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Design of a Rainwater Collection System for Irrigation Purposes

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A rainwater collection system implemented in a small community garden in San Antonio proposes to operate as efficiently as possible. The original design problem and proposed solution are discussed, and the construction process and the final design are evaluated. A set of experiments was conducted to help determine specific building parameters that would be included in the final design. Once built, the system successfully completed the major goal, to distribute water through a garden plot, by employing each of the other system components. The drip hoses, on average, flowed at 0.64 GPH/ft which is higher than our minimum of 0.45 GPH/ft. However, this was at a water height of 36" from the ground. The complete stepwise process taken to construct such a system is outlined below, and includes recommendations for future work or similar systems. With the goals of renewability, sustainability, and conservation in mind, a simple and intelligent design could eventually become a common structure in residential and commercial buildings.

1 Executive Summary

The main function of this project is to reduce demand for potable water in irrigation systems such as a garden while using as little municipal energy as possible. Using collected rainwater is not only cost effective, but also an environmentally safe practice. As rainwater is a free commodity, effectively collecting and re-allocating it when needed drives down energy costs both on a utility bill and at the treatment facility. The largest obstacle was the allotted budget of $1000, which is incredibly restrictive for a full-scale construction project. Fortunately, an additional $800 was donated by the Jardin de la Esperanza and other donations came in the form of PVC piping from Ferguson Inc. and aggregate for the foundation from Vulcan Materials.

The ideal design used gravity feed instead of a pump, a drip irrigation system, and a tank large enough to provide irrigation for 3 weeks of drought. The system consists of a series of components to collect, transport, store, filter, and distribute rainwater. Of the two filters, the primary filter cleans large particles (twigs, leaves) and the secondary filters smaller dirt particles.

To effectively capture rain water, it was necessary to install gutters onto the roof edge at every horizontal roof margin. Assumptions about watering techniques were made to determine the water demand. The water demand was based on the types of plants in the gardens, climate when watering, and amount of time spent watering. This demand was corresponded with drought sustainability, and required a 1200 gallon tank.

The design specified by the Jardin de la Esperanza indicates a need for a transport hose and a splitter to divide the water into multiple drip hoses which would each be placed in the beds. The water demand flow-rate was determined to be 0.45 gal/hr-ft and can be dispersed over multiple garden beds simultaneously.

A few tests were conducted to predict flow rates and filtration results to determine if gravity was a viable option. Head loss, energy lost due to flow through a pipe or hose (measured in feet), was thought to be a big factor. Testing showed that hose length and the number of hoses used in parallel had minimal effect on the emitter flow rates. The complete rainwater collection system was composed of four main assemblies: collection system (gutters and PVC piping), filter system (primary and secondary filter), storing system (tank and its foundation) and the distribution system (drip-irrigation). All four components were designed in accordance with the design criteria and were cost and energy efficient.

The PVC piping was installed to transport the water from the gutters to the tank. The water flow between the gutters and the PVC was secured via downspouts and various PVC connectors. All of the piping was directed to the location of the installed tank. The primary filter was manually constructed by the group members while the secondary filter was purchased from a store. The final tank foundation design solution consisted of a combination of cinder blocks, limestone aggregate, rebar and concrete. The size of the foundation (18" high and square shaped, 7’x7’) was necessary to allow gravity feed to be possible. The drip irrigation system is comprised of 0.6” inner diameter plastic tubing which runs the length of each of the garden beds.

After the cistern was fully installed, it was necessary to accommodate any overflow the cistern might experience in years of above average rainfall. This setup prevents soil erosion.

Maintenance was minimized with the use of a steel tank (to prevent algae growth in the tank) and easy maintainable and long lasting filters. The plan was to design the system so that the gardener would only have roughly 15 minutes of maintenance per week.

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5 Introduction

As the global population continues to grow and advance, more and more strain is being placed on natural resources. Fortunately, there is also growing awareness concerning renewable energy and resources. One such topic of discussion is water conservation. Many households are using low flow toilets and showers, and alternative water sources are being discussed. The primary goal is to design and build a small rainwater collection system in San Antonio that will collect rain, transport it to a storage tank, filter out medium and large particulates, and distribute the stored water on site to a small garden plot while remaining as energy efficient as possible. As such, this paper will detail the process behind implementing such a system from start to finish, as well as recommend any improvements that can be made. It should also serve as a reference for individuals interested in installing similar systems for residential irrigation purposes.

The main function of this project is to reduce demand for potable water in irrigation systems such as a garden while using as little municipal energy as possible. The overall objective is to implement a system at el Jardin de la Esperanza (JE) that will collect and transport rainwater from an asphalt shingle roof to an onsite storage cistern while filtering out large particles and then deliver the collected water to the existing garden plot. The system is to be low maintenance, requiring no more than 30 minutes per week for upkeep. Furthermore, the system will be reliable and most importantly, the system will effectively meet the water demands of the garden and the plants it contains, and provide enough water to cover a drought period of three weeks.

6 Design Overview

As mentioned previously, the main goal of this project is to reduce demand for potable water in irrigation systems. Using collected rainwater is not only cost effective, but also environmentally safe practice. As rainwater is a free commodity, effectively collecting and re-allocating it when needed drives down energy costs both on a utility bill and at the treatment facility. As such, gravity feed was proposed to water the garden instead of implementing a pump to supply the needed water pressure to the drip hoses. In order to determine if gravity feed was a viable option, sample calculations and prototype tests were conducted. Once the necessary data had been collected and analyzed, it was determined that the storage tank would need to be raised 18 inches above ground to build the necessary pressure. This discovery led to an analysis of the ground soil in San Antonio, which demonstrated that an appropriate foundation was needed. The construction specifications will be discussed in later sections. Another goal is to effectively meet the water demands of the garden, which ultimately led to the determination of the tank volume. Using information gathered from JE and their watering schedule, as well as annual average precipitation data, a water demand table was developed assuming that the year begins with a full tank (Table 1).

Table 1. Annual Water Balance for a Typical Year

Month	**Avg days per mo. w/o rain**	**Evaporation Rate**	**Growing days/mo.**	**Water Demand** (gal)	**Rainfall Collected** (gal)	**Balance** (gal)	**Overflow** (gal)
Jan	23.3	Low	0%	0	1,076	1,200	1,076
Feb	20.0	Low	100%	775	1,299	1,200	524
Mar	20.0	Typical	100%	1,550	1,123	773	0
Apr	22.1	Typical	100%	1,717	1,705	761	0
May	22.0	Typical	100%	1,705	2,686	1,200	541
Jun	22.8	High	50%	1,470	2,442	1,200	973
Jul	22.6	High	0%	0	1,231	1,200	1,231
Aug	25.0	High	0%	0	1,658	1,200	1,658
Sep	22.5	High	100%	2,907	2,084	377	0
Oct	21.1	Typical	100%	1,638	2,314	1,053	0
Nov	21.7	Low	100%	842	1,515	1,200	527
Dec	23.0	Low	50%	446	1,143	1,200	550
Total				**13,049**	**20,276**		**7,079**

With these goals in mind, constraints were also considered and evaluated. The largest obstacle was the allotted budget of $1000, which is incredibly restrictive for a full scale construction project such as the one described. Fortunately, an additional $800 in funding was donated by JE, as they had made room in their budget to complete a rain harvesting project. Additionally, the team received generous material donations from Vulcan Materials, who supplied the aggregate for the foundation, and Ferguson Inc., who supplied the PVC piping necessary to transport the collected water to the tank. Another constraint is time. Finding the site to implement this system took much longer than anticipated, and building could not commence until appropriate tests and calculations had been completed. Lastly, the system needs to be fully operational by the end of April 2008.

One of the byproducts of the financial situation was the size of the tank that could be purchased. Although a 2,400 gallon tank would have collected more water and allowed the system to sustain a garden through a longer drought period of 6 weeks, the budget would not allow for such a tank. Instead, a compromise was made to ensure that the system would sustain the garden for up to 3.2 weeks of drought by installing a 1200 gallon tank.

7 Alternatives

To determine which alternative best met the criteria outlined in Memo 1: Project Descriptions and Specifications, the following tables were developed. Table 2 describes the alternatives and their components. Table 3 shows the ratings for how each alternative fulfills the criteria. The ratings were developed based upon the considerations of which combinations of the system components suit the "ideal" design the best. The "ideal" design would implement a system which would use the least possible energy, would be most cost efficient, offer sufficient filtration and provide irrigation for at least 6 weeks of drought. Each rating is multiplied by its weight and summed with the other ratings for each alternative. This produces a final score for each alternative, a percentage rating of how well the alternative meets the design criteria.

Table 2. Alternative Systems

System Component	**Alternative 1**	**Alternative 2**	**Alternative 3**	**Alternative 4**
Catchment Surface	Parking lot	Pond	Elevated impervious cover	Roof
Water Transportation (Surface to Storage)	Natural slope of land + barriers	Natural slope of land	Gutters + PVC piping	Gutters + PVC piping
Storage	In-ground cistern	Pond	Tank on ground	Tank on raised mound
Filtration	Screen filter + first flush diverter + settling in tank	Mesh + sand filter	Gravel + sand filter	Gutter Filter
Energy Source	Bicycle w/ pump	Grid + pump	Solar + battery for pump	Gravity
Distribution	Drip irrigation	Sprinkler system	Mist irrigation	Solar-powered valve for drip irrigation

Table 3. Alternatives Matrix and Design Criteria Weighting

Design Criteria	**Weighting**	**Alternative 1**	**Alternative 2**	**Alternative 3**	**Alternative 4**
Ease of Maintenance & User Friendliness	15%	5	7	5	9
Water Purity	25%	7	8	9	8
Water Supply (Quantity & Delivery)	30%	10	8	4	8
Cost	15%	3	7	4	5
Energy Demand	12%	10	1	10	10
Aesthetics	3%	8	9	3	8
Total Score	**100%**	**74%**	**69%**	**61%**	**79%**

Based upon the scores in Table 3, it was decided that the best system is the last choice, alternative four. Using a roof makes the system versatile and easy to implement in the home or in a commercial setting. Additionally, it satisfies the design criteria originally outlined by remaining cost effective, low maintenance and as energy efficient as possible (meaning using the least amount of electrical energy as possible to run the system, if any at all). Furthermore, the overall system is a fairly simple design, which translates to ease of manufacture.

Although alternative four was chosen, not all of its prescribed system components were utilized. Due to the strong desire of JE employees for hands on gardening, the original plan of using a solar powered water timer system was not desired. Instead, the gardeners will just turn the valve at the outlet of the tank to start and conclude the daily or bi-daily watering of the plants. Also, the pre-tank filtering system in alternative four, GutterFilter, was not used, but was rather replaced with a more comprehensive filtration system. All of the other components remained the same.

The system consists of a series of components to collect, transport, store, filter, and distribute rainwater. The first system component at JE, the catchment surface, is a shingled roof. The catchment surface had no means of collecting rainwater and thus, gutters were purchased and installed. The roof of the house beside the garden plot at JE provides a surface area of 1152 ft^2 and the gutters are sized accordingly. From the gutter system, the water enters the downspout system and just before reaching the tank's inlet, the water will pass through a self-cleaning screen filter in order to remove large particles. A central component in the design is the above ground storage container; not only is it the most expensive component ($800), it is also the largest and most visually obvious piece of the system. The tank has an overflow pipe, which will allow excess water to escape if the tank has reached its maximum capacity (1200 gallons). A secondary filter is placed at the tank outlet to catch any remaining particles which were smaller than the mesh openings in the first filter. This secondary mesh ensures that particles small enough to clog the emitters, after exiting the tank, do not enter the hose line. An outlet spout at the bottom of the tank connects the tank to the distribution system.

The outlet valve is opened to flood the distribution system with the collected rainwater. The height of water standing in the tank will create 1 psi for each 2.31 feet of water depth, providing the pressure needed to distribute water to all the garden beds. The outlet valve connects to a splitter via a transport hose to divide the flow into multiple lines for drip irrigation. These drip lines are fitted with emitters to distribute the water throughout the garden plot.

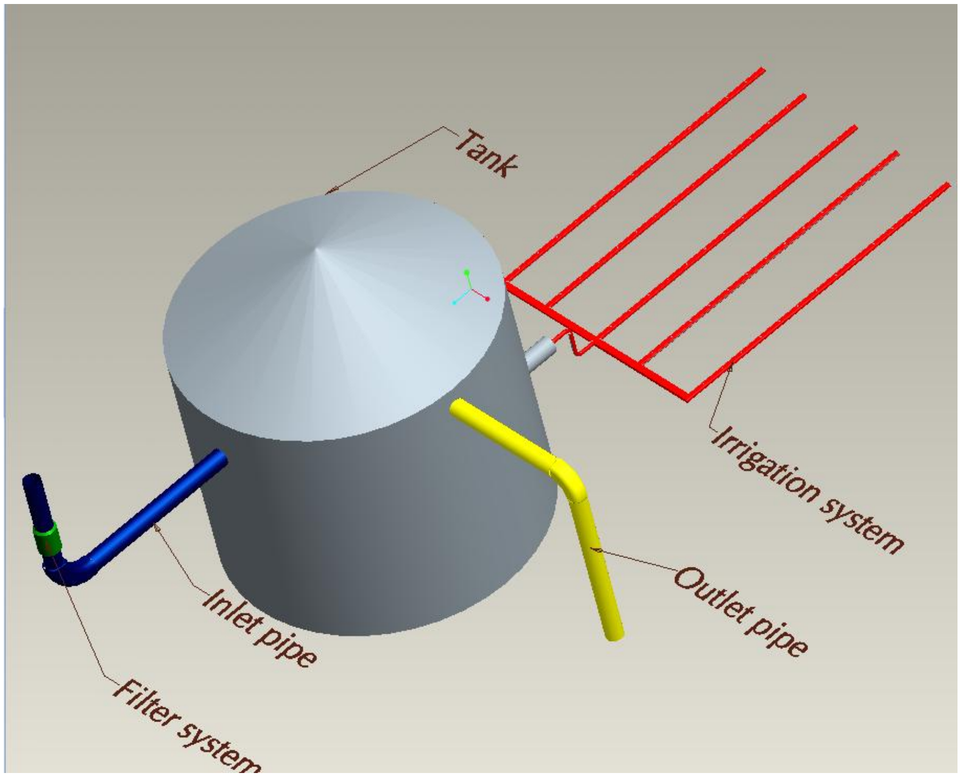


Figure 1. CAD drawing of filter, inlet, storage tank, outlet, and distribution method

In Fig. 1, the blue inlet pipe is attached to the downspouts on the building and is the pipe which brings the water from the catchment surface into the storage tank. This inlet flows into the green filter system, which is comprised of a mesh screen in between two pieces of PVC. The location of the first mesh is shown in this assembly and will be detailed later in this section.

7.1 Filters

The primary filter will clean out large particulates such as tree litter before the water reaches the storage tank. The chosen alternative specified that GutterFilter (a foam filter that fits into standard-size gutters) would be used in the design, but a more economic solution has been since discovered. When visiting the Montgomery County Extension Office in Conroe, Texas, members of the design team saw the use of a self-cleaning filter (Fig. 2).

Figure 2. Self-cleaning filter for tree litter and similarly sized particulates

The filter shown in Fig. 2 uses an aluminum screen (16 mesh) which is tilted at a 45˚ angle. The water easily passes through the screen while the leaves, twigs, and other debris are caught and fall off due to the sloped mesh. One of the important design goals of the project was ease of use and maintenance; this addition to the system virtually eliminates the need for daily maintenance. The extra PVC will add cost to the system, but reduces the maintenance required in cleaning off a screen filter, a much more useful gain. An additional drawing of the proposed design can be seen in Fig. 3.

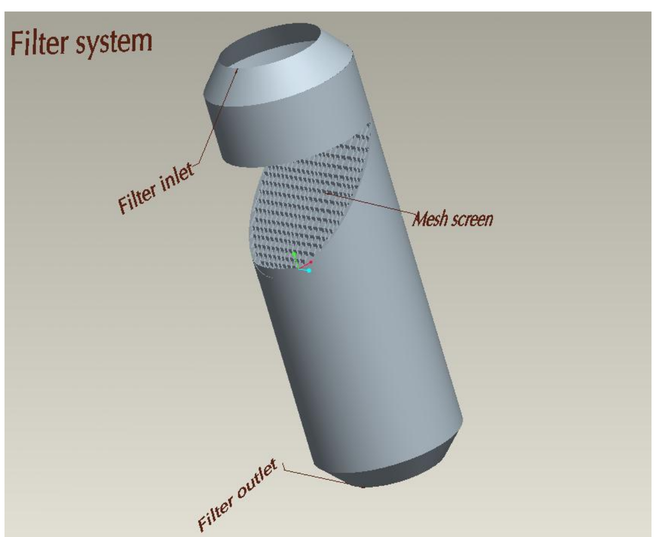


Figure 3. Proposed design for large particulate filter

7.2 Storage

Another main goal of this system is the ability to sustain a 6 week drought (this number was later adjusted), since rainfall patterns (particularly in San Antonio) tend to be irregular within the year and among years. The monthly variation of rainfall throughout the year in San Antonio is shown below in Table 4, along with the quantity of water available for collection at JE. These data are based on a roof area of 1,152 ft^2 and a system which can capture 85% of the rainfall.

Table 4. Available Rainwater for Collection in San Antonio

Month	**Average Rainfall** (inches)	**Quantity of water avail. for collection** (gal)
January	1.59	1,076
February	1.92	1,299
March	1.66	1,123
April	2.52	1,705
May	3.97	2,686
June	3.61	2,442
July	1.82	1,231
August	2.45	1,658
September	3.08	2,084
October	3.42	2,314
November	2.24	1,515
December	1.69	1,143
Total	**29.97**	**20,276**

The average rainfall data for San Antonio is based upon information provided in the Texas Manual on Rainwater Harvesting (1). The 85% system efficiency falls within the common system efficiency range used by professionals who design similar systems (1). The reduction from a full 100% efficiency is a factor of spillover in gutters during particularly intense rainfall events and absorption and subsequent evaporation of some water on the catchment surface. The shape and orientation of the catchment surface, an asphalt-shingled residential roof, is shown in Fig. 4.

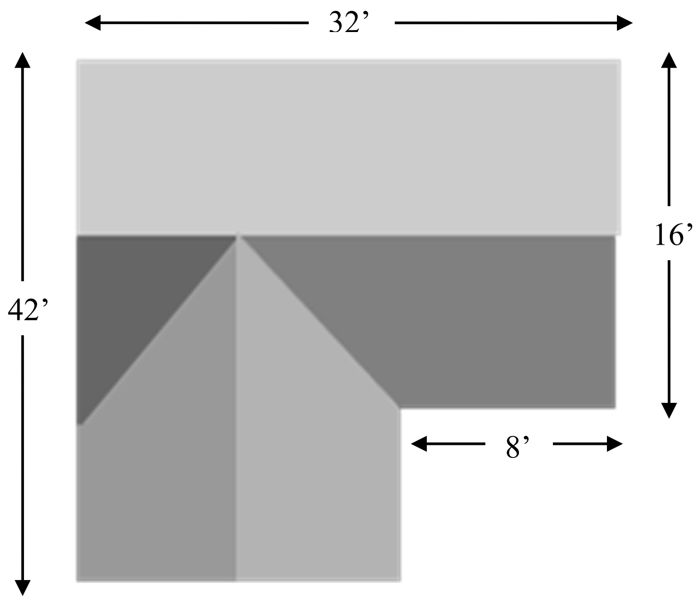


Figure 4. Catchment surface at JE totaling 1152 ft^2

To effectively capture the quantities of water shown in Table 4 above, it was necessary to install gutters onto the roof edge at every horizontal roof margin. Considering how the system may best meet the water demands of JE, it is preferable to capture rainfall from the entire roof so as to have the maximum quantity of water available in dry years. In order to determine if a rainwater collection system based around this collection surface could meet the water demand of the garden on a yearly basis, a water balance was drawn up for a typical year (Table 1).

In this predictive balance, assumptions about watering techniques were made to determine the water demand. Through a discussion with Angela Hartsell, the Community Gardens Project Manager at Bexar Land Trust (the organization which sponsors JE), the following seasonal growing patterns were determined: the warm and cool growing seasons begin in February and September, respectively, when seedlings are planted. The plants mature and their growing seasons continue throughout the rest of the year, except for the months when the weather is typically too hot or cold. During the hot months, the latter half of June and all of July and August, and the cold months, the latter half of December and all of January, there will be no plants so no watering is necessary. Furthermore, during the hot months any surviving plants require increased watering because of increased water evaporation (from the soil) and evapotranspiration (from the plants) rates; likewise, the cool months require less frequent watering. According to The Agriculture Program of the Texas A&M University System (2), closely spaced vegetables (less than two feet between plants), like those at JE, in medium coarseness soil, like that of its garden beds, thrive best with watering from a drip irrigation system with the following characteristics: one drip hose per row of vegetables, one emitter every 20” of hose, 0.75 gallons per hour flow rate for each emitter, and 2 hours of watering per irrigation event. The agriculture program suggests that weekly irrigation times with this setup should total to 3 hours during cool weather, 6 hours during warm weather, and 10 hours during hot weather. As one would expect, however, the plot is watered only on days for which there is no rain. Thus, these weekly watering times were applied across the total number of days per month without rain. The data pertaining to average days per month without rain represent a monthly average taken from eight years (2000 through 2007) of actual daily rainfall data. The total number of days of rain in a month is subtracted from the number of days in the month to give the final value. This daily rainfall data is from the local airport records, accessed through the Weather Underground website (3).

The above calculations for water demand assume a plot area of $414ft^2$ (see Fig. 5), with the rows spaced two feet apart within each bed. Thus, based upon the row spacing, row lengths, the number of days per month without rainfall, and the agriculture program’s suggested watering schedule for a garden like JE, the total water demand per month was calculated. This watering program will replace the current one developed by Angela Hartsell in which 1.5” of city potable water are supplied to the entire plot via a spray nozzle and hose. Both these methods are verified by the vegetable water demand information provided by The Agriculture Program of the Texas A&M University System (2):

> In sandy loam soils, broccoli, cabbage, celery, sweet corn, lettuce, potatoes and radishes have most of their roots in the top 6 to 12 inches of soil (even though some roots go down 2 feet) and require frequent irrigation of about 3/4 to 1 inch of water. Vegetables which have most of their root systems in the top 18 inches of soil including beans, beets, carrots, cucumbers, muskmelons, peppers and summer squash. These vegetables withdraw water from the top foot of soil as they approach maturity and can profit from 1 to 2 inches of water per irrigation.

A few vegetables, including the tomato, cantaloupe, watermelon and okra, root deeper. As these plants grow they profit from irrigations of up to 2 inches of water.

Next, the water balance (quantity of water in the tank at the end of each month) assumes a 1,200 gallon tank which is entirely full at the start of a given year (January). The balance is calculated as the volume of water in the tank from previous months, plus the rainfall collected in the current month, minus the month's water demand. Any balance over 1,200 gallons leaves the tank as overflow. As this analysis is performed based on data available for typical yearly San Antonio weather, the fact that there is an overflow of 4,350 gallons and that the tank is never quite empty suggests that the system will be able to meet full yearly demand and sustain the garden temporarily during years larger than average dry spells. The projected goal of sustaining a water supply for 6 weeks of drought with no rain, however, is not achievable with the limited funding for this project. The average weekly demand for the garden plot is 394 gallons, thus a full tank with a capacity of 2,400 gallons would be required to meet a six week drought. The projected 1,200 gallon tank could sustain a drought of 3.2 weeks. Thus the system is expected to meet the full water demand on a typical year in San Antonio; however, the system would have to be supplemented with city water to sustain the garden, as is, through an extended drought in a year when all garden beds were planted throughout all described growing seasons. Another approach to extending the time period for which the system can sustain the garden would be to reduce the water demand. Mulching and covering beds with shade-cloth are two examples of demand-reducing measures. A final solution for extending the system's watering capacity during periods of drought should be decided in collaboration with the gardeners who will perform the irrigation.

Figure 5. Plan of JE

7.3 Distribution

With the final plot location being JE, it is ideal to replicate their desired distribution system. As shown in Fig. 5, the garden will consist of several raised beds containing vegetables, which have a high water demand. The design specified by JE indicates a need for a transport hose and a splitter to divide the water into multiple drip hoses which would each be placed in the beds. A water demand and flow rate estimation was developed for each bed, and can be seen below in Table 5.

Table 5. Bed Watering: Time, Demand and Flow Rate

Bed	Bed length ft	Bed Width ft	Number of Drip Hoses	Length of Each Hose ft	Total Length of Drip Hose ft	Watering Time hr	Water Demand per Watering gal	Flow Rate per Length Hose gal/hr-ft
1. West Bed, North	23	4	2	23	46	2.00	41	0.450
2. West Bed, South	23	4	2	23	46	2.00	41	0.450
3. East Bed	20	4	2	20	40	2.00	36	0.450
4. North Bed, West	8	4	1	18	18	2.00	16	0.450
5. North Bed, East	8	4	1	18	18	2.00	16	0.450
6. West Child. Bed	23	2	1	23	23	2.00	21	0.450
7. East Child. Bed	20	2	1	20	20	2.00	18	0.450
Total			**10**		**211**		**190**	

A watering time of two hours and the various water demands per plot per watering event follows the schedule outlined by the document “Efficient Use of Water in the Garden and Landscape” distributed by The Agriculture Program of the Texas A&M University System[3]. It would be necessary to water 1.5 times per week during the cool months, 3 times per week during the warm months, and 5 times per week during the hot months.

Figure 6 below shows a simplified layout of the garden beds for watering considerations (applicable to the data in Tables 5 and 6):

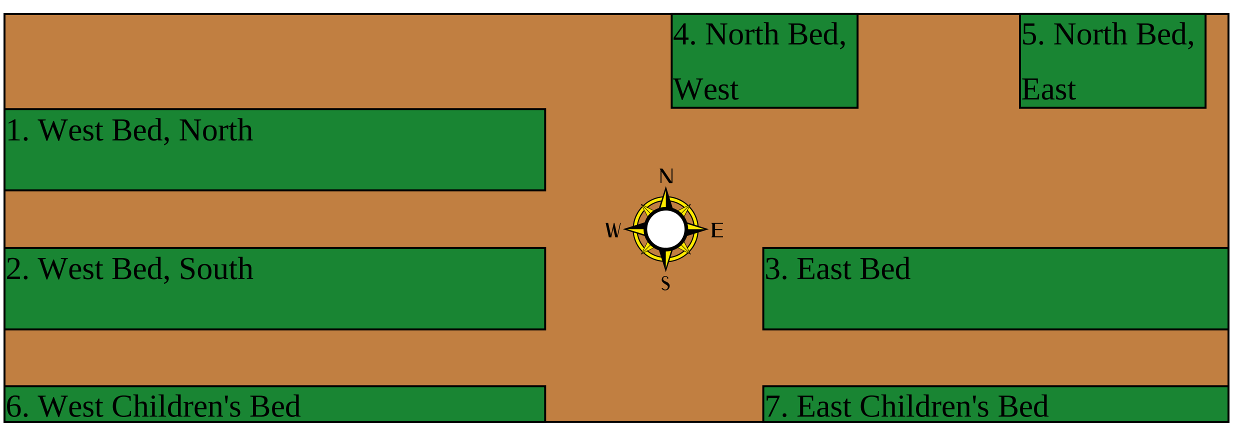


Figure 6. Garden Beds at JE, Names and Locations

Table 6. Various Watering Plans with Corresponding Watering Times and Flow Rates

Number of Sequential Waterings	Bed Groups	Total Watering Time hr	Volumetric Flow Rate in Transport Hose gal/min	Average Linear Flow Rate in Transport Hose by Diameter ft/sec					
				1/2”	**5/8”**	**3/4”**	**1”**	**1½”**	**2”**
7	Individual	14.0	0.23	0.37	0.24	0.16	0.09	0.04	0.02
5	(1)(2)(3)(4,5)(6,7)	10.0	0.32	0.52	0.33	0.23	0.13	0.06	0.03
3	(1,4)(2,6)(3,5,7)	6.0	0.53	0.86	0.55	0.38	0.22	0.10	0.05
2	(1,2,6)(3,4,5,7)	4.0	0.79	1.29	0.83	0.57	0.32	0.14	0.08
1	All Together	2.0	1.58	2.59	1.65	1.15	0.65	0.29	0.16

Table 6 shows that, if multiple beds are watered at once, the total watering time can be decreased by reducing the number of sequential 2-hour watering events during a day. Table 6 also shows the resulting total watering times, and volumetric and linear flow rates, which increase as the total watering time decreases. These theoretical flow rates must be substantiated with tests to determine if they can be achieved by a setup like the one proposed. However, the final decision of how to divide the beds into watering groups should also be made with the gardeners who must keep the watering schedule throughout the lifetime of the garden. For the sake of the gardeners, it is logical to group the beds, as a 14 hour watering period (for individual watering) extends far beyond an expected 8 hour workday shift.

8 Prototype Test Plan

In order to determine whether the system has the capability to perform using gravity feed rather than a pump, a few tests were conducted to predict flow rates and filtration results. The prototype allowed for testing the flow rate of water from a 5-gallon bucket at various heights, hose lengths, number of hoses (in parallel), and drip emitter ratings (1 GPH and 4 GPH)

In order to examine how the flow rate is affected by varying the water tank height, number of hoses, length of the hoses, and size of the emitters, a test matrix was devised. The matrix (Tables A-1 and A-2) consisted of fifty-four experiments involving each possible combination of the variables. The resulting flow from the emitters was then measured for each of the fifty-four combinations. However, before beginning the experiments, the test apparatus had to be constructed which would allow for the proposed experiments to be performed. The long ½" hose was first cut up in three lengths: 10, 20, and 30 feet. Next, holes were punched in the hose line, and emitters were manually inserted every two feet. The bucket used to simulate the water tank had to be modified to allow the hose to be connected. A hole was drilled on the side of the bucket about a quarter of an inch above the bottom in order to insert a pipe. Next, the female part of the pipe was connected to the male part from inside the bucket, and rubber gaskets were placed in between for a tighter, more secure connection. In order to prevent leakage, an epoxy glue was used around the pipe-bucket connection. A sketch of this can be seen below in Fig. 7.

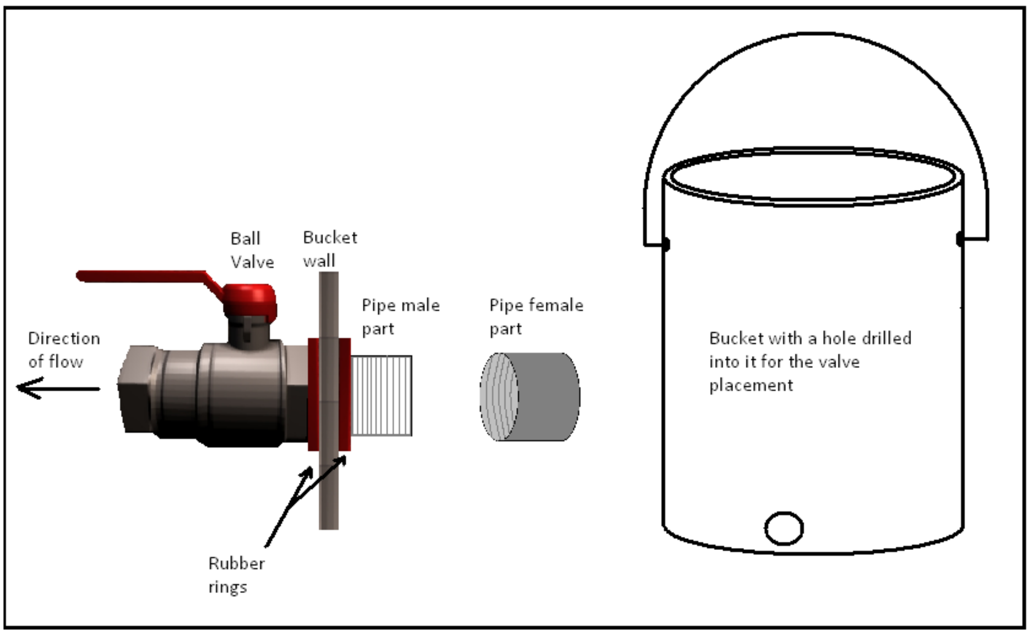


Figure 7. Bucket-pipe connection

8.1 Experimentation

The testing was conducted on a relatively flat surface to prevent discrepancies in each emitter's height. In order to keep the hoses straight and at a uniform height, small wooden stands were constructed (Fig. 8).

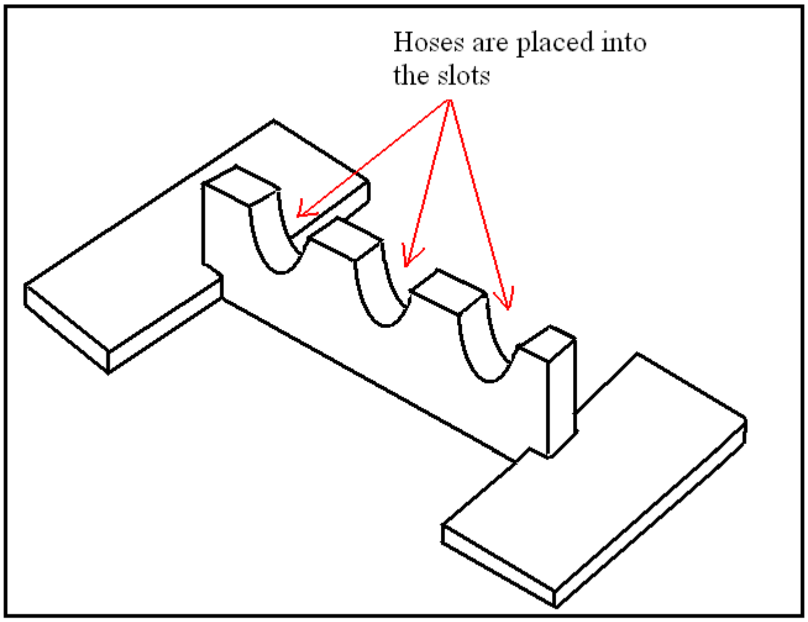


Figure 8. Hose stand

After the hoses were inserted into the stands, the bucket was then set to the desired height (12'', 34'' and 48''). Using a hose clamp, a small piece of a hose was connected to the pipe while the other end connects to a three-way splitter. Using another three-way "T" splitter, three hoses could be connected simultaneously. When the hoses were not being used in a test, the open holes in the "T" splitters were plugged using a clamped segment of tubing. A simple sketch of this setup can be seen in Fig. 9. Once the test is set up accordingly, the valve on the pipe is opened and the water fills the hoses. Once the emitters are all dripping at a constant flow, cups are placed under the first, middle and last emitter of each hose to collect the water for one minute. After one minute, the cups are removed and their contents measured using a graduated cylinder. The data from each trial is recorded for analysis. After the first round of experimentation and measurements were completed, the secondary filter was finally available for use. A second and less extensive group of tests were conducted varying only the height of the bucket and the drip emitter ratings. The results from these tests showed a 10% - 15% decrease in flow rate compared to the results without the filter in place.

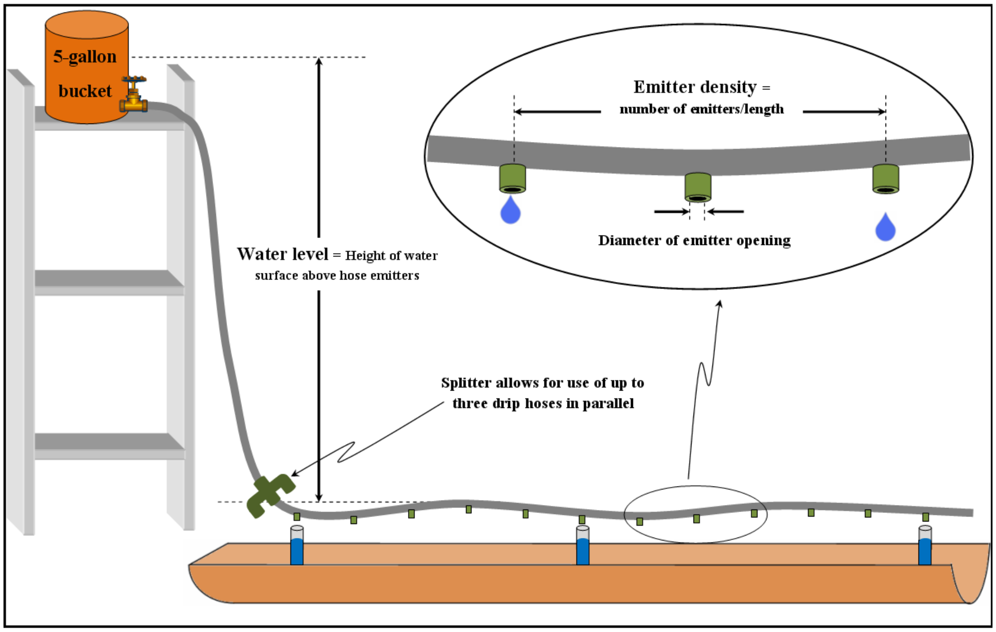


Figure 9. Drip irrigation testing setup

8.2 Prototype Testing Results

The results of the fifty four experiments conducted can be seen in the last two rows of Table A-1 (for the 1 GPH emitters) and Table A-2 (for 4 GPH emitters). Head loss, energy lost due to flow through a pipe or hose (measured in feet), was thought to be a significant factor when dealing with internal pipe flow over the lengths of hose used. Testing showed that hose length and the number of hoses used in parallel had minimal effect on the emitter flow rates.

Using the data in Appendix A, the testing was grouped in order to show the minimum water level necessary for the system to work and how the 1GPH emitters compared to the 4GPH emitters (Fig. 10 & 11).

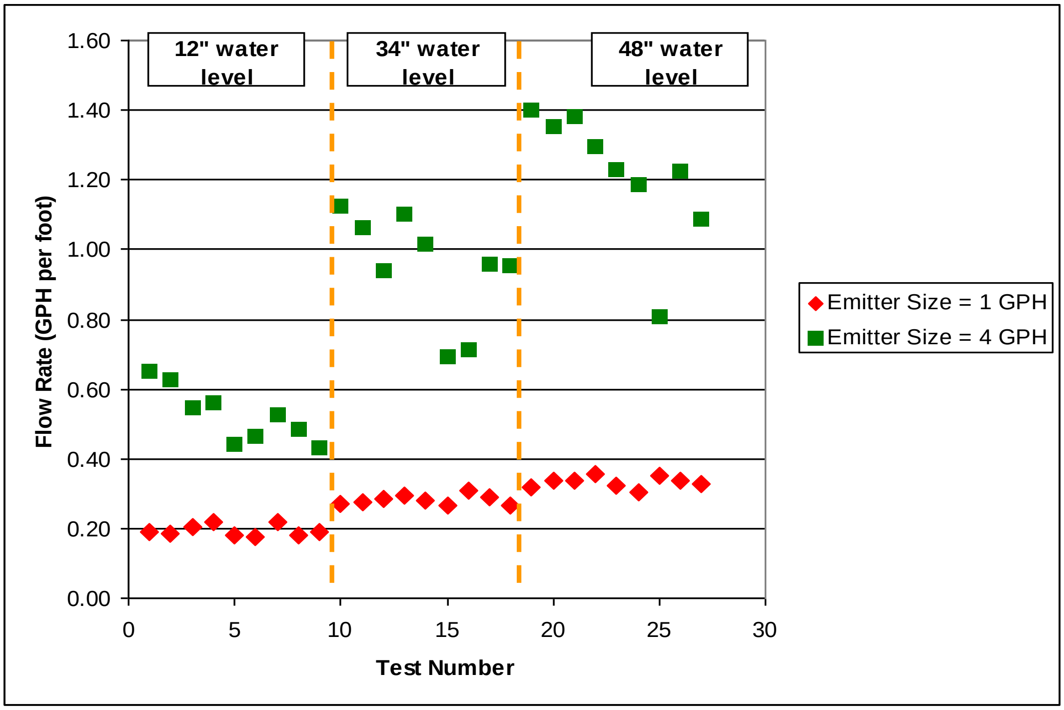


Figure 10. Variance in flow rate by emitter size (water level grouping)

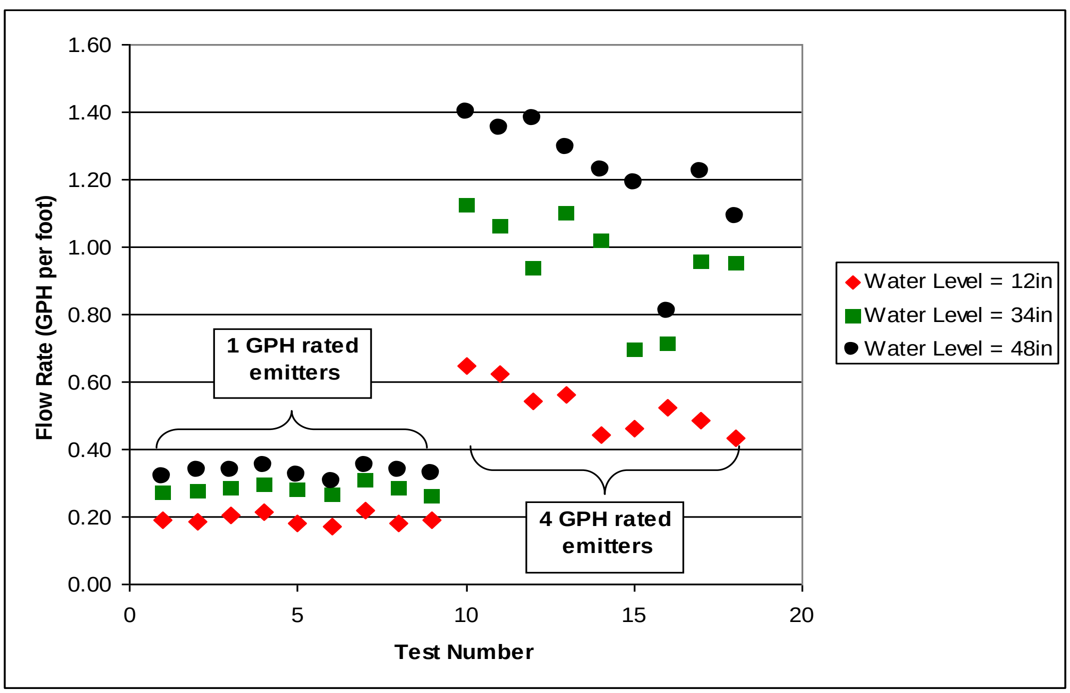


Figure 11. Variance in flow rate by water level (emitter size grouping)

The data make it clear that, by varying the water level and the emitter rating, it is possible to achieve the necessary flow rate of 0.45GPH/ft (determined based upon a 2 hour watering time for maximum infiltration, while considering time constraints of gardeners). While the effects of hose length and number of hoses are of little consequence, scaling up the rest of the system for watering at the Jardin de la Esparanza may induce some additional head loss due to friction within the transport and drip hoses. A transport hose of sufficient diameter should help reduce such losses. As the data show that flow rate varies greatly with water level, and since the tank to be used in the final system is approximately 6' in height, one can expect major changes in flow rate as the tank either empties or fills over time. This must be accommodated for by either adjusting the degree to which the watering valve will be opened. or by installing a pressure reducing valve which will reduce the pressure to a constant value regardless of the height of the water level within the tank. This pressure value will correspond to the determined water level (1psi per 2.31ft of head), which will be selected after further analysis of the data.

9 Final System Design and Construction

The complete rainwater collection system was composed of four main assemblies: collection system (gutters and PVC piping), filter system (primary and secondary filter), storage system (tank and its foundation) and the distribution system (drip irrigation). All four components were designed in accordance with the design criteria, as well as to have the most efficient and cost-effective system as possible with the available financial resources.

9.1 Collection System

In order to catch as much rain as possible, an efficient collection system of gutters and PVC was required to transport the water.

9.1.1 Materials and Design

The roof used as the collection surface did not have any guttering previously; this system component was installed first. Much of the construction time was allocated for this step in order to achieve the highest level of skill and precision possible. To minimize the weight of the collection system, 3" and 4" foam-core PVC was implemented along with aluminum gutters.

9.1.2 Methods and Construction

In order to put the gutters in place, it was easiest to install guttering one section at a time. Before a section was installed, it was measured and scaled down to the length required for that particular section of the building. Once the section was cut, it was simply placed onto metal "hangers" that were screwed into the building wall. The gutter's position was also outlined the with plumber's line before securing it with the hangers, as the optimal slope of the gutters to increase collection capacity and prevent clogging is 1/8" over a 1' length of gutter. Downspouts were placed at least every 20' along each run of gutter. To connect sections of the gutters to other sections, downspouts, and elbows, gutter "joiners" were employed. They were secured with one-inch rivets and gutter caulk.

The PVC piping was installed essentially the same as the gutters. Each of the segments was cut to a length needed for that particular segment. Then they were placed at the same sloping angle as the gutters so the water would flow in the desired direction. The PVC segments were connected via PVC connectors and, depending on the expected water flow on a particular side of the building, the group used either a 3" or a 4" diameter PVC pipe. The pipes were secured next to the building wall using copper strapping. The strapping was cut down to a needed size (depending on the PVC diameter), wrapped around the pipe and screwed into the building wall. A sketch of the gutter and PVC placement along the building can be seen in Fig. 12.

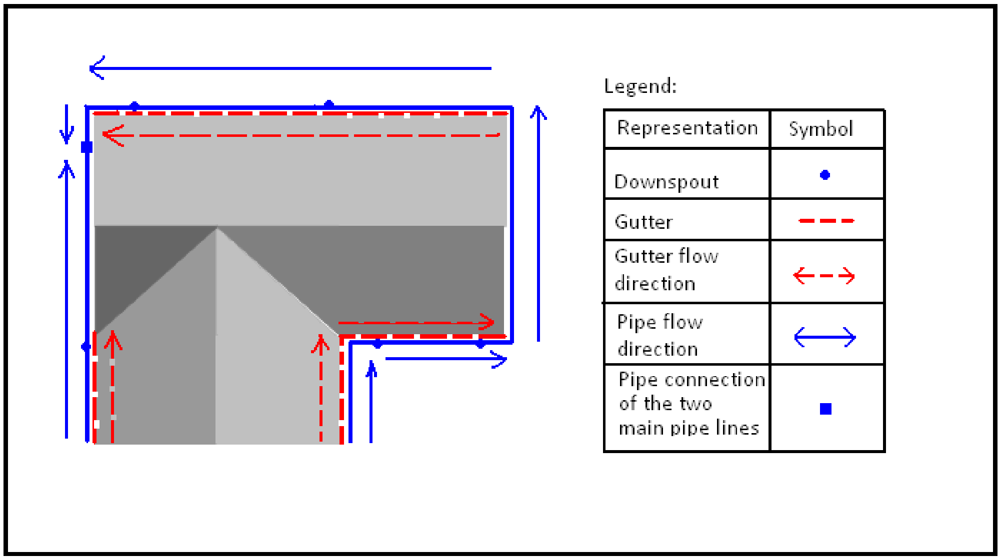


Figure 12. Gutter and hose placement along the catchment surface (building roof)

The water flow between the gutters and the PVC piping was secured via downspouts and various PVC connectors, which were used depending on the downspout position with respect to the piping. All of the piping was directed to the location of the installed tank, making for an easy transition from transport to storage.

9.1.3 Results

After some rain had fallen, it was apparent that the gutters and PVC were working properly. They directed the rainwater into the storage tank successfully. Additionally, the construction of the design to support the gutters and PVC had lasted a significant amount of time to show that they were sturdy and stable.

The leak testing, conducted by examining the collection and transportation components of the system while water is running across/through them, was slightly less successful. It is apparent that there is a small amount of leakage at the collection system and transportation system interface. Two guttering elbows were used to bridge the gap between the roof's fascia and the underlying outer wall of the building. They connected the collection (guttering) downspouts to the PVC transportation. These fittings were not precise (not the intended 90 degree angle) because the fascia of the house, instead of being vertical, is angled perpendicular to the slope of the roof. Thus all the leaking in the collection and transportation system occurred at this interface, but can easily be fixed by using caulking in the gaps.

9.2 Filtration System

The filtration system was one of the most essential parts of the system in order to make it low maintenance and employ a drip irrigation distribution method. The primary filter was placed before the tank's inlet to remove large particulates, such as leaves, twigs, pollen and bugs. The secondary filter was placed after the tank's outlet valve to remove small dirt particles that could clog a drip emitter.

9.2.1 Materials and Design

The primary filter was manually constructed, while the secondary filter was purchased from a store. In order for the primary filter to operate successfully, several details such as the angle of the mesh to the horizontal had to be very precise (Fig. 13). The construction required significant labor and precision (final construction shown in Fig. 14).

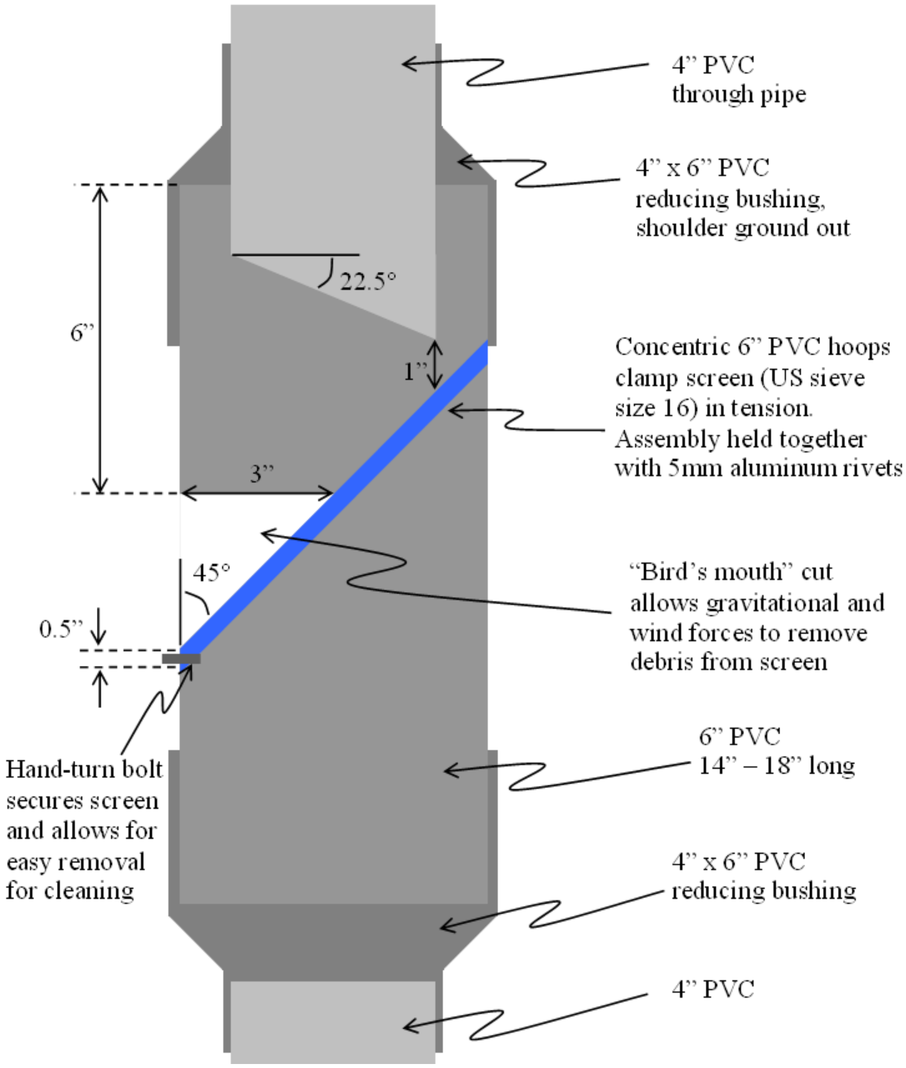


Figure 13. Primary filter design

Figure 14. Primary filter after construction

The secondary filter required finer mesh than the large particulate filter, which is difficult to buy in small quantities. Therefore, a fine-mesh filter was purchased from an irrigation store. This was very useful for the design because it was easy to attach to the outlet and easy to clean (cap at the bottom unscrews and the water will flush out any debris).

To install the secondary filter, a two part PVC reducing bushing was needed to connect the cistern’s 1.5” male outlet with pipe (Nation Pipe Thread, NPT) threading to the 1” male inlet with NPT threading. The secondary filter was strapped to the foundation to prevent any jostling which could damage it. A combination of four fittings was necessary to connect the 1” male NPT outlet of the secondary filter to the female standard hose inlet of a splitter. The “Y” splitter (with two ball valves to allow shutoff of each fork of the “Y”) diverts the flow from the cistern into two transport hoses which supply water to the beds to the east side and to the west side of the tank. A 75’ garden hose was cut into seven sections to connect all the beds in series within the two parallel sets of garden beds (east and west). This description is made clear by the system plans shown in Fig. 15 below. The seven sections of hose were fitted with either a male or female hose end at each end using "hose end menders," as shown in Fig. 15. To divert water to each bed, a splitter with ball valves was affixed at the head of each garden bed (represented by valves in Fig. 15). Adapters intended to connect male garden hose ends to drip irrigation plastic tubing were used to tie the irrigation lines into the splitters at each bed.

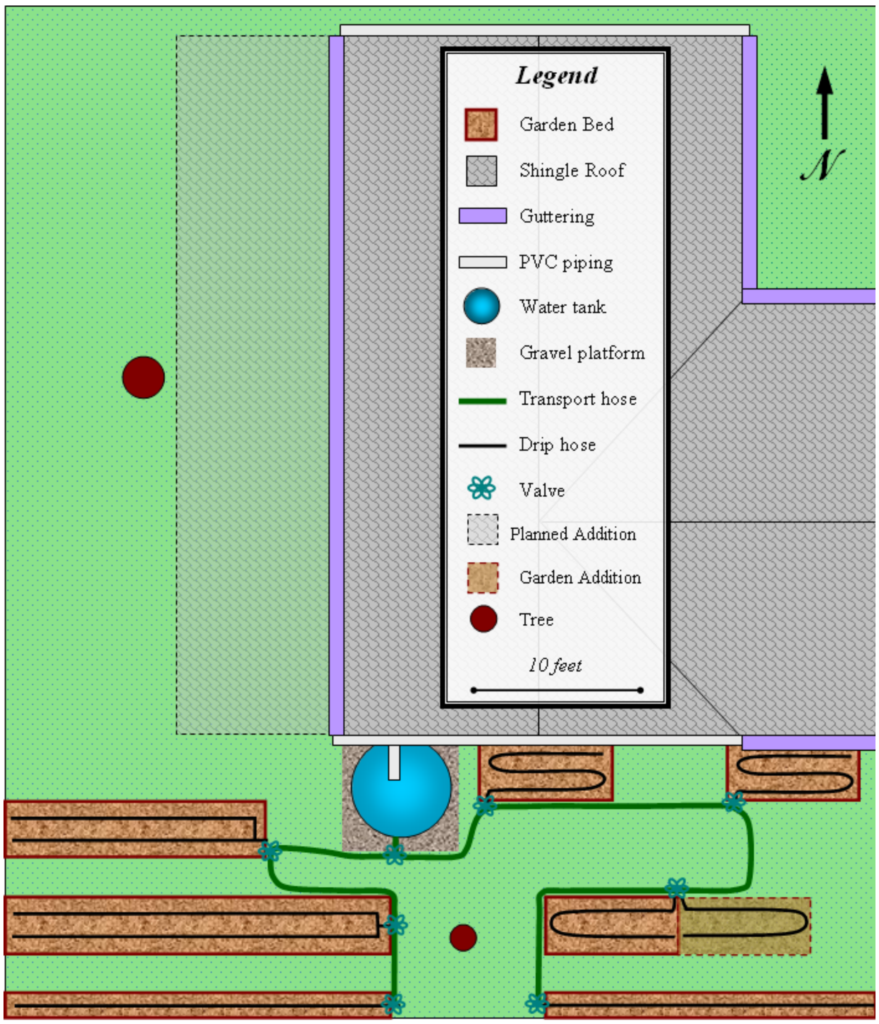


Figure 15. Rainwater Collection System Plans, JE

9.2.2 Methods and Construction

Using 4” PVC, the self cleaning primary filter was installed at the juncture between the PVC which pipes the rainwater from the guttering and the metal cistern (Fig. 16). The water from the transportation system should be directed to the top of the filter, allowing the water to proceed through the mesh and the large particulates should pass down the face of the mesh and out of the filter (the self-cleaning feature).

Figure 16. Primary filter installed at tank inlet

As one will notice, the primary filter was reduced in height between the initial plans and construction phase and the final construction and installation. This is due to height constraints from above and below: the foundation was designed to raise the cistern 18” above ground level and the cistern is 68” in height, placing the cistern inlet 86” above ground. The bottom of the fascia, where the PVC can begin is 120” above ground level. As a slope of ¼” per foot of PVC was desired (to expedite water transport to the cistern and clean out any built up debris in the piping), and the longest PVC run is 84', the PVC dropped below the fascia 21" to 99" above ground level. Thus, the large particulate filter, its connecting tee and its 90° elbow which attaches it to the cistern had to all fit into the 13" between the PVC and the cistern inlet.

9.2.3 Results

It was very difficult to simulate the final operation of the filter during prototype testing because the angle of the water hitting the screen was the most essential variable to determine if the design was successful. However, once it was installed into the system at JE, it was no longer possible to isolate the filter as an individual system and test its efficiency. Therefore, the filter was only tested visually.

While the filter effectively removes all large debris, a significant amount of water runs down the angled screen and off the filter instead of through the mesh and down into the tank. Adjustments will have to be made to rectify this problem; otherwise the system may fall below the projected 85% collection efficiency and fail to meet the water demand at peak months on a typical year. Also, the filter is not entirely "self-cleaning" and requires some manual cleaning to remove buildup which adheres to the mesh.

9.3 Tank and Foundation Installation

The size and efficiency of the tank was very important because the tank is the entire storage capacity for the system. Many of the calculations done in this report are made assuming a full tank at the start of the year, 1200 gallons. In order to successfully harness the energy available from gravity, the tank had to be raised 12". Research was done to formulate the best possible design for the platform.

To install the tank, it was hoisted onto the foundation, centered, and aligned such that the outlet was most accessible and the inlet would meet up with the PVC piping.

9.3.1 Materials and Design

The final tank foundation design solution consists of a combination of cinder blocks, limestone aggregate, rebar and concrete. This foundation was necessary for several reasons. The primary issue was the fact that the tank had to be raised 18 inches above ground to provide the water pressure required to obtain the 0.45GPH/ft flow rate discussed previously. Raising the tank to such a height would negate the use of a pump, which requires energy. The foundation also had to be dug out in order to stabilize the above ground platform. After digging about 12 inches underground, the foundation plans could be executed properly. Furthermore, raising a 1200 gallon tank poses a slight safety issue, particularly in a community garden. As San Antonio soil quality is questionable, ensuring a safe structure for the tank was a high priority. A rough sketch of the tank foundation design can be seen in Fig. 17 and Fig. 18.

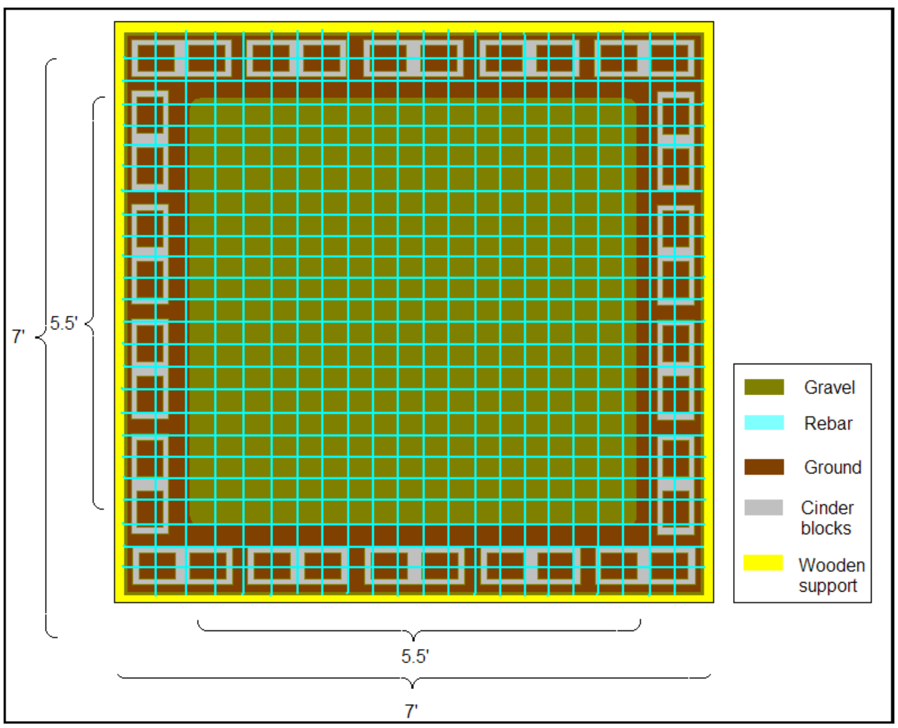


Figure 17. Top view of tank foundation design; Note: Figure not drawn to scale

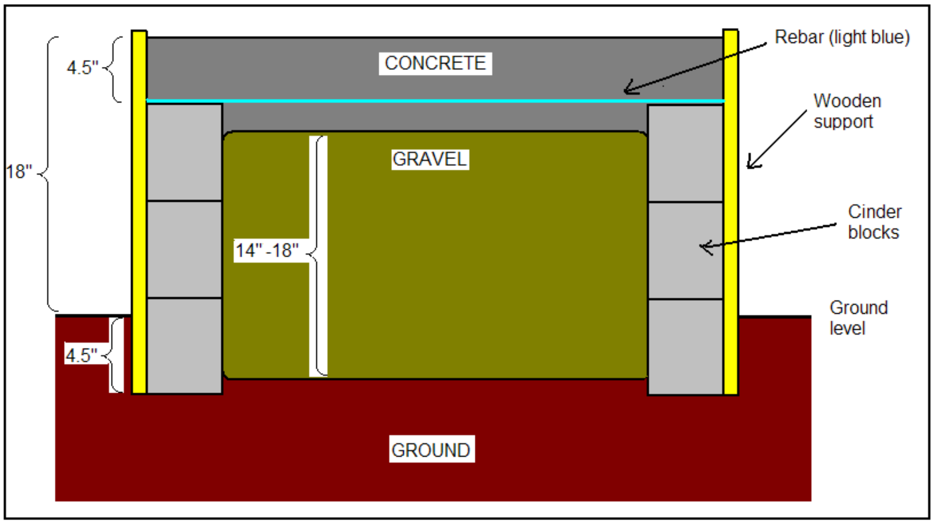


Figure 18. Side view of tank foundation design; Note: Figure not drawn to scale

9.3.2 Methods and Construction

The group first dug about 1'-1.5' deep 7'x7' area and removed any roots, rocks and other material that might potentially cause the ground to shift and be unstable. Wooden boards were placed along the area's edges to later provide support when the concrete was poured. A series of cinder blocks were placed along the perimeter of the foundation, right along the wooden support (about 1.5" of space will be left between the cinder block series and the wooden boards as well as between two consecutive cinder block series). A single series of cinder blocks consisted of three individual cinder blocks stacked on top of each other. These cinder block series acted as beams in order to provide horizontal support as well as additional vertical support. The cinder block series were stuck about 4.5" in the ground while the rest was above ground level. In order to provide additional support, rebar 2' in length with ¼" diameter were placed through each of the holes in the cinder blocks. Next, the aggregate was placed inside the cinderblock perimeter (about 5.5'x5.5' wide and 14"-18" deep). The aggregate was covered with a sheet of plastic so it would not shift and would keep its square shape Once the cinder blocks and the aggregate were in place, rebar mesh was placed over the whole 7'x7' area, leaving the rebar to rest on the cinder block series. As the final step, premixed concrete (Quickrete) was poured over the entire area. Since the concrete was very hard to level, the about 2" of pure cement was poured over the entire area to help provide a smooth and level surface.

The final foundation was 18" high and square shaped (7’x7’). The pressure that the tank will exert on the foundation when completely full will be about 2.5 psi, which is less than an average person exerts on the ground when standing on two feet. Therefore the group is confident that this design will provide more than enough support for the tank and the cinder block beams will provide horizontal support so the foundation, and thus the tank, do not shift.

After the cistern was fully installed, it was necessary to accommodate any overflow the cistern might experience in years of above average rainfall. The overflow outlet (Fig. 19) in the cistern was connected to 4” PVC piping which was directed into a trench below ground level that was filled with aggregate (approximately 1.5’L x 1.5’ W x 3.0’ D). The piping ran approximately 10’ away from the house where it entered perforated irrigation PVC in a gravel trench. The PVC piping and gravel trench were then covered with soil so the area could continue to be used as a walkway. This setup allows the water to infiltrate into the soil and become part of the groundwater system instead of contributing to flooding, storm water runoff and pollution, and soil erosion.

Figure 19. Overflow pipe, next to primary filter, in final system.

9.3.3 Results

The tank has performed as expected. There are no leaks in the design from Texas Metal Cisterns. The inlet and outlet of the tank were cohesive with the inlet, overflow and outlet valve. Presently, positive results have been achieved with the foundation design and construction. There is some minor cracking in the cement on the surface of the platform. The cracks are only about a millimeter wide and seem to be only surface-oriented which signifies that the most important part, the core, has dried well and thus strengthened properly.

9.4 Distribution System

To satisfy one of the main design goals of the project, a successful distribution system is essential. It consists of two main transport hoses, which each feed water to half of the garden. These hoses run along their respective halves of the garden, sending water down the drip hoses in each bed. At each bed, there is a valve which controls if that bed receives water.

9.4.1 Materials and Design

The layout of the irrigation system was designed following recommendations of the Texas A&M University System Agriculture Program (2). Closely spaced vegetables (less than two feet between plants), like those at JE, in medium coarseness soil, like that of its garden beds, will thrive with a watering system that allows for one drip hose per row of vegetables, with one emitter placed every 24" along the hose. Based upon prototype testing, the team determined that 4GPH emitters with at least 12" of head of water would provide the necessary flow rate of 0.45GPH per foot of hose.

The hoses were laid out as shown in Fig. 20, using a tee to divide the flow into the multiple lengths of hose where necessary, and pinning the hoses down using stakes designed to hold drip irrigation hose. The hoses were turned so that all the emitters face upward, as this prevents clogging of the emitters from contact with the soil and prevents the water drops from pounding the soil as they fall. This also places the emitters as far away from any gravity sedimentation in the hose. The ends of the hoses were pinched closed using hose enders. Figure 20, a photograph of the layout of one bed, depicts the irrigation setup. The layout of the irrigation system concluded the construction of the rainwater collection system.

Figure 20. Final layout of drip hoses in beds.

The drip irrigation system is comprised of 0.6" inner diameter plastic tubing which runs the length of each of the garden beds. Depending on the size of the bed, one, two, or three hoses are installed in parallel to ensure the plants contained get sufficient hydration. There is a transport hose running from the outlet of the tank into a splitter valve which flows to each of the seven garden beds. This transport hose is a standard 5/8" garden hose.

9.4.2 Methods and Construction

For beds 6 and 7 (Fig 6), a single length of hose (22.3' and 17.3', respectively) with 4GPH emitters is laid out and staked in place to ensure even flow and that the emitter heads are face up. Beds 1 and 2 require similar lengths of hose, though since these beds are considerably wider they require two hoses in parallel per bed. These have also been staked down and are connected to the tank. Beds 3, 4, and 5 are about 8' in length and roughly 4' wide. These beds have three hoses in parallel per bed and are staked down like the rest of the garden. The hoses are attached to the tank via a standard size garden hose. The beds containing 2 or three hoses are connected together using splitters, and then connected to the garden hose. Each garden bed has its own ball valve to allow for watering directly at bed site.

9.4.3 Results

When the distribution system was tested, all of the emitters were dripping, which showed that none of them had gotten clogged since installation. They were all functioning properly, which suggests that the particulates capable of clogging the system are being removed effectively by the combination of the primary and secondary filters.

The flow rate testing on site at JE is essential to determine if the system is able to produce the flow rates needed (0.45GPH/ft) to infiltrate the soil to the root systems within the timeframe of gardener availability. The results of the final design testing are shown below in Table 9.

Table 7. Final design flow rate testing results, 36" head

Test	Bed	Flow rate		Average bed flow rate
		mL/min/emitter	GPH/ft	GPH/ft
1	1	75	0.59	0.69
2	1	95	0.75	
3	1	90	0.71	
1	2	62.5	0.50	0.63
2	2	70	0.55	
3	2	105	0.83	
1	3	59	0.47	0.60
2	3	78.9	0.63	
3	3	88	0.70	
				0.64

The results show that, as expected, flow rates decrease as distance of garden bed from tank increases. While the losses in flow rate are significant (13.0%), it is not clear that the lower flow rate will have significant negative effects upon the health of the plants in the beds furthest away from the tank. Also, the system includes valves at each bed, and such versatility allows for watering selected beds to accommodate any differences in flow rates.

Testing the final design of the irrigation system in place at el Jardin de la Esperanza using the same methodology as the tests conducted in the lab setting allows for data comparison. Averaging the flow rates for the three beds yields an overall flow rate of 0.64 GPH/ft. While this is above the necessary optimal flow rate of 0.45 GPH/ft (and could be reduced to this value by partially closing the valve at the outlet of the tank) it is not necessarily true that the optimal flow rate can be attained at every water level. Plotting the flow rate against water level in the same plot as the laboratory testing shows that the flow rate is lower than expected (see Fig. 21 below).

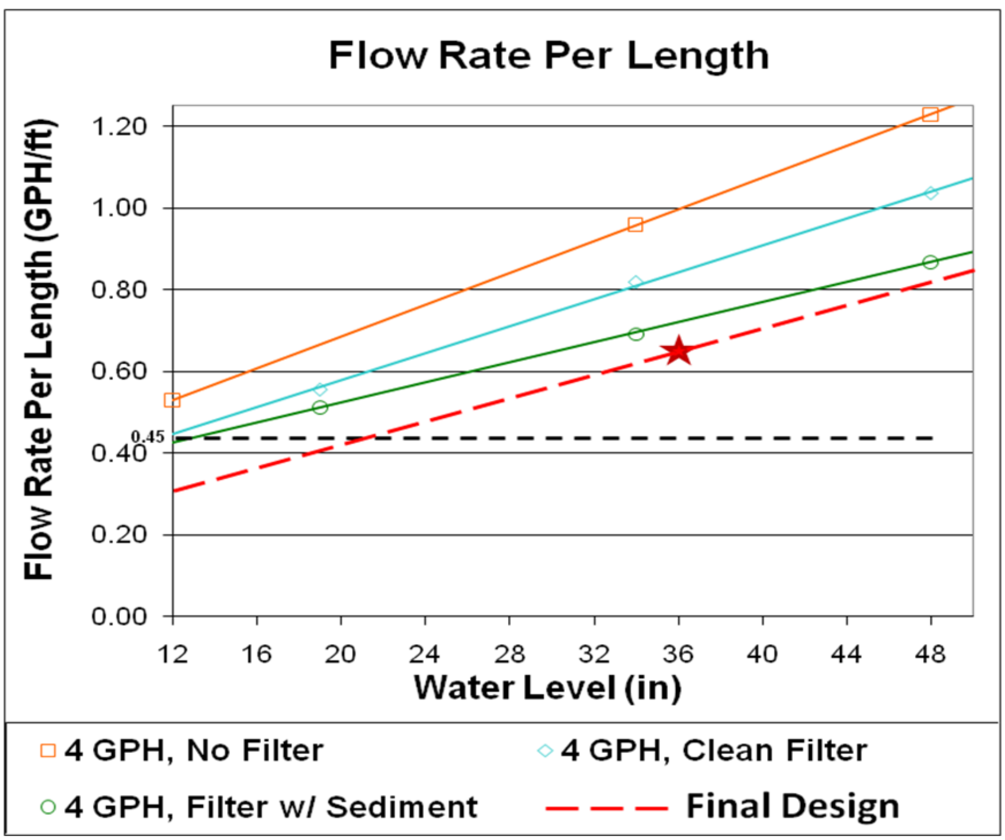


Figure 21. Comparison of final design testing with laboratory testing

To generate the expected flow rate at every water level, the slopes of the laboratory testing with a clean filter and with a partially blocked filter were averaged (this relation is substantiated by a qualitative analysis of the filter status which showed partial sedimentation, but less than experienced in laboratory testing). Then the final design data describing a flow rate of 0.64 GPH/ft was extrapolated to the entire water level range using the average slope. Such an extrapolation shows that the system will drop below the optimal flow rate for water levels less than 22". As the tank is elevated 12" above the raised beds, this means that the flow rate will be less than optimal when there is less than 10" of water in the tank. When the tank is approaching empty (water level is 12" above garden beds), the flow rate will only be 0.31 GPH/ft, or 69% of the desired flow rate.

10 Analyzing the Design

After construction was completed at JE, the next step was to analyze the design to determine how well it satisfied the original criteria and determine how successful the system operation was.

10.1 Satisfaction of Criterion

In the early stages of the design project, initial design criteria were put together. Since that time, new criteria have been added to the project, based on the specifications of the client and additional constraints encountered.

10.1.1 Budget and Location

The most obvious criteria to adhere to was the budget – beginning with $1000 from the department. Once it had been decided to undergo a construction process to build the design at full-scale, it was immediately apparent that the tank alone would consume nearly the entire budget. Fortunately, the client, Bexar Land Trust (associated with JE), offered to contribute the $800 budget they had set aside to build a system similar to the one proposed. Unfortunately, the budget was still exceeded by $29.60.

The proposed system is ideal for a small garden or greenhouse, much like the one at JE. While it took considerable time to find a location, it functioned as a perfect location to implement the system. A similar system could also easily be implemented in the home.

10.1.2 Maintenance

When selecting the tank, careful considerations were made of initial criterion such as cheap but weather-resistant tank material (including the discouragement of algae growth) and the presence of an inlet, outlet and overflow valve. To get a custom tank, Texas Metal Cisterns in San Marcos, Texas was contracted for construction. There was originally a desire to have a gauge on the tank that would show the level of the water. Presently, this feature has not been incorporated, but a compromise could be made later.

Another goal was to build or use filters with long life spans. The primary filter was constructed according to a model seen at the Montgomery County Extension Office in Conroe, Texas. In addition to the initial observations of the filter, members of the team spoke with the designer of the self-cleaning filter, Jim Bundscho. He explained the specifications necessary to make the filter work. The secondary filter was purchased to simplify construction for the team; it was also extremely difficult to find small quantities of the mesh required (US sieve size 100).

The plan was to design the system so that the gardener would only have roughly 15 minutes of maintenance per week. Once the contract with JE had been signed, it was discovered that they wanted the system to leave room for some “hands-on” maintenance from the gardeners. They preferred that the system was not self-sufficient because they had people who wanted to put time into the garden. It was decided to minimize most of the labor that would be required to set up watering at each plot (shown in Fig. 22 below). There is a main transport hose running from the tank in both directions (east and west). This hose runs underground to reduce the potential of people tripping over it. With this design for the system, the gardener can turn on the main valve at the tank, and then open or close the valves at each bed at his/her leisure.

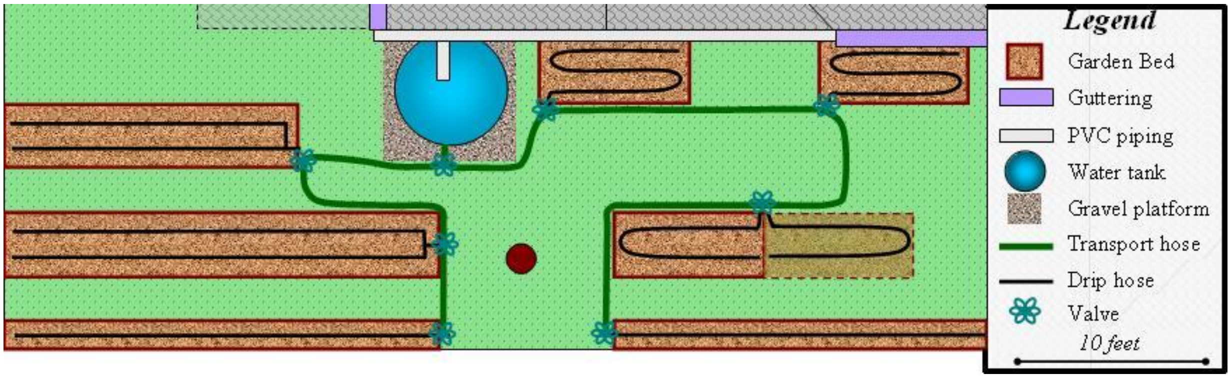


Figure 22. Layout of transport hose and valves with tank.

10.1.3 Energy Conservation and Sustainability

It was desired that this system would function without grid energy, so it could be as energy efficient as possible. Since a pump was not incorporated into the design, it was decided that gravity feed would be used to supply the garden. To go with the gravity feed, drip irrigation was chosen as the distribution method.

It was originally desired to design and build a system that could sustain itself for six weeks of drought. After calculating the water available for collection throughout the year locally, it was discovered that it would be impossible to account for a six week drought while still remaining inside the budget. The average weekly demand for the garden plot is 394 gallons, thus a full tank with a capacity of 2,400 gallons would be required to meet a six week drought. The projected 1,200 gallon tank could sustain a drought of 3.0 weeks. Thus the system is expected to meet the full water demand on a typical year in San Antonio; however, the system would have to be supplemented with city water to sustain the garden, as is, through an extended drought.

Another approach to extending the time period for which the system can sustain the garden would be to reduce the water demand. Mulching and covering beds with shade-cloth are two examples of demand-reducing measures. A final solution for extending the system's watering capacity during periods of drought should be decided in collaboration with the gardeners who will perform the irrigation.

10.2 Effectiveness of the System

After the project's completion, it was noticed during testing that there are some leaks in the transport system as mentioned previously. Again, this minor inconvenience can be fixed by simply using a waterproof sealant or caulk.

One concern is the efficiency of the primary filter, as it did not test well in the lab. A significant amount of water was running directly down the surface of the mesh, and not going through. Part of the problem during testing was that the water was poured straight down the tube onto the filter. While it was assumed the filter would perform as desired once installed in the system, it unfortunately did not. Again, some water was lost through this system and will need to be corrected in order to provide the necessary effectiveness.

Another area tested was the effectiveness of the drip irrigation system. The hoses and emitters performed very well during the prototype testing. Fortunately, they behaved in a similar fashion upon testing on location at JE. Assuming there is more than 10" of water height in the tank, the drip irrigation system will perform at a higher rate than needed. When it drops below 10" however, the emitters will not meet the minimum required flow rate of 0.45GPH/ft.

The actual collection percentage is currently a topic of discussion. For calculations, 85% efficiency was assumed to account for evaporation and the general climate of central Texas. It is highly desired that the actual number is not less than the estimated value. There is no precise way to test for this.

10.3 Problems Encountered

As stated above, few problems have been encountered during the project. There was slight concern that a permit would need to be obtained for the foundation. After doing some research on permits according to the International Building Code, it was discovered that the tank was exempt from its stipulations because the tank capacity does not exceed 5,000 gallons and the height to diameter ratio does not exceed 2:1.

The main problem encountered was with the budget. Attempting to produce a full scale construction project on a budget of $1800 proved to be very challenging, even with donations received.   Also, two receipts were misplaced and group members ended up absorbing those costs instead of coming out of the budget.

Time was another concern, as this project was implemented in a garden for daily use by a client. To date, the project is complete with a few minor adjustments that should be made; the construction process began March 1.

10.4 Maintenance and Upkeep

In order for the people at JE to maintain and keep the system within their garden, a maintenance manual will be provided should any questions or problems arise. This manual will be short, and geared towards users with non technical backgrounds. This can be found in Appendix B.

11 Conclusions and Recommendations

Although the overall project is complete, there were still problems encountered along the way that required extra time and attention. Upon testing of the final product, a few unanticipated problems surfaced as well. When testing the system as described above, some leaks were observed; first in the gutter assembly and more in the primary filter. The "S" curves connecting the gutter to the PVC transport pipe were leaking at the connection of the two bends; this was most likely due to bending of the components themselves either during transport or construction. The primary filter, which was the designated self cleaning filter, was installed with the intent of reducing maintenance. However, there was also some obvious water loss at this point in the system as well. The overall system, however, did collect the water that entered the system via the roof and transport pipes, as well as deliver water from the storage tank to the garden beds through the system of drip hoses. While the system ultimately met the goals outlined by the team earlier in the year, these minor problems obviously still have an effect.

In order for the system to operate more effectively, it is suggested that the design of the primary filter be reworked, as it appears to be faulty. This problem could have been sidestepped by more thorough testing in earlier stages of the design. While the idea of a self cleaning filter is a good

one, the design specifications received were inadequate for this project. Another option is to leave the primary filter out altogether. Going back to the alternatives section, perhaps the GutterFilter option that was examined earlier would have been a better fit for this system. It would have continued to keep the system low maintenance while filtering out the larger particles that were undesirable in the storage tank. Lastly, a simple screen filter, again of U.S sieve size 16, could have been placed in the gutter at the downspouts to prevent particulate matter from entering the stored water. However, this would require a manual sweep of the gutter after each rain event, which significantly increases the maintenance of the system.
For the “S” curves in the transport system, more care could have been used when joining pieces together as to not bend the metal. Another option would have been to use a higher quality gutter product made of a heavier weight metal, though this would add to the cost of the system. In order to remedy the system in place at JE, a clear waterproof sealant will be used to fill in the gaps created by the bent guttering.

While this project was ultimately successful, there were two other factors that proved difficult: time and money. Initially given a budget of $1000, an additional $800 was donated from JE from funds that were allocated for a similar project. By combining these resources, the budget nearly doubled. However, when implementing a full scale construction project, the initial budget proposal and final budget summary are usually not the same. Furthermore, the initial budget estimate did not account for the foundation that was later added. The group was fortunate to receive material donations from local businesses to help remedy such unexpected costs. Vulcan Materials graciously donated six tons of aggregate which was used for the foundation, and Ferguson Enterprises donated 140’ of PVC and fittings for the transport system. Without these two donations the project would have suffered greatly. For future student groups considering a full scale construction project, it is highly recommended that they seek out donations as well, and leave room in their budget for unexpected costs.

Additionally, it was difficult to keep the construction process on schedule. Each segment of construction took longer than anticipated to complete and there were problems encountered along the way which took additional time to address. There were also times when more materials were needed to complete a phase; this slowed progress considerably as construction bottlenecked while the team waited on one member to attain the additional materials. Again, for future groups who are on a schedule, not only is it wise to keep all necessary tools in the same place at the job site, it is imperative that all necessary materials are readily available to keep the project moving at a smooth pace.

Ultimately, the rainwater catchment system implemented at JE was a successful design. After testing of the system was complete, the observations made allowed for the above recommendations to be made. These solutions can be corrected for future work. However, the system caught water, transported it to an onsite storage facility, filtered out particulate matter, and delivered the water to a garden plot as outlined in the preliminary problem statement.

12 References

1. The Texas Manual on Rainwater Harvesting, 3rd Edition. Texas Water Development Board. http://www.twdb.state.tx.us/publications/reports/RainwaterHarvestingManual_3rdedition.pdf.

2. The Agriculture Program of the Texas A&M University System. http://aggie-horticulture.tamu.edu/extension/homelandscape/water/water.html

3. Weather Underground. 2008. http://www.wunderground.com

APPENDICES

A Drip Irrigation Testing Data

Table A-1. Drip Irrigation Testing, Flow Rates for 1GPH Emitters

Emitter Size	Hose Length	Hose Number	Water Level	1st Emitter Flow Rate	Middle Emitter Flow Rate	Last Emitter Flow Rate	Average Emitter Flow Rate	Flow Rate per Length
GPH	ft		in	mL/min	mL/min	mL/min	GPH	GPH/ft
1	10	1	12	24	23	25	0.38	0.19
1	10	1	34	33	34	35	0.54	0.27
1	10	1	48	39	42	40	0.64	0.32
1	10	2	12	28	23	19.5	0.37	0.19
1	10	2	34	35	37	33	0.55	0.28
1	10	2	48	42	45	41	0.68	0.34
1	10	3	12	27	28.66	22.5	0.41	0.21
1	10	3	34	38	35.5	35	0.57	0.29
1	10	3	48	42.17	42.8	43	0.68	0.34
1	20	1	12	18	28	36	0.43	0.22
1	20	1	34	34	35	42	0.59	0.29
1	20	1	48	40	44	50	0.71	0.35
1	20	2	12	19	24	25	0.36	0.18
1	20	2	34	33.5	35	37	0.56	0.28
1	20	2	48	38	42	42	0.64	0.32
1	20	3	12	19	22	24.7	0.35	0.17
1	20	3	34	32.7	33.3	35.3	0.54	0.27
1	20	3	48	35.7	39.7	39.3	0.61	0.30
1	30	1	12	25	31	27	0.44	0.22
1	30	1	34	45	34	38	0.62	0.31
1	30	1	48	48	41	44	0.70	0.35
1	30	2	12	25	20	23	0.36	0.18
1	30	2	34	37.5	33	38.5	0.58	0.29
1	30	2	48	42	39	46.5	0.67	0.34
1	30	3	12	27.7	24.7	19.3	0.38	0.19
1	30	3	34	36	32	32	0.53	0.26
1	30	3	48	41.3	40	43.3	0.66	0.33

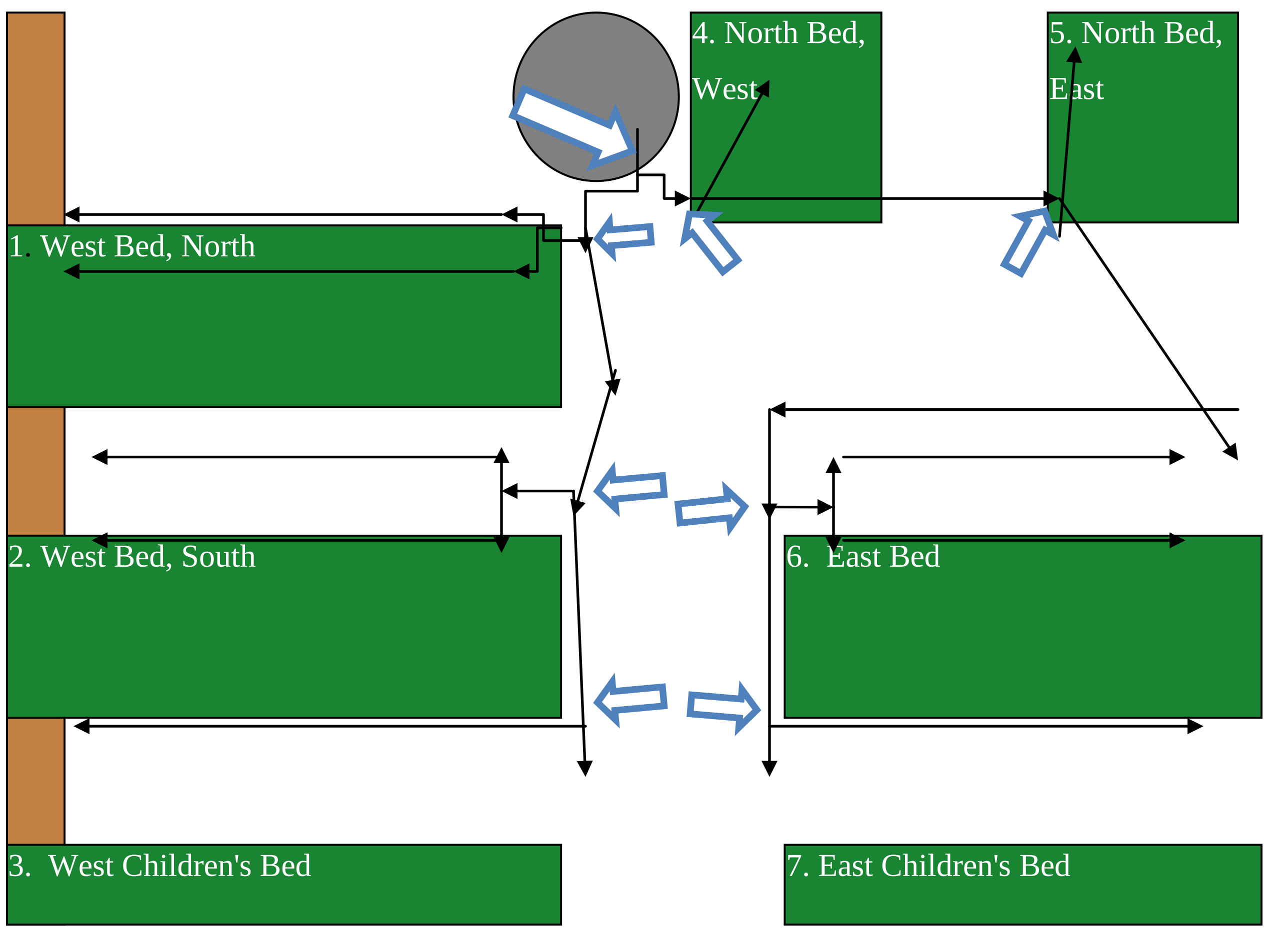
Table A-2. Drip Irrigation Testing, Flow Rates for 4GPH Emitters

Emitter Size	Hose Length	Hose Number	Water Level	1st Emitter Flow rate	Middle Emitter Flow rate	Last Emitter Flow rate	Avg Emitter flow rate	Flow rate per Length
GPH	ft		in	mL/min	mL/min	mL/min	GPH	GPH/ft
4	10	1	12	74	84	88	1.30	0.65
4	10	1	34	129	148	149	2.25	1.13
4	10	1	48	159	186	185	2.80	1.40
4	10	2	12	71	80.5	85	1.25	0.62
4	10	2	34	114	145	143	2.12	1.06
4	10	2	48	163.5	177	171	2.70	1.35
4	10	3	12	65.7	73.3	67.3	1.09	0.55
4	10	3	34	113.5	122.2	120	1.88	0.94
4	10	3	48	171.3	176.5	174.7	2.76	1.38
4	20	1	12	76	74	62	1.12	0.56
4	20	1	34	137	146	134	2.20	1.10
4	20	1	48	166	154	170	2.59	1.29
4	20	2	12	53	59	55	0.88	0.44
4	20	2	34	122	140	123	2.03	1.02
4	20	2	48	148	163	154	2.46	1.23
4	20	3	12	55.3	61.3	58.7	0.93	0.46
4	20	3	34	84	93.3	85	1.39	0.69
4	20	3	48	142	148	160	2.38	1.19
4	30	1	12	67	67	65	1.05	0.53
4	30	1	34	92	96	82	1.43	0.71
4	30	1	48	101	105	100	1.62	0.81
4	30	2	12	67	63	53	0.97	0.48
4	30	2	34	125	117	121	1.92	0.96
4	30	2	48	147	163	153	2.45	1.22
4	30	3	12	57.3	54	52.7	0.87	0.43
4	30	3	34	125.3	118.7	116.7	1.91	0.95
4	30	3	48	138	138	136	2.18	1.09

B   Maintenance Manual

In order to proceed from here, now that the installation of the system is complete, JE will receive the following maintenance manual. It will be bound and laminated to prevent it from being damaged by water. It is important that they receive this information because they will inevitably have questions and concerns.

User Guide for the rainwater catchment system at el Jardin de la Esperanza



The system is equiped with an on/off valve at each of the beds and at the outlet of the tank (the Blue Arrows point to their locations). A few pieces of helpful information before using the system:

When the switch on a valve is **parallel** (in line) with the hose, that section is on.

When the switch on a valve is **perpendicular** to the hose, that section is off.

Each of the blue arrows in the picture above is pointing at a Y-shaped, yellow valve.

For watering any or all of BEDS 1, 2, and 3, turn off both valves at BED #4

To water BED #1 only:

- Turn the on the valve flowing into bed #1 and turn off the other valve.
- Turn on the valve located at the base of the tank.

To water BED #2 only:

- Go to the BED #1 valve.
- Turn off the valve going into bed #1
- Turn on the other valve.
- Go to BED #2
- Turn on the valve going into bed #2
- Turn off the other valve.
- Turn on the valve located at the base of the tank.

To water BED #3 only:

- Go to the BED #1 valve.
- Turn off the valve going into bed #1
- Turn on the other valve.
- Go to BED #2
- Turn off the valve going into bed #2
- Turn on the other valve
- Turn on the valve located at the base of the tank.

To water BEDS #1 & #2 only.

- Go to BED #1
- Turn on both valves
- Go to BED #2
- Turn on the valve going into BED #2
- Turn off the other valve.
- Turn on valve located at the base of the tank.

To water BEDS #1 & #3 only

- Go to BED #1
- Turn on both valves
- Go to BED #2
- Turn off the valve going into BED #2
- Turn on the other valve
- Go to BED #3
- Turn on the valve (this valve is not a Y-shaped. It only have one outlet)
- Turn on the valve located at the base of the tank.

To water BEDS #2 & #3 only

- Go to BED #1
- Turn off valve going into BED #1
- Turn on the other valve

- Go to BED #2
- Turn on both valves
- Go to BED #3
- Turn on valve (this valve is not a Y-shaped. It only has one outlet)

To water any or all of BEDS #4, #5, #6, or #7:

For this section, make sure the valve located at the bottom of the Black filter is turned off for the section heading towards BED #1.

To water BEDS 4, 5, 6, & 7:

- Turn on all valves on each bed.

To water BEDS 4, 5, & 6:

- Go to BED #4
- Turn on both valves
- Go to BED #5
- Turn on both valves
- Go to BED #6
- Turn on valve going into BED #6
- Turn off the other

To water BEDS 5, 6, & 7:

- Go to BED #4
- Turn off valve going into BED #4
- Turn on the other
- Turn on all the valves for the remaining beds.

To water BEDS 6 & 7:

- Go to BED #4
- Turn off valve going into BED #4
- Turn on the other
- Go to BED #5
- Turn off the valve going into BED #5
- Turn on the other
- Turn on the remaining valves

After using the system a few times, you will become more accustomed to how to modify the water flow to water which ever beds you would like.

Maintenance

The system is relatively maintenance free. The filter connecting the roof to the tank should be swept off after each rain event, but it is truly designed to clean itself. **All you need to do is remove large leaves or other things that might be clogging the large filter** (don't worry, just brush the stuff off with your hand).

The only other thing you will need to do every third time you use the system is flush the black filter that is strapped to the side of the tank's foundation. All you need to do for this is turn on the valve coming out of the tank, and then unscrew the black cap located on the bottom of the filter. This will flush out all the dirt and small particles out of the filter and essentially clean it. After 30 seconds or so of flow, just turn off the valve from the bottom of the tank and then screw the black cap back into place. Then your system is ready for use.

Additionally, inspect your system every few weeks to ensure there are no leaks, cracks, or other potential problems. Check to make sure the gutters and piping are still securely attached to the building. Also, observe the drip irrigation system while in use to make sure that no emitter heads are clogged; these can be changed out easily by simply pulling the emitter head out of the hose and replacing it with a new one, or cleaned with higher water pressures.

C Final Budget

Final Budget Summary

Income		Expenses			
Supplier	**Amount**	**Cost**	**Purchaser**	**Vendor**	**Reimbursed**
Trinity Univeristy	$1,000	$800.00	Libby	Texas Metal Cisterns	
Bexar Land Trust	$800	$164.15	Alex	Home Depot	No
Ferguson Enterprises	$272.32	$17.50	Tyler	Longhorn Irrigation	
Vulcan Materials	$159	$20.02	Tyler	Longhorn Irrigation	
		$13.76	Philip	Truevalue	No
Total Working Budget	$2,231.32	$267.86	Alex	Home Depot	
		$28.00	Tyler	Home Depot	
		$45.00	Libby	Home Depot	No
		$11.38	Alex	Home Depot	
		$20.03	Tyler	Truevalue	
		$28.00	Tyler	Fergusons	
		$55.00	Dario	Home Depot	
		$162.66	Philip	Home Depot	
		$70.29	Philip	Home Depot	
		$60.27	Philip	Truevalue	
		$35.43	Libby	Home Depot	No
		$13.25	Philip	Home Depot	No
		$17.00	Dario	Truevalue	No
		$272.32	Libby	Fergusons	
		$159.00	Libby	Vulcan Materials	
		$2,260.92		**Total Purchases**	

Total Budget	Budget Remaining
$2,231.32	($29.60)

D Bill of Materials

Date	Item(s)	Cost	Vendor
Dec-07	Tank - funded by Time Dollar's grant through Bexar Land Trust	$800.00	Texas Metal Cisterns
21-Jan	Valve, 2 PVC caps, fitting, 2 poly tubes, 3 drip hose endcaps, two tees, two 1/2" adapters, 9 drip packages (1 GPH), 9 drip packages (4 GPH), PVC primer, two nut/washer sets, washer, clamp, PVC cement, 1/8" rivet pack, 3/16" rivet pack, 3"x2' PVC, 200' drip hose	$164.15	Home Depot
23-Jan	PVC reducing 6" x 4" SDR35 fittings	$17.50	Longhorn Irrigation
12-Feb	In-line sieve filter	$20.02	Longhorn Irrigation
16-Feb	Two sets of 3 fittings (1" pipe to 3/4" pipe, 3/4" nipple, & 3/4" pipe to 3/4" hose) to connect 1/2" drip hose to in-line sieve filter	$13.76	Truevalue
28-Feb	Guttering for 72' of roof line (gutters, joints, downspouts, hangers, endcaps, sealant), screws, drill bits, hack saw blade	$267.86	Home Depot
29-Feb	Two rental step ladders, 8'	$28.00	Home Depot
29-Feb	Chain and lock for tank -- **RECEIPT NOT SUBMITTED**	$45.00	Home Depot
1-Mar	Additional gutter stuff (joints, hangers)	$11.38	Home Depot
7-Mar	PVC piping and fittings: foam core, 140' of 3" and 40' of 4", 18 fittings These items were donated, free of cost, by Fergusons	$0.00	Fergusons
8-Mar	Metal strapping to hang PVC, 4 rolls of 10'	$20.03	Truevalue
	PVC piping, 10' of 6" SDR35 -- **RECEIPT MISPLACED (not turned in)**	$28.00	Fergusons
	Wood, brackets **-- RECEIPT MISPLACED (not turned in)**	$55.00	Home Depot
3-Apr	Wood, rebar, wire mesh, cinder blocks, cement, splash guards, plastic cover	$162.66	Home Depot
4-Apr	75' Garden hose, drip emitters, hose stakes, drip hose ends and couplings to garden hose, drip tee and couplings, PVC bushings and adapters for filter	$70.29	Home Depot
4-Apr	Female hose menders, male hose menders, 2 way connections, shut off valves, male to male garden hose connector	$60.27	Truevalue
17-Apr	Four 4" PVC elbows, caulk, garden hose staples	$35.43	Home Depot
19-Apr	2 hose fittings, brass splitter valve	$13.25	Home Depot
19-Apr	PVC reducers, hose clamps, hose enders	$17.00	Truevalue