HUMBOLDT STATE UNIVERSITY

the SANCTUARY Arcata

ENGR 215 Fall 2016

Greywater Filtration System

Team Four Squared

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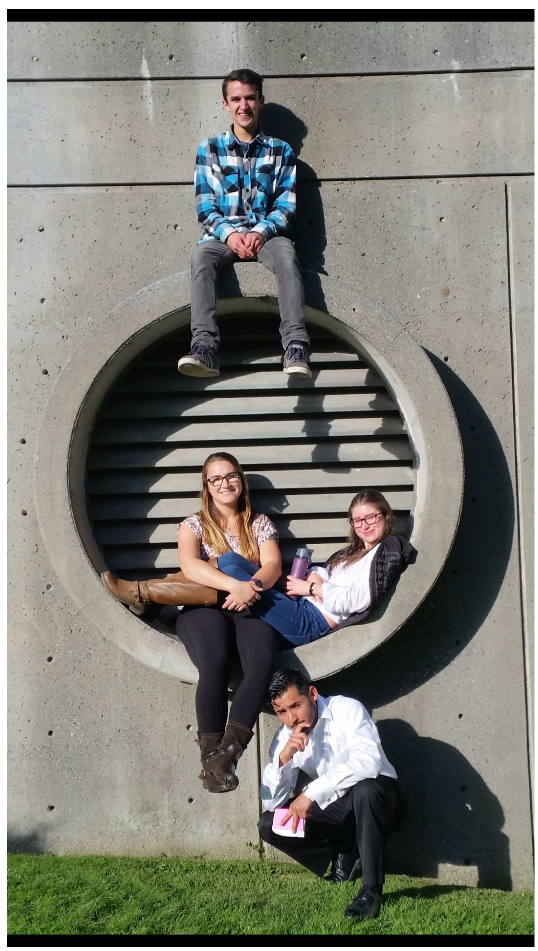

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1 Problem Formulation

1.1 Introduction

The purpose of section 1 is to introduce the client, the team, a brief explanation of the problem and our process, and to show how the project will benefit the client after.

1.2 Background

The Sanctuary, located on J street in Arcata, CA is a community building dedicated to offering a creative space where members of the community can grow, create and build not just physical things but experiences and memories as well. Below is a photograph of the Sanctuary. The Engineering 215 class of fall 2016 were given a number of projects to enhance the Sanctuary and make it more environmentally friendly inside and out. Team Four Squared has four members: Christopher Bautista, Baylee Carson, Juliette Cortez and Jennifer Turk. A current problem at the Sanctuary is that they are using unfiltered greywater from the kitchen sink to water outdoor plants. To fix this problem Team Four Squared built a greywater filtration system that will allow the Sanctuary to use repurposed filtered water on the outdoor plants.

Figure 1-1: The Sanctuary in Arcata, CA taken by Baylee Carson on September 15, 2016.

1.3 Objective

The objective of this project was to reduce the amount of city water that the Sanctuary uses outdoors by filtering the kitchen sink water from the neighboring house, allowing the Sanctuary to use recycled water for outdoor use.

1.4 Black Box Model

The black box model, as shown in figure 1-2, illustrates the state of the world before and after the completion of our project.

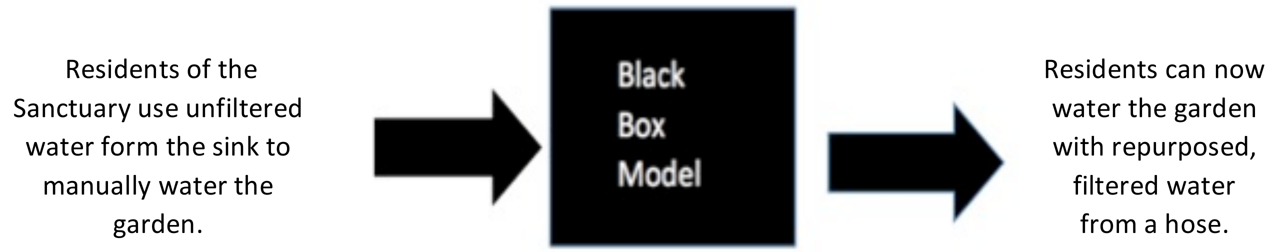

Figure 1-2: Black Box Model

2 Problem Analysis and Literature Review

2.1 Problem Analysis

2.1.1 Introduction

The purpose of section 2.1 is to define the framework for the grey water filtration system. We will review the definite and necessary specifications that must be met for the final design. Included in section 2 are descriptions of the specifications, considerations, criteria, usage, and production volume.

2.1.2 Specifications and Considerations

Specifications are components that must be implemented into the design. Considerations are aspects that must be kept in mind while creating the design but do not need to be implemented. Our specifications include: adhering to legal standards. Considerations include: winter weather conditions in Arcata, potential safety hazards.

2.1.3 Criteria

Table 2-1 illustrates the criteria, which are specific design standards for the project. Constraints are included which explains the needs of the client.

Table 2-1: Criteria and Constraints Defined

Criteria	Constraints
Safety	Must be safe for all persons including children. Also must be safe for the ducks that live on the property.
Reuse of Materials	At least 90% of the materials must be reused.
Maintenance	Must be easy enough for two adult people to clean in one day
Aesthetics	Must look professional for adults who come to learn about the system.
Cost	Must cost at maximum 400$
Ease of Use	Must be easy enough for one adult person to use

2.1.4 Usage

Section 2.1.4 defines the frequency of usage for the system. The final design will be used at the sanctuary for grey water filtration. The system will be used as needed daily. The system is automatic, human interaction is not necessary for the system to function.

2.1.5 Production Volume

Section 2.1.5 defines the volume of products that will be built. One final greywater filtration system will be built at the site. Many prototypes of aspects of the system will be created throughout the process.

2.2 Literature Review

2.2.1 Introduction

The literature review analyzes background information in order to expand knowledge and develop ideas on the many topics regarding grey water.

2.2.2 Client Interview

Two members of our team met with the Sanctuary at the site to discuss the client's needs and ideas. Our client said that on average they dispose of 10 gallons per day minimum and 30 gallons per day maximum of grey water. Currently the grey water is poured on the vegetable garden directly with no filtration. The residents of the sanctuary pass a bucket out the kitchen window and spread it around the garden bed. Our client would like to implement gravity in the system. Currently the residents of the sanctuary use whatever soap is available and free to wash the dishes. The client also explained that the pipes for the kitchen sink drain run the opposite direction of the garden under the house. The client expressed interest in incorporation an interactive aspect to the system to accompany the fun atmosphere of the Sanctuary. (Arnold, J 2016)

2.2.3 Grey water

2.2.3.1 Storing and settling tank

The purpose of a settling tank is to allow larger particulates to settle to the bottom, while allowing fats, oils, and grease (FOG) to float to the top (Duttle,1994). The water in a settling tank should not sit for more than 24 hours, or the water could have spikes in bacteria and produce objectionable odors (Ludwig 2006). It could be problematic during the winter months, due to the fact that cold water takes more time to settle compared to warm or hot water. To ensure proper efficiency of the tank in the system it must be large enough to hold 240% of expected water volume on an average day. The settling tank should not be larger than 55 gallons or the system has a greater chance of failure, which will turn the grey water into black water. Another important component of settling tanks are proper oxygen flow for an aerobic system, otherwise the bacteria concentrations will be too high to be used for irrigation (Ludwig 2006). Proper cleaning of the system is to be noted, otherwise contamination to the next filtration process could be a concern. Some of these concerns such as cleaning, amount of time, and oxygen can be accounted for by using smaller tanks and natural filters such as dirt, plants, and sand (Ludwig 2006).

2.2.3.2 FOG (fat, oils and grease)

Fats, oils, and grease or better known as FOG are the by products of food preparation and cleaning of kitchen appliances. Common FOG sources include butters, cooking oils, dairy products, meat products, salad dressings, and nuts. Pouring excess FOG down kitchen drains is discouraged by city and state government (Washington suburban sanitary commission 2016). To ensure proper practices of what goes down the drain, it is recommended to scrap these FOG products into the trash, not pouring excess grease down drains, and wiping up grease and throwing it away (city of Arcata Environmental Services). Having low amounts of FOG going down the drain is important to the success of a grey water system. FOG sources are damaging to plants and may also reduce the lifespan of the system. Also a secondary settling process should be installed to remove as much FOG by product as possible. By reducing the amount of FOG in the system, it will prolong the overall life of the grey water system, ensure that the irrigation from this water is healthy for the plants, and will reduce the potential of turning your grey water into black water from excess in bacteria and microorganisms(Grey water action 1999).

2.2.3.3 Filtration

Filtering grey water before irrigation is an important aspect to the success of the grey water system. By filtering the rest of solids, FOG, and soaps that come from the primary filtration settling tank, you will now be able to water all your plants in the garden including fruits and vegetables (Grey water action 1999). If the water is not properly treated, then the water should not be used for edible plants because transfer of dangerous pathogens is possible. Filtering will also be healthier for the plant vs. not filtering out the grey water. It will have a more stable pH and will be safer for the soil and the plants (Grey water action 1999). Another benefit of doing this process is the filtration limits the chance of dangerous pathogens to be passed from the water to the plants, which can be passed on to humans. Through a filtration process called phytoremediation, wetland plants such as reeds filter and recycle waste through their root systems (Edgar 2013). A system such as this can take about 120 cubic feet for the average building, for our purposes this could be near 200 cubic feet (Ludwig 2006). The system is inexpensive and easy to maintain. Another filtration system would be though the use of sand, coal, and dirt. This system is nearly free and requires little maintenance. A benefit of using dirt like earth materials is that it is a natural filter and introduces important nutrients and oxygen to the grey water so that it would be great for irrigation. In addition through the use of a dirt filtration system the total amount of space needed is significantly less than the space needed for a plant based filtration system.

2.2.3.4 Worm Composting

Red wigglers are the most commonly used worms for composting. Worms eat organic matter. Red wigglers adapt better to temperature and moisture changes than other worm species (O'Connor 2012). Worms in a good environment can reproduce sustainably for approximately 5 years ("Composting At Home," 2016). Worms can compost most organic waste, however limiting the amount of animal products, such as dairy, meat, fats and grease is important for a healthy worm environment ("Composting," 2016).

2.2.3.5 Aerobic System

Oxygen plays an important role in the grey water system. Using a tank to store water temporarily can cause the water to turn septic. In a tank, microorganisms will quickly use up all of the oxygen; this will produce pathogens that could be harmful to human health. Using active dirt, plants, or filters will introduce more oxygen into the system. The microorganisms in the water will not use up all of the oxygen, this way the water is properly treated before reuse. Plants that produce lots of oxygen will make a tank system possible when the water needs to sit for upwards of day. Alternatively pumps can be used to percolate oxygen into the tank so the water will not turn septic.

2.2.3.6 System Sizing

Aspects that need to be measured are the rate at which our filtration devices filter grey water and the maximum input volume possible. For example, if bulrush is used as a plant filter, 30 gallons of water would need to filter through the roots in one day. After filtration, if the water was going to be stored, a large enough storage tank must me used. The amount of water that would be taken out of storage per day would also need to be calculated. According to Broome, Jencks, Jurosek, Kehoe, Kraai, Ortiz, Rhodes, Allen, Knott, Day, Panelli, Weintraub. 2012, grey water needs to be discharged a minimum of three feet above the groundwater table.

2.2.3.7 Optimal Plants for Filtration

Larger plants such as fruit trees, bushes, and perennials are easier to irrigate and thrive in grey water systems. These plants could include blackberry bushes, peach trees and kiwi trees. When it comes to deciding which plants are best suitable for filtering the grey water, different types of root systems should be considered. For the purpose of this system wetland plants such as reeds, bulrush, cattail, juncus and water iris are best suitable for filtering medium use grey water. Plants that have varying root systems from fibrous and complex to large and sparse are great for filtering out the high concentrations of nutrients in grey water. The main nutrients expected to be found in grey water are phosphorus and nitrogen. The other main pollutant that these plants will filter out will be the large particulates of food and other bacteria. It is also best for the grey water system to use wetland plants because they will adapt better in wet conditions along with the mild cloudy climate in the winter and spring months.

2.2.4 Screens

Screens are meant to trap larger organic waste and any other solids that are not desirable in the system. It is vital that this system uses screens that will not rust or corrode in the presence of water. Thus aluminum, stainless steel, silver, mesh and plastic are affordable and effective screens (Erlenbach and Lachapelle 1998). These screens act as a filter and are easy to clean out and re-insert into a system with appropriate connectors to the tanks. The screen size should be between ½" to ¼" to maximize filtration of organic solids (Winneberger 1984).

2.2.5 Measurements and definitions

2.2.5.1 Biological Oxygen Demand (BOD)

Biological oxygen demand is a measurement of how much oxygen bacteria will absorb when decomposing organic matter in water. BOD is measured over a period of 5 days to determine the maximum amount of oxygen the bacteria will absorb (Watershed Protection Plan Development Guidebook n.d.).

2.2.5.2 Grey water

Any water has been used in the home, except for the toilet is considered grey water. Grey water is primarily used for watering outdoor plants. Plants and bacteria in the soil consume and filter out the organic nutrients, which turn it into clean water. Grey water is not suitable to drink but it works very well for watering gardens (Brain, Lynch and Kopp 2015). The EPA estimates landscape irrigation to account for almost a third of all residential water use, totaling over 7 billion gallons per day (EPA 2014).

2.2.5.3 Black water

Black water is water flushed from the toilet. In some states kitchen sink and dishwasher water are also considered black water (Brain, Lynch and Kopp 2015).

2.2.5.4 Clearwater

Clearwater is solid- free wastewater. This includes water wasted while waiting for the shower to heat up, refrigerator compressor drip, as well as swamp cooler and air conditioning "sweat" (Brain, Lynch and Kopp 2015).

2.2.6 Examples

2.2.6.1 AEF Grey water

Drew and Annika rebuilt the grey water system at Arcata Educational Farm. The grey water for this system comes directly from the kitchen sink on site. They used a settling tank, with a grease trap and food screen to divert large solids and FOG. The grease trap and food screen are emptied as needed. Figure 2-1 illustrates the path the water takes through the system and the bulrush and cattail roots that are used at filters. Baffles are used to make the water move slower through the roots which cleans the water more efficiently. The clean water is then diverted to a near by apple tree for watering. As of October 2013 the grey water system no longer exists because the maintenance was too difficult for the owners of the farm to maintain. ("AEF greywater" 2015)

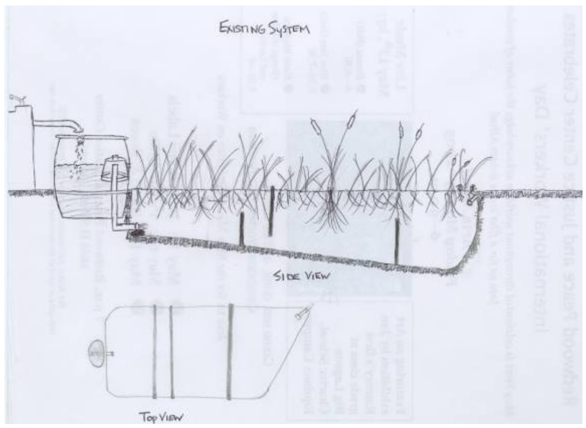

Figure 2-1: AEF Grey Water treatment system: ("AEF greywater" 2015)

2.2.6.2 Greywater Ecuador La lagrima purificadora

A greywater treatment system was built in Ecuador for filtration of kitchen sink water and environmental education. The team built a greywater marsh using Holy stones and clay based soil. Adobe was used to strengthen the structure of the stonewalls. Doubled over plastic is used for pond liner. The pond liner and gravel are shown in figure 2-3. Large stones and gravel fill the bottom of the pond to give the aquatic plants a base for growth. Cattails are planted on top of the gravel. The roots grow down into the water and filter the bacteria out of the water. A removable food screen is used to filter out large solids from the water. Figure 2-2 illustrates the brick box that is used as a grease trap. The brick box is split into two sections by a removable board that sits two inches above the bottom of the box. When water flows through the box the grease will stay trapped in the first chamber while the rest of the water flows through to the second. ("Grey water Ecuador La lagrima purificadora" 2012)

Figure 2-2: Grease trap brick box: (“Grey water Ecuador La lagrima purificadora” 2012)

Figure 2-3:Pond with liner and stone layer: (“Grey water Ecuador La lagrima purificadora” 2012)

2.2.6.3 CCAT Greywater Marsh

The creation of the grey water marsh at Campus Center for Appropriate Technology (CCAT) was a previous ENGR 305 project at Humboldt State University. A settling tank and grease trap are used to separate out food, fats and oils. A 55-gallon drum of food grade plastic was used as a settling tank. The blue barrel in figure 2-4 is a surge tank, which protects against backed up pipes. In figure 2-5 there is a gravel layer, under the gravel layer is where the filtration takes place. The grey water will never surface eliminating contamination to wildlife, humans and storm water. Bulrush and cattails were used as filters. Baffles covered in pond liner were used to slow the water flow through the roots. (CCAT greywater marsh 2011)

Figure 2-4: Surge tanks and marsh baffles (“CCAT greywater marsh” 2011)

Figure 2-5: Subsurface marsh with inlet: ("CCAT greywater marsh" 2011)

2.2.6.4 Samoa Hostel grey water island

The grey water for this system comes from the bathroom sinks, showers and laundry washing machines. Grey water pipes comes from the building parallel to the existing black water pipes. A three-way divider allows the grey water to be diverted back into the black water pipes to be treated as black water if needed. The water flows into a settling tank, which allows the suspended solids to be filtered out. Retention time of this settling tank is less than 24 hours, which is a California Code, see Figure 2-6. Filtering of F.O.G through the secondary treatment through the marsh and wetlands. The microorganisms in the roots of the plants filter out the F.O.G from the water. Retention time for secondary treatment is 3.5 days for the maximum load of 3,257 gallons per day. After secondary treatment the water flows into a leach field where it flows through sand that contributes to removal of Nitrogen, phosphorus and TSS (Samoa Hostel grey water island 2013).

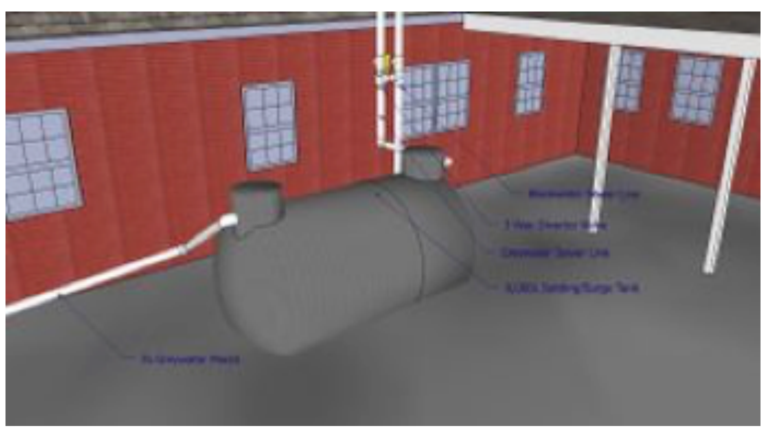

Figure 2-6: Settling tank and three-way flow diverter: ("Samoa Hostel grey water island" 2013)

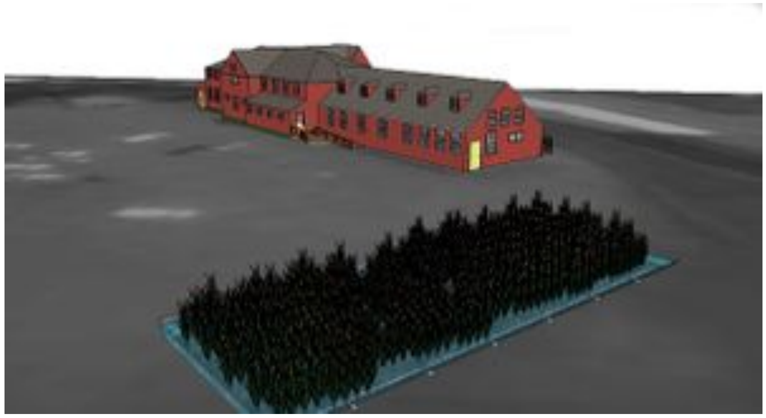

Figure 2-7: Secondary treatment horizontal constructed wetland: ("Samoa Hostel grey water island" 2013)

2.2.7 Regulations and City Codes

California recently changed the Grey water codes and regulations in 2009 allowing residents and commercial companies to reuse grey water as long as they have a permit. According to the California Plumbing Code there are three types of systems: a clothes washer which does not require a permit, a simple system which uses less than 250 gallons a day and a complex system which uses more than 250 gallons a day. The discharge of grey water cannot be used to irrigate root crops or food crops intended for human consumption that come in contact with soil unless filtered to certain specifications. The capacity of the grey water tank must be able to divert an over flow of grey water either to another tank for further filtration or piped back into the sewer. A diverted valve must be provided for this system to be legal. The location of the grey water system must be on the resident's property that is using the grey water. The legal locations of the grey water systems near water sources, wells, and sewers are shown in figure 2-8 (California Plumbing Code 2013).

LOCATION OF GRAY WATER SYSTEM

MINIMUM HORIZONTAL DISTANCE IN CLEAR REQUIRED FROM	SURGE TANK (feet)	SUBSURFACE AND SUBSOIL IRRIGATION FIELD AND MULCH *BASIN* (feet)	*DISPOSAL FIELD*
Building structures[1]	5[2, 3, 9]	2[3, 8]	*5*
Property line adjoining private property	5	5[8]	*5*
Water supply wells[4]	50	100	*100*
Streams and lakes[4]	50	*100*[5, 10]	*100*[5]
Sewage pits or cesspools	5	5	*5*
Sewage disposal field[10]	5	4[6]	*4*[6]
Septic tank	0	5	*5*
On-site domestic water service line	5	*0*	*0*
Pressurized public water main[7]	10	10	*10*[7]

For SI units: 1 foot = 304.8 mm

Figure 2-8: Location of Grey Water Systems: ("California Plumbing Code" 2013)

2.2.8 Irrigation

There are four basic methods of irrigation; surface, subsurface, drip and sprinkler. Surface irrigation is when water is simply poured or passed over the plants. Subsurface irrigation is when water is fed to the plant underground with buried irrigation systems. Drip irrigation is when water is distributed to plants with a pipe system that either dispenses water in small streams or droplets. Lastly sprinkler irrigation is when plants are watered using a sprinkler system (Nort 2010).

Of these four methods three can be used to water a garden with grey water, sprinklers being the exception. Sprinklers should never be used when irrigating with grey water because vaporizing the grey water with sprinklers puts any pathogens potentially in the water airborne and readily available to be inhaled (Ludwig 1989). In any case, mulch must be placed between the soil and the grey water so that the organic matter in the grey water does not clog the pores in the soil; the mulch acts as a filter. Additionally an air buffer zone must be introduced so that the roots of the plants do not grow into the water discharge points (Allen, Laura, Erskine 1999).

Surface irrigation could be used by pouring a bucket of grey water into pathways dug around and through the garden for the water to travel through more evenly. Alternatively, a drip irrigation system could be implemented in place of the pathways. Although a subsurface system could work, it is not optimal because if a watering system is place underground it would not have any mulch filter to stop the grey water from clogging the pores of the soil (Allen, Laura, Erskine 1999). Another level of difficulty would also be added in terms of maintenance should this method be installed. (Ludwig 1989)

2.2.9 Protecting Pipes from Root Invasion

To protect the pipes from clogging by roots growing into them, a recycled plastic flowerpot can be placed over any water outlet in the pipe to create an air space between the pipe opening and the soil (Allen, Laura, Erskine 1999). To fit the pot over the pipe, holes will be cut into the plastic pot so that the pot will sit over the part of the pipe with a water outlet(s). The pot may be covered and buried with mulch on the out side, however an air barrier will be left between the pipe opening and the mulch, as the pot will be covering the opening in the pipe where water flows out. This air pocket separating the ground and the pipe will prevent roots from growing into the pipe, because roots will grow where water is making contact with the ground. If the roots are being supplied water through the space where the water lands instead of directly from the pipe, roots will not grow into the pipe. Mulch should be placed at any point where the grey water will be making contact with the soil to act as an extra filter for the grey water (Allen, Laura, Erskine 1999).

2.2.10 Cutting Holes in Cast Iron

When using a drill to cut metal or ceramic safety goggles should always be worn for eye protection. To cut a hole in the cast iron first a hole must be cut in the ceramic. If a clean hole is desired the hole should be drilled very slowly with an appropriately sized diamond core drill bit, adding cutting lubricant to prevent the ceramic from chipping due to high temperature. To prevent slipping while drilling in the ceramic, masking tape can be placed over the drill site. If the hole does not need to be cut cleanly, a hammer and nail can be used to chisel a hole in the ceramic of the cast iron. Once the ceramic has been cut on both sides of the cast iron, a metal hole saw can be used to drill through the steel again adding cutting lubricant to prevent the chipping if the ceramic (Hazell 2016).

2.2.11 Soap and Detergent Information

Hand soap and dish soap ingredients must be looked into carefully when using a grey water system for an edible garden (Department of Environmental and Resources Management 2010). Many of the soaps we use today contain harmful ingredients that can damage the soil. It is best to use soaps that are "biocompatible" or "biodegradable" meaning these products will be safe to use on living tissue and will decompose without leaving excess nutrients (Pinderhughes 1969). Thus, using soaps with "boron, sodium [anything with sodium], chlorine bleach, peroxygen, petroleum distillate, alkylbensene, water softeners, anti-bacterial soaps, enzymes and much more. These ingredients actually can make the water either more acidic or basic, which will not help plants grow (Allen and Erskine 1999). Water has a natural pH of 7 and if the water is above or below 7 then some plants may die. However, cleaners with nitrogen, phosphorus, potassium, sulfur and other nutrients that can help the plants grow are great cleaners for grey water system (Department of Environmental and Resources Management 2010).

2.2.12 Health Risks

There are no cases of illnesses transmitted by using a grey water system on edible food in the US (Ludwig 1989). However, there are many precautions when using grey water. For instance, putting the grey water directly on parts of the plant that will be eaten raw is hazardous. There are many reason for this, grey water will turn into black water after 24 hours, the water may contain microorganisms, bacteria, etc., that are not safe to ingest and grey water should always be sprayed on the roots and never the leaves and stems (Department of Environmental and Resources Management 2010). Other health risks are concerning "free grey water" or grey water that somehow has gotten out of the piping system or the storage containers. Free grey water is a risk because if humans ingest grey water they have a higher chance of becoming ill. It is very crucial that grey water stays in designated areas because if grey water does get into a stream or water source it can contaminate it and potentially feed the bacteria too much nutrients and form toxic-bluegreen algae (Allen and Erskine 1999).

3 Search for Alternative Solutions

3.1 Introduction

Section 3 discusses the alternative solutions for grey water filtration at the sanctuary. Also included in this section is a description of our brainstorming sessions that led to the 7 solutions. All solutions meet the criteria specified in section 2.1.

3.2 Brainstorming

Team Four Squared conducted two brainstorming sessions to generate ideas for grey water filtration. Our first session led to the creation of 5 solutions. The last brainstorming session allowed us to create 2 more solutions and fine-tune the ones we already had. Both brainstorming sessions were done on white boards. Appendix A contains documentation of the brainstorming sessions.

3.3 Alternative Solutions

3.3.1 The Scenic System

The Scenic System is similar to The Worm Tub however there are a few variations to make the system looks more aesthetically pleasing. The first change is the fog tub is moved next to the wine barrel to make the transfer of water easier. Second, the other tubs are replace with, simply burying the marsh plants into the ground and laying a water proof liner under the plants to prevent the plants from growing to large. This system will have a more natural look because all filtration will be done under ground. After running through the gravel and marsh plant roots the water will then leach into a water reservoir where the water can either be poured manually onto the garden an optional dripper system maybe implemented.

Optional Dripper System: I dripper system may be implemented to make it easier for the plants to be watered. Timers can be added to drippers so they will water automatically. Alternatively an on/off valve can be added to manually water the plants via drippers.

Hose Option: Alternatively a hose option may be applied to this solution to manually water plants.

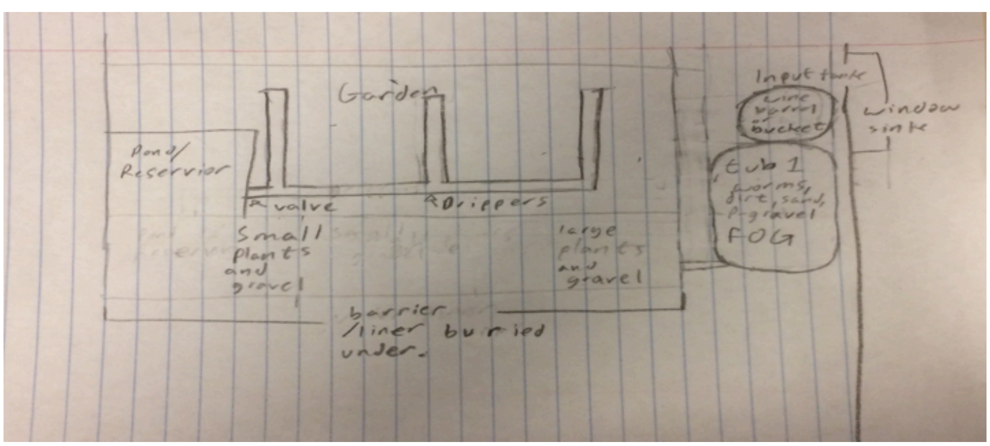

Figure 3-1: Representation of the Scenic System Solution, drawn by Chris Bautista on October 12, 2016

3.3.2 The Easy as 1,2,3 solution

The Easy as 1,2,3 solution meets all of our specifications and criteria. The water is filtered by plants as it flows through the bathtubs. The water will be carried from the inside of the house to the outside in the garden. The water will initially flow into a temporary storage tank that will be a plastic cube. The water then flows through a 2" plastic pipe that will go to a FOG tank. Here the water will sit for 12-24 hours to allow solids to settle and lighter oils to float to the top that can later be scraped off. The water will be release by a valve connected to the bottom of the FOG tank that will lead the water to the primary filtration process. The primary filtration is a repurposed bath tub that is filled with wetland plants such as water iris. The water is drained from the bottom of the first tub to the second tub through a 6ft long 2" diameter pipe that will be buried beneath the surface. The water is forced upwards through a layer of rock and soil to be placed in the tank. The secondary treatment tub is filled with aqua phonic plants that have more fibrous root systems, which filters more nutrients out of the water. On the side of this tub will be an evacuation pipe to compensate for heavy use days, and rainfall in the wintertime. To utilize the rest of the space that we are given we will also include a bench, bird feeders, solar lighting, and various trees and plants. The primary use of this water will be used to irrigate fruit trees and flowers that will surround this system. These plants will also serve a dual purpose to counteract any unwanted smells that may be produced by the gray water system.

Optional Garden: The Easy as 1,2,3 solution feeds a garden in the center. Due to time constraints our team feels that outside help, time and resources must be used by the client to complete the garden. Our team is happy to present a few garden designs and optimal plant choices for the area and grey water system. To utilize the rest of the space our team would like to suggest adding a bench, and other aspects to make the area pleasant for socializing.

Hose Option: Alternatively a hose option may be applied to this solution to manually water plants.

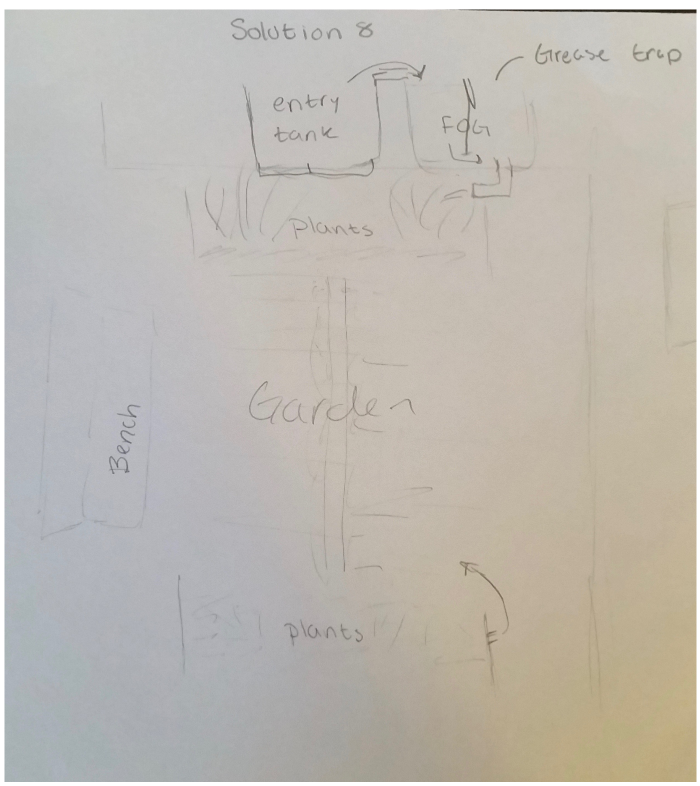

Figure 3-2: Respresentation of Easy as 1,2,3 solution, drawn by Jennifer Turk on October 10, 2016.

3.3.3 The Split Tub

The Split Tub solution aims to save space by sectioning one of the tubs into two parts. First, water from the sink is poured or led to an input tank. The large waste is settled out with two or three screens inside the tank. Once the water has passed through the screens, it will flow through a 4" pipe to the first tub. The first tub is sectioned into two parts with two separate drains. One side serves to separate the F.O.G from the water and contains a layer of mulch on top and underneath a layer of sand and dirt with worms. The worms will consume any smaller solids the mulch and screens did not filter out. Under the worm layer there is gravel. The water will drain out the bottom of the tub to be collected and poured to the other side of the tub. This second side serves to filter the water further with wetland plants and gravel. Once the water passes through the second side, it is led to a second tub filled with gravel, sand, dirt, and wetland plants to further filter the water. The water is then drained to a reservoir.

Optional Dripper System: A dripper system may be implemented to make it easier for the plants to be watered. Timers can be added to drippers so they will water automatically. Alternatively an on/off valve can be added to manually water the plants.

Hose Option: Alternatively a hose option may be applied to this solution to manually water plants.

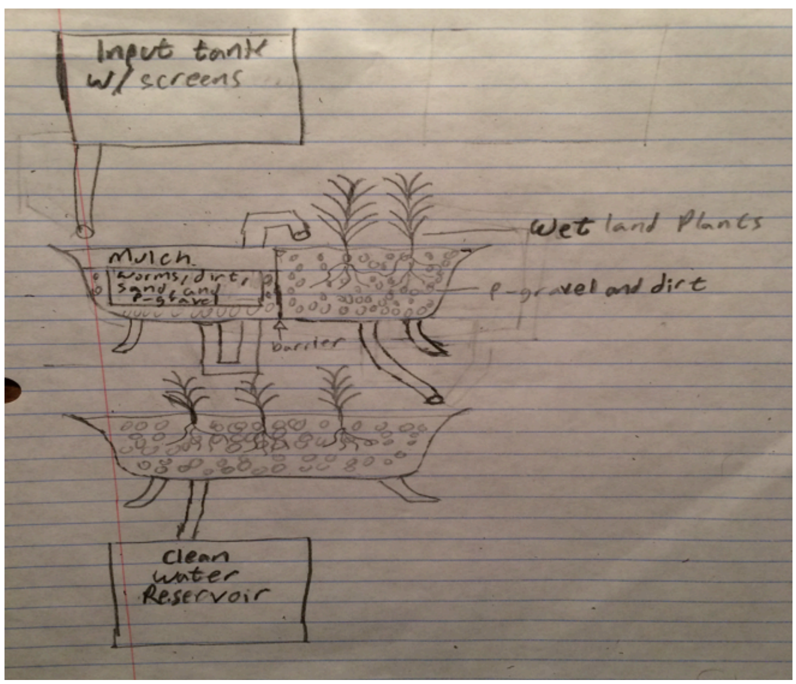

Figure 3-3:Representation of the Split Tub Solution, Drawn by Chris Bautista on October 10, 2016

3.3.4 The Tub Basket

The tub basket contains more wetland plants in order to clean the nutrients from the water as well as providing more foliage to the system. Grey water from the sink will be manually poured into the input tank which can be seen in Figure 3-4. The input tank takes the F.O.G. out of the grey water and contains a bigger screen to help get rid of big solids. The grey water travels through a 4-inch pipe to the top of the wine barrel. In the wine barrel there are two screens that sift through solids and F.O.G. These screens lead to a 4-inch pipe that travels to the first tub. In the first tub there are multiple sizes of gravel in order to maximize filtration. There will be two baffles to help slow the flow of water in order to more effectively filter out the nutrients. In this tub there are bigger wetland plants that thrive on organic nutrients. Once the water has traveled through this tub it will flow through a 4-inch pipe to the second tub. The second tub has an inlet on the side where there will be another baffle along the center of the tub to maximize filtration. In this tub the gravel size will be very similar in diameter again to clean microorganisms. The wetland plants in this tub will be medium sized with thick root systems to soak up nutrients. Once the water has made a full cycle through this tub is will exit through the bottom and travel through another 4-inch pipe across the ground into the bottom of the third tub. This tub is filled with small gravel to help filter any remaining microorganisms or bacteria. There will be smaller wetland plants on top of the gravel in order to continue filtration but will allow for enough space in the tub to have free flowing water for the garden.

Optional Garden: The Tub Basket solution feeds a garden in the center. Due to time constraints our team feels that outside help, time and resources must be used by the client to complete the garden. Our team is happy to present a few garden designs and optimal plant choices for the area and grey water system.

Hose Option: Alternatively a hose option may be applied to this solution to manually water plants.

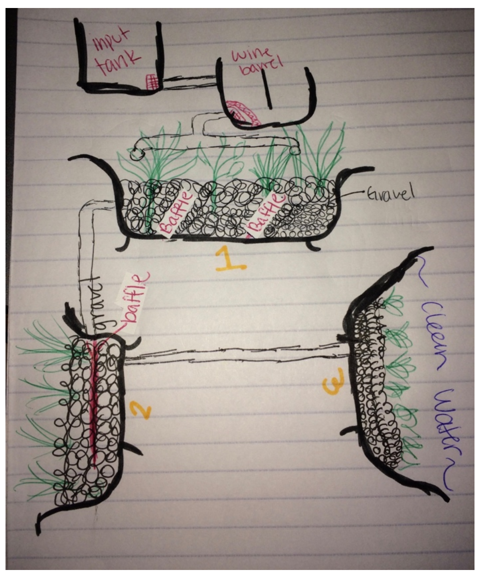

Figure 3-4: Representation of the Tub Basket solution, drawn by Juliette Cortez on October 10, 2016.

3.3.5 The Worm Tub

The worm tub grey water system uses biological processes to clean the grey water. The unfiltered grey water is poured into a 30-gallon wine barrel, outlined in black in figure 3-5. The wine barrel aids in filtering out FOG because of the anti-microbial properties in the wood. There are two screens in the wine barrel to help sift out solids. The screens lead to a 3” pipe where the grey water is transferred to the first tub. In the first tub, the worm tub, there is a mesh along the tub in order to keep maintenance simple. Then there are two multi-layers of p-gravel, dirt, worms and hay. The p-gravel helps microorganisms clean the water by being a “natural filter”. The worms eat up residual solids and FOG that was not removed in the previous filtrations. The water is drained and travels through a 3” pipe into the second tub. In the second tub, the water is filtered by gravel and wetland plants. There is a single baffle to slow the flow of water though the tub, allowing for more filtration. The gravel cleans the water of microorganism and bacteria while the wetland plants absorb the nutrients (phosphorus, nitrogen, potassium, carbon, etc.). The water flows out the top of the tub through a 2” pipe and into a third tub which is strictly for holding. No filtration occurs in the third tub.

Hose Option: Alternatively a hose option may be applied to this solution to manually water plants.

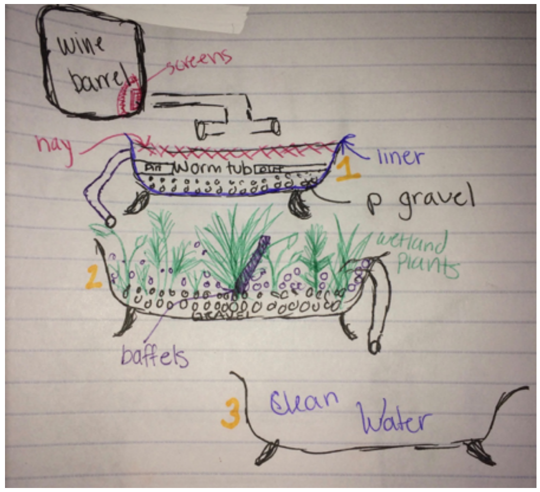

Figure 3-5: Representation of the Worm Tub solution, drawn by Juliette Cortez on October 10, 2016

3.3.6 Terrace Garden Solution

The Tetris Garden Solution begins with a wine barrel as the input tank, as shown in step 1 of Figure 3-6. Used wine barrels are made out of redwood and coated in crystals from the alcohol that seeps into the wood, meaning it does not rot easily. The wine barrel will however need to be replaced when it starts to rot, in approximately 5 years. A layer of gravel will be spread around the wine barrel to soak up any leaks or spills. A cover will be put over the wine barrel to prevent contamination from rain during the winter months. Wine barrels are also quite decorative and will look nice next to chairs on the terrace. Alternatively it could also be used as a table if a proper cover is put over it. All grey water will be manually poured into this brief holding tank as to not disturb the rest of the system. The wine barrel will be placed on the terrace above the garden to take advantage of gravity. From the wine barrel the water flows into the worm tub, step 2 in Figure 3-6. Step 2 is filled with dirt and worms to clean the F.O.G. out of the water. A layer of hay is placed on top of the dirt to keep the worms from drying out and to contain any smells the worms may create. No holes need to be dug for this bathtub. A pipe will transfer the water from step 2 to step 3. Step 3 is a bathtub filled with gravel and aquatic plants. The plants will filter out any bacteria and left over contaminants from step 2. After this step the water is cleaned enough to water plants. The water from step 3 flows through a pipe into step 4. Step 4 is the third and final bathtub. This tub contains mostly gravel and small plants. The small plants will filter the water even more. This tub is a holding tank. Once the water in the tub has reached a certain height it will flow out a large overflow pipe into the center where the optional garden will be as shown in Figure 3-6. All pipes will be at least 2 inches in diameter to prevent clogs. All bathtubs will have overflow pipes that flow into the garden incase of overflow due to rain, however we want the main water source for the optional garden to be step 4.

Optional Garden: The Terrace Garden solution feeds a garden in the center. Due to time constraints our team feels that outside help, time and resources must be used by the client to complete the garden. Our team is happy to present a few garden designs and optimal plant choices for the area and grey water system.

Hose Option: Alternatively a hose option may be applied to this solution to manually water plants.

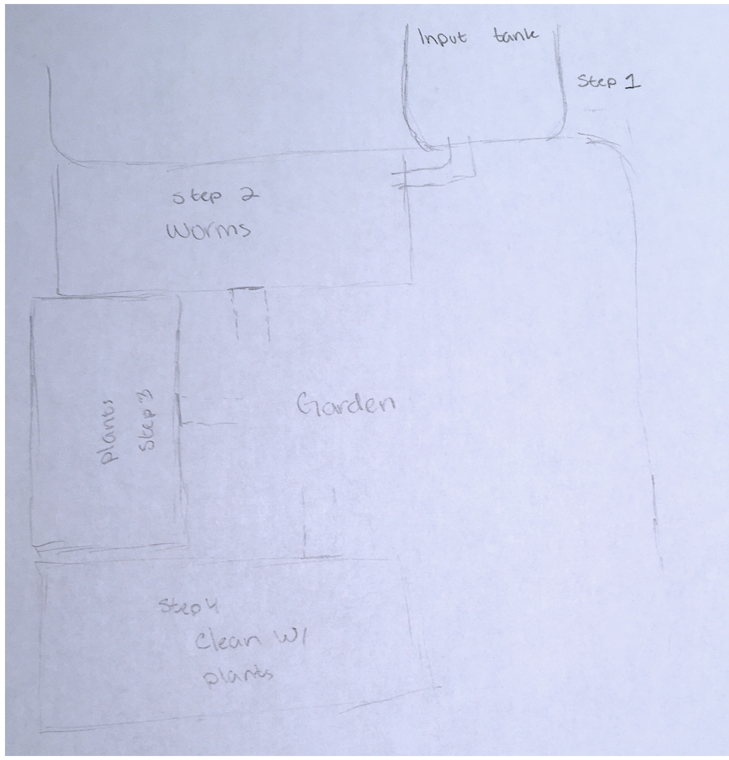

Figure 3-6: Representation of Tetris Garden solution, drawn by Jennifer Turk on October 10, 2016.

3.3.7 Pond in the Middle Solution

The Pond in the Middle solution begins with a wine barrel, step one in figure 3-7. The wine barrel is used as a deposit site. Used wine barrels are made out of redwood and coated in crystals from the alcohol that seeps into the wood, meaning it does not rot easily. The wine barrel will however need to be replaced when it starts to rot, in approximately 5 years. All grey water is manually poured into this brief holding tank as to not disturb the rest of the system. The wine barrel is placed on the terrace above the garden to take advantage of gravity. A layer of gravel is spread around the wine barrel to soak up any leaks or spills from the wine barrel. A cover is put over the wine barrel to prevent contamination from rain during the winter months. Wine barrels are also quite decorative and will look nice next to chairs on the terrace. Alternatively it could also be used as a table near the chairs if a proper cover is put over it. Step two is a reused bathtub. General ceramic bathtubs are 35-60 gallons. The bathtub is lined with a screen to prevent the dirt from moving between steps. Then it is layered first with dirt and earthworms then hay on top to protect the worms from the sun and to keep the dirt moist. The worms eat the F.O.G. and large food particles allowing the water to flow into step three will less contamination. Step three is also a reused bathtub. The bottom of the tub is filled with gravel for the roots of the plants to grow into. On top are water irises and bulrushes. The roots of both plants use the bacteria and contaminants from the water as food, which in turn cleans the water. The water then flows into step four. Step four is a decretive pond, which can be filled with plants and fish. A 30 square foot hole will be dug and lined with pond liner. Rocks will hold down the pond liner. All pipes will be reused and at least 2 inches in diameter to prevent clogs. All pipes will have a screen on one end to keep debris from flowing into the next step.

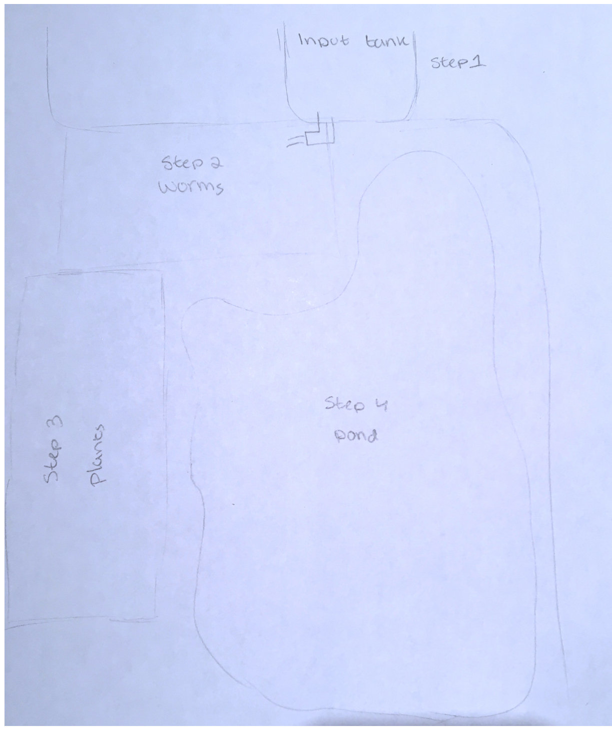

Figure 3-7: Representation of Pond in the Middle, drawn by Jennifer Turk on October 10, 2016.

3.3.8 Relax and Chill solution

The Relax and Chill solution meets all of the criteria listed while adding inviting aesthetics to serve two purposes, a gray water filtration system and a relaxing place to enjoy nature in the sun. The first aspect of this solution begins with the primary filtration of the Gray water. This is done by pouring the untreated water into the top of a 30 gal half wine barrel. The wine barrel is filled with small river rocks, hay, dirt, and sand. This filters out large solids and some of the FOG in the gray water. The water will then be expelled out of the bottom of the wine barrel through a 2" pipe with screens to prevent as much clogging as possible. The next part of the system is a repurposed bath tub filled with wetland plants. The secondary treatment of the water further removes solids and some of the high concentrations of bacteria in the water. The water is moved to the next part of the system through a 2" pipe with screens to prevent clogging. The water is led to another repurposed bath tub with smaller wetland plants with a much tighter and more complex root system that will utilize the rest of the nutrients and solids in the water. The water moves to the next part of the system through a 2" pipe with screens to prevent clogging. The next part of the system is a third repurposed bath tub that is filled with water. The final part of the system will be a small pond where the water may be collected and then dispersed throughout the garden. To meet the safety aspect of our criteria screens or wooden tops are placed on the edged to ensure that children or others don't come into direct contact with the water, as it may be hazardous. There is an overall low embedded energy because most of the systems parts are repurposed. The only new materials that we may have to purchase would be 2" pipes, screens, fish, and pond liner. The rest of the materials can be found at the Arcata Marsh, wineries, scrapyards, and the local community. The system is easy to use because as long as the system is functioning properly the user will only have to pour the water in the wine barrel at the beginning of the system and then transport the water where it is ended that will be found at the end of the system in the pond. Maintenance includes, clogging of the pipes, cracks in the pipes from roots, screen destruction, cleaning the primary treatment barrel, and the grey water turning into black water. To ensure that the user will know how to repair or fix a problem a manual is include describing in detail all of the maintenance operations. The final criterion that is meet is the cost because we only bought new materials if absolutely necessary.

Optional Aesthetics: For the Relax and Chill solution aesthetics are very important, as we want this space to be both functional and inviting. Unfortunately due to time constraints these aspects will need to be implemented by the client. We want to incorporate seating, and bird feeders as well along with new plants and fruit bearing trees so that this space will be one that people of the sanctuary will want to be at.

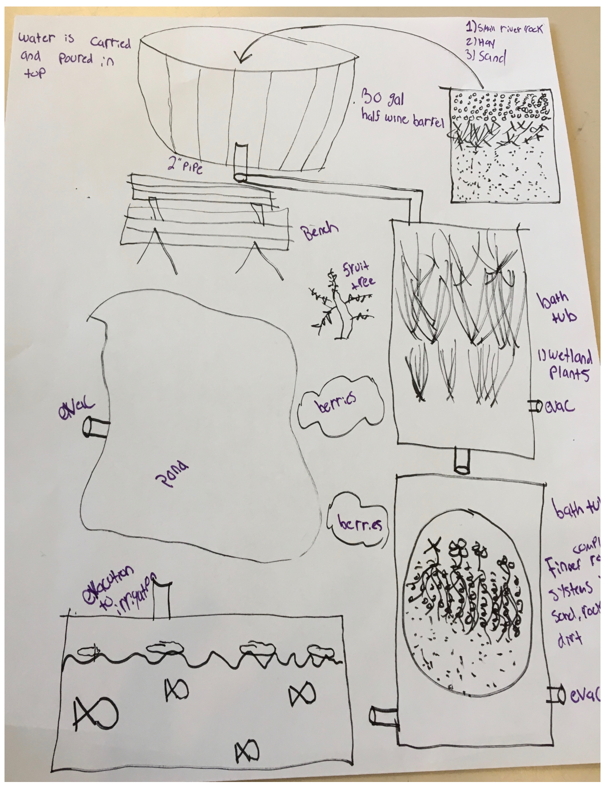

Figure 3-8: Representation of the relax and chill solution, drawn by Baylee Carson on October 12, 2016

4 Decision Phase

4.1 Introduction

Section 4 explains how team Four Squared evaluated each alternative solution, which can be found in section 3, and came to a final design decision. The Team used a Delphi matrix with weighted criteria to rate each solution. The Delphi matrix helped to finalize our decision with the client.

4.2 Criteria Definition

The criteria are defined below and are also used in the design process from section 2.

Safety: It must be safe for all, including children. Safety signs will be included around the area. All above ground pipes will be labeled. Greywater will not be

Maintenance: The system must be able to be cleaned out by two adult people. An instruction manual will be included for maintenance.

Ease of Use: The system must be easy enough for one adult person to use and understand from the instruction manual.

Cost: Cost is defined as the total cost for all the materials needed for the greywater filtration system. A total of $400.00 can be spent for the entire greywater filtration system.

Aesthetics: The system must look equally or more aesthetic than Sean Armstrong's in Arcata, CA. Appendix B has documentation of his system.

Reusing of Materials: The Sanctuary would like at least 90% of the materials to be recycled, reused or up-cycled.

4.3 Decision Process

The decision process was completed through brainstorming, criteria defined by the client, and weighting of the same criteria. The final greywater filtration system design was determined by the client with advice from our team.

4.3.1 Delphi Matrix

The Delphi matrix was created by Team Four Squared to illustrate the significance of each alternative solution related to the criteria. The criteria from section 2.1 were weighted from zero to ten, ten being the highest. Each alternative solution was weighted from zero to fifty, fifty being the highest, for each criterion. A high score means the alternative solution met the criteria the best. The highest scoring solutions are highlighted in green. The lowest scoring solutions are highlighted in red.

Delphi Matrix for Alternate Solutions									
		Alternate solutions (0-50 high)							
Criterion	Weight (0-10 high)	Split Tub	The Worm Tub	The Tub Basket	Relax and Chill	Easy as 1,2,3	The Terrace Garden	Pond in the Middle	Scenic Solution
Safety	5	35 / 175	35 / 175	35 / 175	35 / 175	35 / 175	35 / 175	35 / 175	35 / 175
Reuse of Materials	9	45 / 405	45 / 405	45 / 405	30 / 270	45 / 405	45 / 405	30 / 270	20 / 180
Ease of Use	6	40 / 240	40 / 240	40 / 240	40 / 240	40 / 240	40 / 240	40 / 240	40 / 240
Maintenance	7	40 / 280	50 / 350	20 / 140	25 / 175	20 / 140	40 / 280	40 / 280	30 / 210
Aestheics	10	15 / 150	20 / 200	35 / 350	25 / 250	40 / 400	45 / 450	30 / 300	50 / 500
Cost	8	50 / 400	45 / 360	35 / 280	15 / 120	30 / 240	25 / 200	20 / 160	40 / 320
Totals		1650	1730	1590	1230	1600	1750	1425	1625

Figure 4-1: Delphi Matrix, created by Team Four Squared on October 14, 2016

4.4 Final Decision Justification

The final decision came down to a combination of the worm tub solution, which can be found in section 3.3, and easy as 1,2,3 solution, which can be found in section 3.3, with a few minor variations. The worm tub solution scored second in the Delphi Matrix from figure 4.3-1. Easy as 1,2,3 solution scored fifth in our Delphi matrix from figure 4-2. After talking with the client we decided to create a new combined solution as follows. Our new solution will be the worm tub solution but landscaped as easy as 1,2,3 solution. Below is a drawn representation of the greywater filtration system that will be built at the Sanctuary.

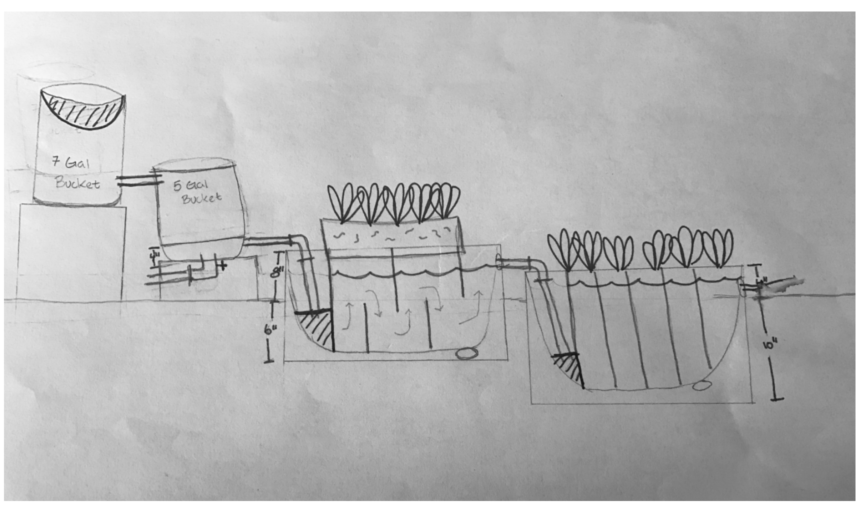

Figure 4-2: Representation of the final design, drawn by team member Jennifer Turk on 10/25/16

5 Specification of Solution

5.1 Introduction

Section 5 includes a detailed description of the grey water filtration system. The cost entails materials costs, hours spent, and maintenance costs. Each main section of the solution descriptions has an AutoCAD representation.

5.2 Solution Description

5.2.1 Input Tank and Grease Trap

The entry point will be a 5 gallon plastic bucket. In the top of this bucket is a plastic screen filled with barely that captures grease as the water flows through it. The water then flows through a 2” pipe into the 7 gallon bucket. The two buckets act like a baffle. The grease will stay trapped in the first bucket while the clean water will flow into the second bucket. The second bucket fills up and then drains into the first tub through a 2” pipe out the top of the bucket.

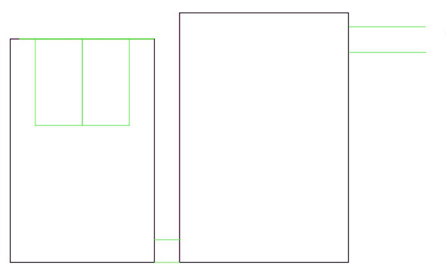

Figure 5-1: Side View of Input Tank and Grease Trap, created by team member Jennifer Turk on 11/24/16

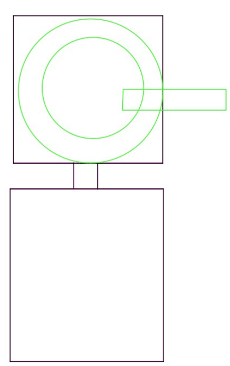

Figure 5-2: Top View of Input Tank and Grease Trap, created by team member Jennifer Turk on 11/24/16

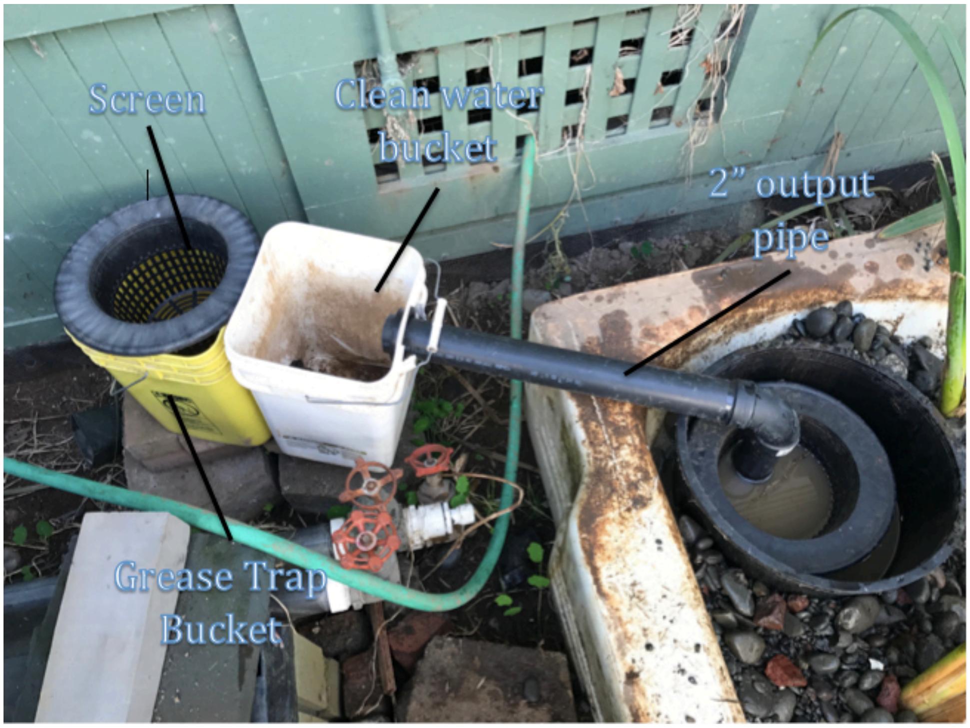

Figure 5-3: Input tank and grease trap, angle view, taken by Jennifer Turk on 12/2/16

5.2.2 Tub 1: Plant Filtration

Tub 1 is filled with approximately 2” gravel. Baffles, shown in orange in the figure below, are placed throughout the gravel to slow and divert the flow of water to better filter it. Bulrush and Water Irises are the main plant filters. Small local plants grow in the tub as well. These plants generally have flowers and look more aesthetically pleasing than the filtration plants. All plants will grow into the gravel creating a network of root systems to filter the water. The plant roots will clean out the bacteria and microorganisms from the water. The water flows out of tub 1 through a screen covered 2” pipe and into tub 2.

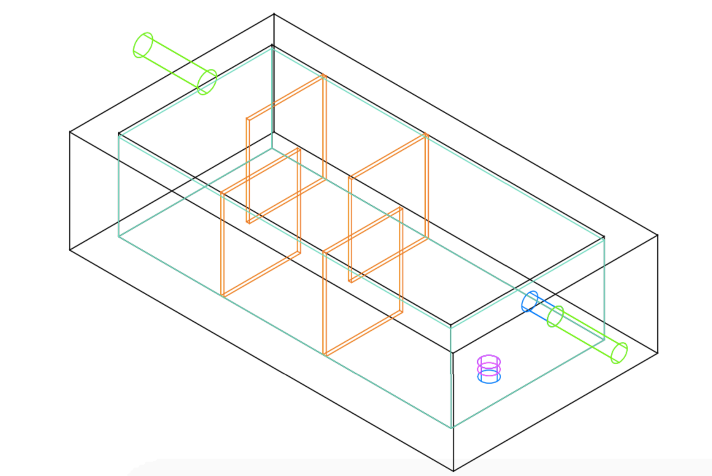

Figure 5-4: Corner View of Tub 1 , created by team member Chris Bautista on 11/6/16

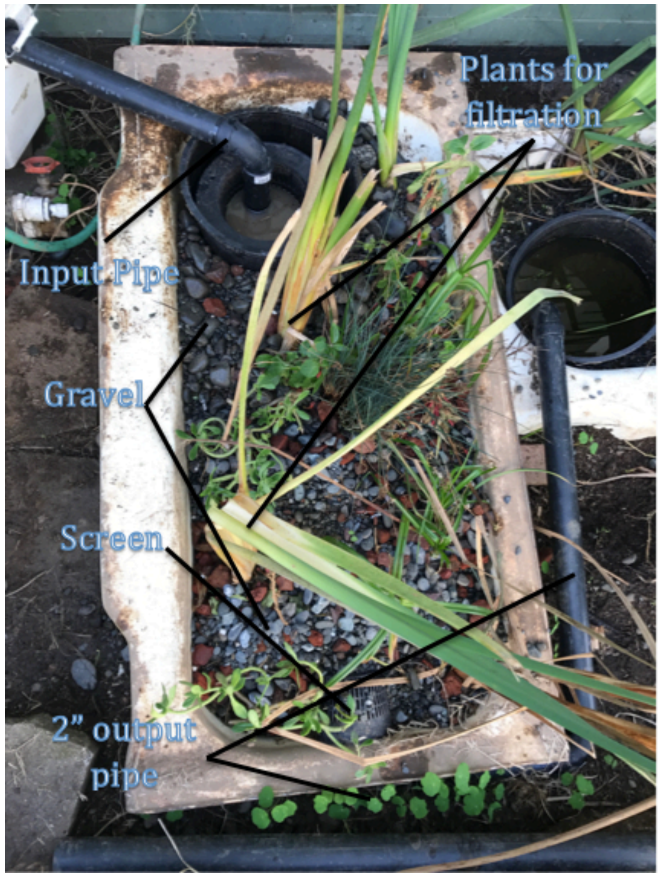

Figure 5-5: Tub 1, top view, taken on 12/2/16 by Jennifer Turk

5.2.3 Tub 2: Plant Filtration

Tub 2 is filled with approximately .5" gravel. The smaller gravel filters out smaller bacteria. Tub 2 is filled with mostly Water Irises, and smaller local plants. The plant roots will capture and utilize the excess nitrogen, phosphorous, carbon, etc. The gravel serves as a natural microorganism catchment system. The water flow in this tub is controlled by a series of baffles that extends the time the water is being filtered, while allowing the water to pass through the entire tub for complete filtration. The baffles can be seen in the figure bellow. The water flows through a screen and out of a 2" pipe and into a hose.

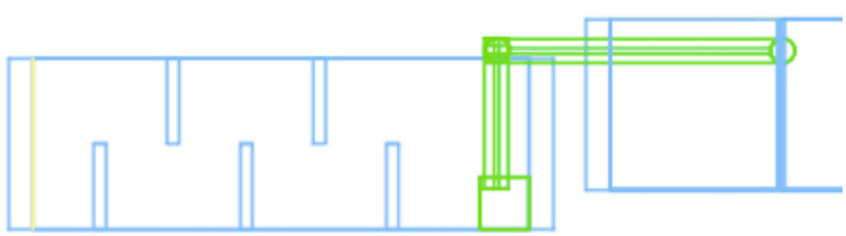

Figure 5-6: Side View of Tub Two, Created by team member Jennifer Turk on 11/6/16

Figure 5-7: Tub 2, Top View, taken on 12/2/16 by Jennifer Turk

5.2.4 Clean Water Use

After the water has gone through the complete filtration process the water can either be dispersed throughout the garden by a hose connected to tub 2 or be stored for use later on. Below is an overview of the final system.

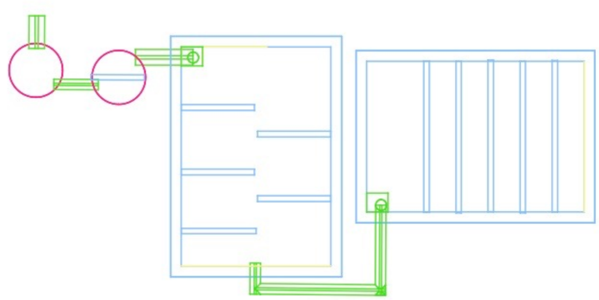

Figure 5-8: Overview representation of the greywater filtration system, created by team member Jennifer Turk on 11/6/16

5.3 Cost Analysis

5.3.1 Design

The design cost is the amount of time in hours Team Four Squared put into designing and building the Grey Water Filtration System for the Sanctuary. A total of 266.36 hours have been spent on the project. The majority of design hours have been spent working on the design process document. Figure 5-5 represents the divided hours spent by Team Four Squared for each individual section of the total project.

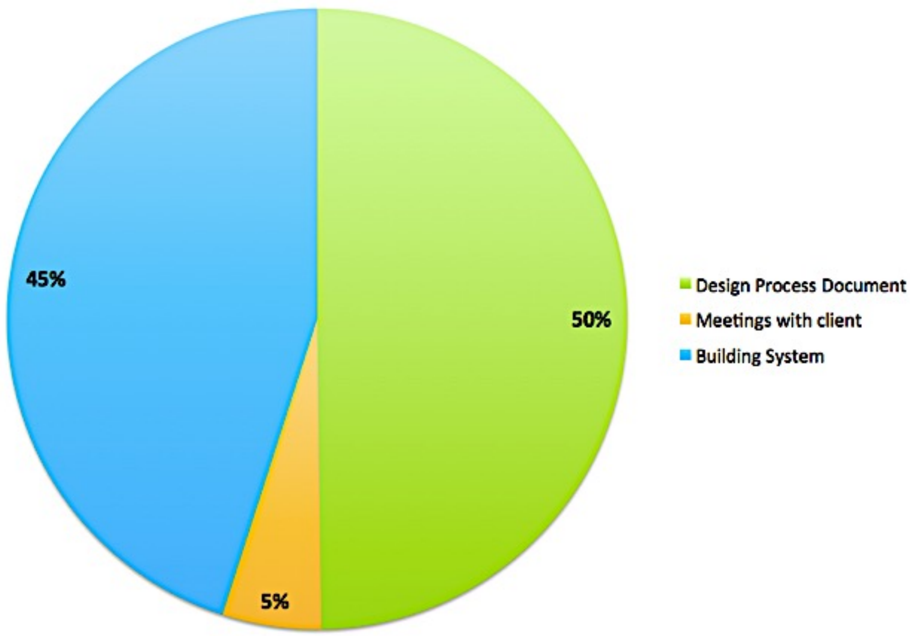

Figure 5-9: Pie chart illustrating distribution of hours team four squared spent on the project.

5.3.2 Construction Costs

Table 5-1 shows the costs in dollars of all materials used to build the grey water filtration system. The total amount spent on materials was $102.39.

Table 5-1: Cost of all materials used to build the Grey Water Filtration System

Cost of Materials			
Material	Quantity	Cost for one (dollars)	Total Cost (dollars)
Bathtubs	2.0	25.00	50.00
2.5" Plug	1.0	5.43	5.43
2" Plug	1.0	10.99	10.99
2" hole to elbow adaption	1.0	8.99	8.99
2" hole to hose adaption	1.0	13.99	13.99
Pipes	6 feet	Already Owned	0.00
Plants	20.0	Donated	0.00
Baffles	5.0	Already Owned	0.00
Elbows	2.0	6.99	13.98
Pea Gravel	10 Full Buckets	0.50	5.00
Gravel	10 Full Buckets	0.50	5.00
Buckets	2.0	Already Owned	0.00
Screens	2.0	Already Owned	0.00
Total Cost			**113.38**

5.3.3 Maintenance

Team Four Squared built the grey water filtration system with low maintenance. Every 5 years the gravel should be taken out and cleaned with a hose. Plants may need to be replaced as some plants may survive in the system better than others. 10 healthy plants per tub are best for filtration.

Table 5-2: Maintenance Costs for the Grey Water Filtration System

Maintenance Time and Cost		
Task	Frequency	Cost (if any)
Checking for plumbing leaks and clogs	Every Week	None
Maintaining plants and replacing if needed	As needed	Donated
Cleaning Gravel	5 years	None
Cleaning Grease Trap	Monthly	None

5.4 Implementation Instructions

The system is a minimum maintenance system. The system runs automatically. The owner needs to periodically check for leaks and clogs in the system. Easy access screens and baffles have been implemented to allow for easy cleaning of pipes. The grease trap will need to be cleaned out every few months for optimal filtration. Every two years the system needs to be emptied and cleaned. The gravel from both tubs with need to be replaced and the plants will need to be maintained.

5.4.1 Performance of the System

Team Four Squared tested the systems retention time. If there is constant water flowing into the system, the water will exit the system in less than 24 hours. Team Four Squared cannot test the filtering ability of the system yet because it has yet to be attached to the kitchen sink.

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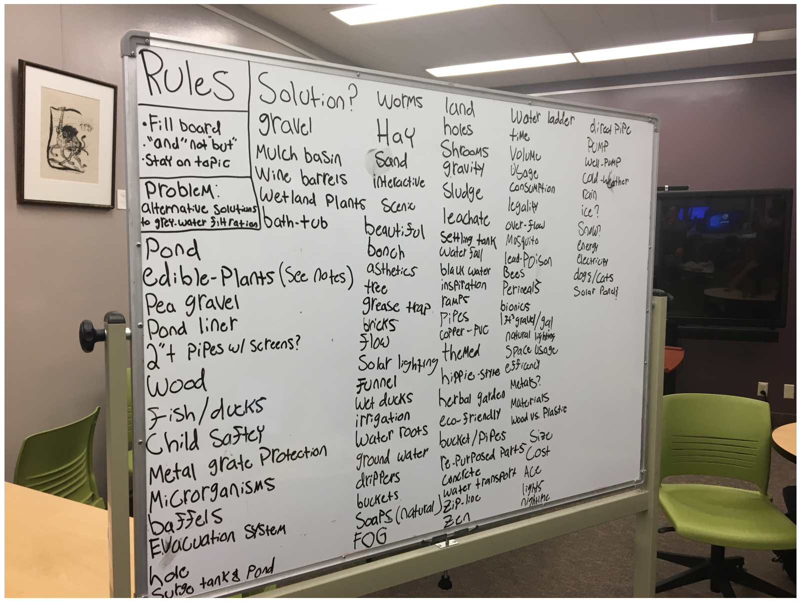
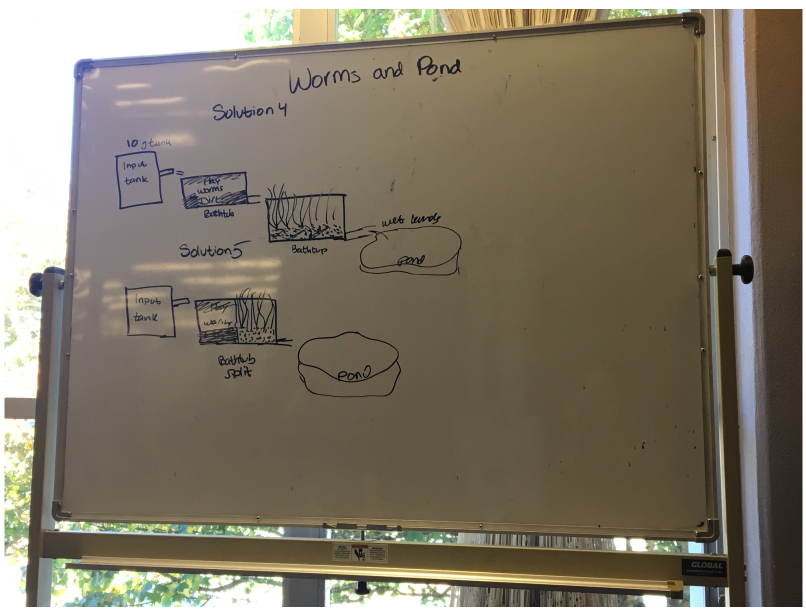
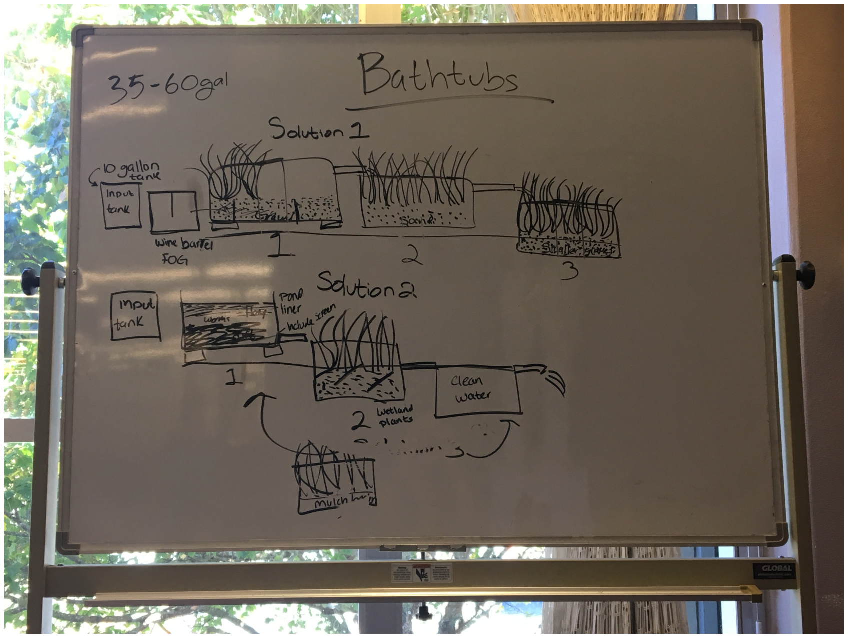
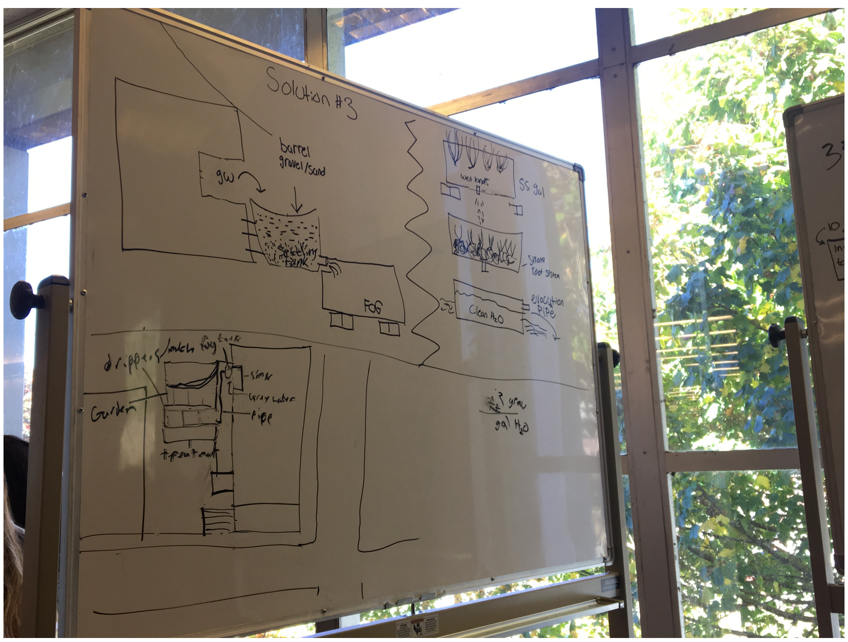
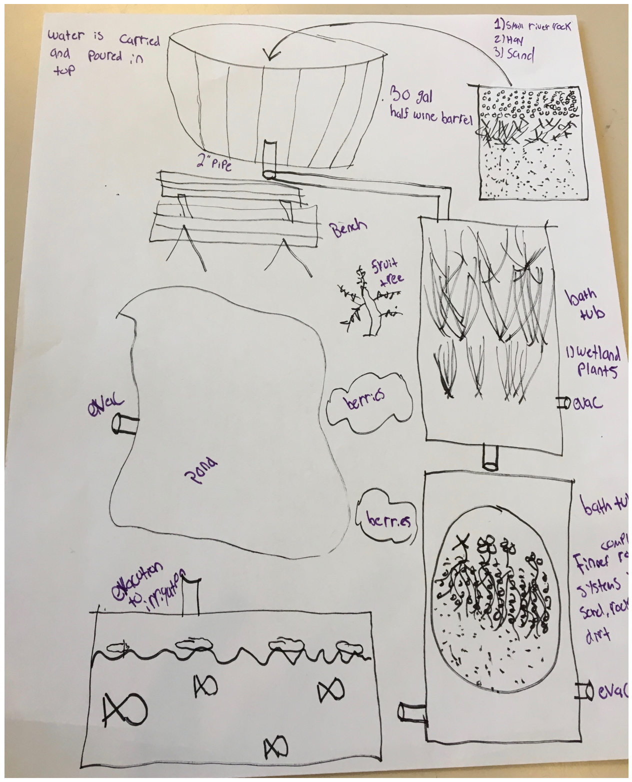
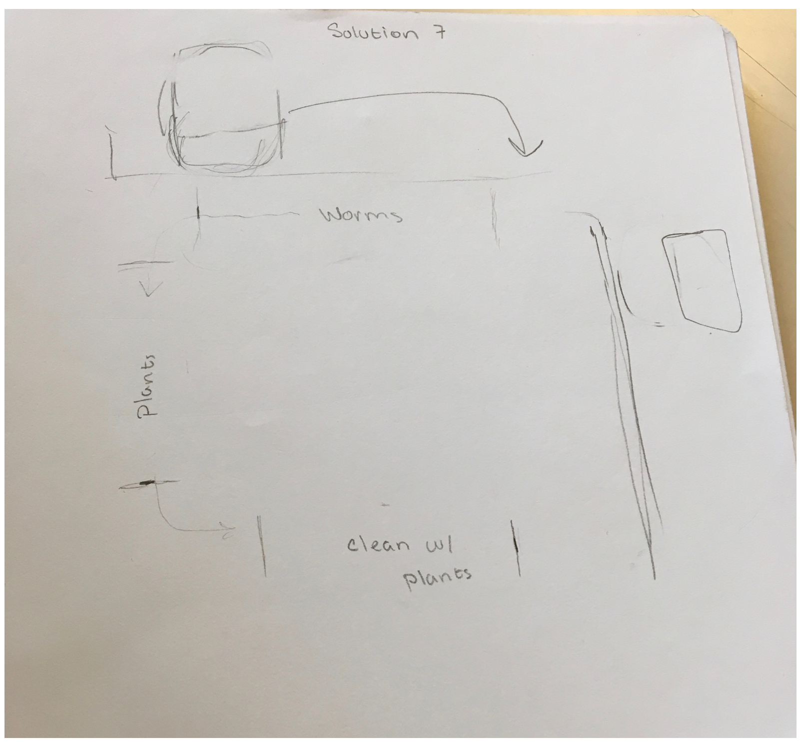

Rules
•Fill board
·"and" not "but"
·Stay on topic
Problem:
alternative solutions to grey-water filtration
Solution?
gravel
Mulch basin
Wine barrels
Wetland Plants
bath-tub
Pond
Edible-Plants (See notes)
Pea gravel
Pond liner
2"+ Pipes w/ Screens?
Wood
Fish/ducks
Child Saftey
Metal grate Protection
Microrganisms
baffels
Evacuation System
hole
Septic tank & Pond
Worms
Hay
Sand
interactive
Scenic
beautiful
bench
asthetics
tree
grease trap
bricks
flow
Solar lighting
funnel
wet ducks
irrigation
Water roots
ground water
drippers
buckets
Soaps (natural)
FOG
land
holes
Shrooms
gravity
Sludge
leachate
Settling tank
Water fall
black water
inspiration
ramps
Pipes
copper - PVC
themed
hippie-style
herbal garden
eco-friendly
bucket/Pipes
re-purposed parts
concrete
water transport
Zip-line
Zen
Water ladder
time
Volume
Usage
Consumption
legality
over-flow
Mosquito
Lead Poison
Bees
Perineals
bionics
Space Usage
efficiency
Metals?
Materials
Wood vs. Plastic
Size
Cost
ADA
lights
direct Pipe
Pump
Well-Pump
Cold weather
Rain
ice?
Snow
Energy
Electricity
dogs/cats
Solar Panels


Worms and Pond
Solution 4
Input tank
Bathtub
Bathtub
wet lands
Pond
Solution 5
Input tank
Bathtub Split
Pond


35-60gal
Bathtubs
Solution 1
10 gallon tank
Input tank
Wine barrel
FOG
1
2
3
Solution 2
Input tank
Pond liner
1
2
Wetland plants
Clean water
mulch


Solution #3
barrel
gravel/sand
GW
FOG
Clean H2O
Garden
sink
gray water
pipe


water is carried and poured in top
1) Small river rock
2) Hay
3) Sand
30 gal half wine barrel
2" pipe
Bench
fruit tree
bath tub
1) wetland plants
evac
berries
pond
berries
bath tub
evac


Solution 7
Worms
Plants
clean w/ plants