublications%2FGravity-fed-

schemes.pdf&usg=AFQjCNH1o67EvT9eEMNndg-ZK3qtlK6Q9A&sig2=S6FGIS2OZDtvanJs_UbyuQ> (Sept. 26,2016)

(Polenghi-Gross et al. 2014) "Water storage and gravity for urban sustainability and climate readiness", E541.

"Climate-Data.org." (2015). Climate: Arcata, <http://en.climate-data.org/location/15733/> (Sep. 28, 2016).

AZoM (2001), Unplasticised Polyvinyl Chloride – Unplasticised PVC – UPVC. http://www.azom.com/article.aspx?ArticleID=770, (Oct. 19, 2016).

Center for Disease Control (2013). Community Water Fluoridation, http://www.cdc.gov/fluoridation/factsheets/engineering/corrosion.htm (Oct. 19, 2016)

Center for Disease Control (2009). Healthy Housing Reference Manual, https://www.cdc.gov/nceh/publications/books/housing/cha09.htm (Oct. 19, 2016)

Galvanized Iron and Steel: Characteristics, Uses and Problems (2016). http://www.gsa.gov/portal/content/111758, (Oct. 19, 2016).

Guide to Fitting Types & Materials. https://www.plumbingsupply.com/fittings-guide.html, (Oct. 19, 2016).

Introduction to Concrete. http://www.ce.memphis.edu/1101/notes/concrete/concrete_properties_slides.pdf (Oct. 19, 2016).

Olaoye, R.A, Olaniyan, O.S. (2012). "Quality of Rainwater from Different Roof Materials", 2(8).

World Health Organization, World Plumbing Council (2006). Health Aspects of Plumbing, Geneva, Switzerland.

6.2 List of Figures and Tables

List of Figures

List of Tables

6.3 Brainstorming Notes

Different ways of getting water from gutter	• Pipes
• PVC	• Black tubing
• Directly from spouts	• No spouts
• Chains	**Alternative Storage**

• Pond w/ bridge	• Pond w/out bridge
• Pond w/fish	• Pond w/out fish
• Pond w/ aeration	• No pond just barrels
• Aeration with barrels with garden	• Storage overflow into barrels
• Storage overflow in groundwater	• Cistern w/ lid
• Cistern w/out lid	• Filters 5gal. barrel screen top filter
• Screen filters	• Screen gutter (keeping out leaves)
• Flushing mechanism system	• Underground storage
• Ground level storage, both?	• Water tower
• Multiple sites of storage	•

Different ways of getting water from gutter

- Pipes
- PVC
- Black tubing
- Directly from spouts
- No spouts
- Chains

Alternative Storage

- Pond w / bridge
- Pond w /out bridge
- Pond w /fish
- Pond w /out fish
- Pond w / aeration
- No pond just barrels
- Aeration with barrels with garden
- Storage overflow into barrels
- Storage overflow in groundwater
- Cistern w / lid
- Cistern w /out lid
- Filters 5gal. barrel screen top filter
- Screen filters
- Screen gutter (keeping out leaves)
- Flushing mechanism system
- Underground storage
- Ground level storage, both?
- Water tower
- Multiple sites of storage