The City College Of New York

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Water Conservation in Single Family Homes

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Table of Contents

List of Figures

1 Abstract

Water protection has been challenged internationally, regionally, and locally due to rapid urbanization, population explosion, and climate change. Although there are several approaches to solving these issues, one of the most groundbreaking is Sustainable Urban Drainage Systems (SUDS), which involves rainwater harvesting systems (RWHS). RWHS is a very useful method for the collection of rainwater for human consumption which typically involves structures with water tanks, pumps, and purification systems for clean water. Owners and residents of residential buildings can be benefited from this method. Since are different approaches for RWHS, a rooftop harvesting system (RHS) is currently more widely used since it simply uses the roof to capture rainwater to store in reservoirs. As a result, the architecture, and components of a typical RHS are reviewed in this paper. The output of RHS with various capacities in terms of quantity and quality of accumulated rainwater and power usage and the opportunities and challenges in terms of environmental, financial, and social factors are also studied.

2 Introduction

Since water is essential to human life and progress, *water security* can be defined as safeguarding human societies from the detrimental effects of water shortages and excess. Climate change has influenced the supply of freshwater and groundwater in recent years, posing a threat to water security. Rainfall frequency and intensity are changing as an outcome of climate change, resulting in a shift in the balance between dry and wet seasons. Changes in the balance between wet and dry seasons have resulted in water shortages during the prolonged dry season and enhanced flood risk due to increasing rainfall intensity, posing concerns for numerous industries such as agriculture, forestry, and energy. As a result, to address these issues, effective rainwater management has emerged as one of the main drivers for achieving the Sustainable Development Goals and improving climate resilience (as a response to climate change). Effective rainwater harvesting also results in enhanced ecological systems that incorporate natural infrastructure management, rehabilitation, and sustainability to ensure water supply and long-term management.

The Roof Harvesting System (RHS) is more well-known and has been used in Spain, Italy, and Malaysia, among other places (Chang, Goh, Zabidi, Zakaria, 2020). Rainwater collected from the RHS is often used to meet non-potable and potable water needs. For an RHS, there are two types of control tanks: aboveground and subsurface storage. The figures below show both types of RHS.

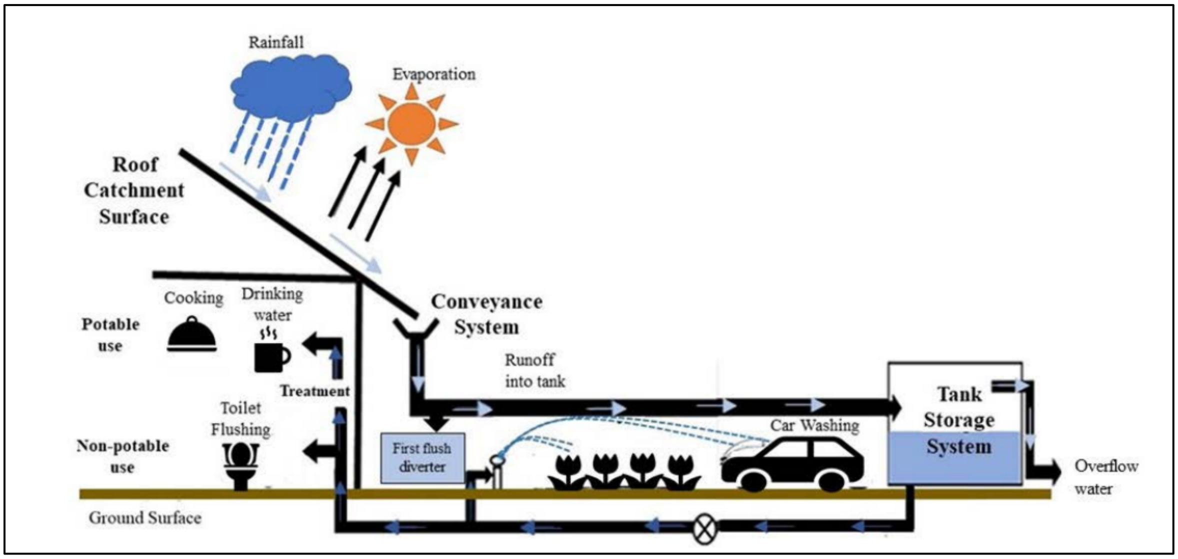

Figure 1: Design of a roof harvesting system aboveground

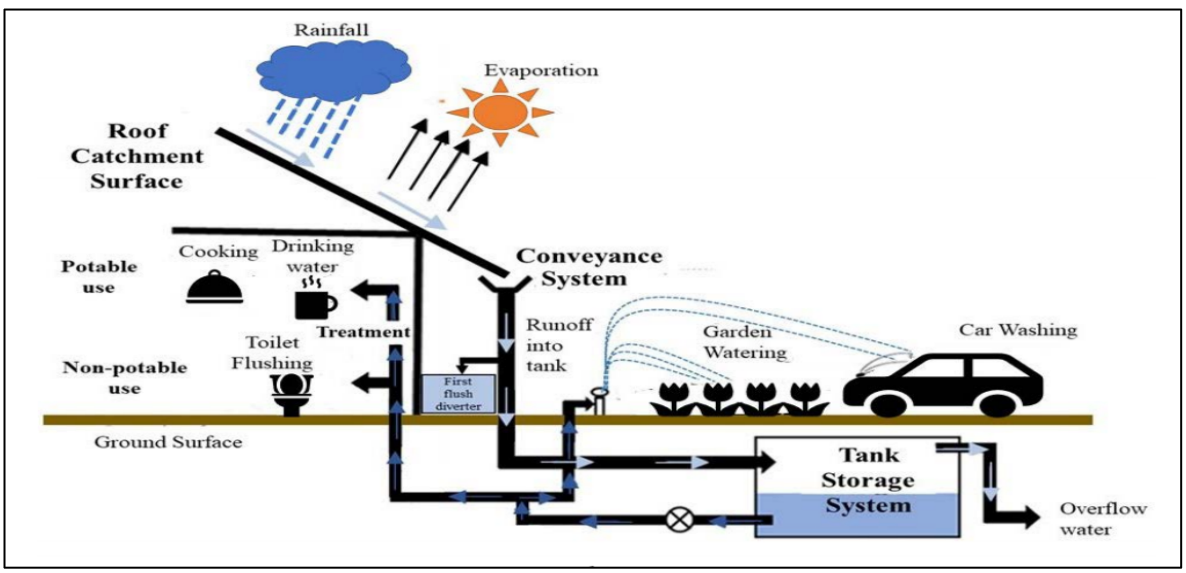

Figure 2: Design of a roof harvesting system underground

As seen in both figures, both systems have the same components, but the storage tank is in different locations. These systems are very beneficial to many home uses such as washing, cooking, gardening, etc. Since this project focuses mainly on rainwater conservation, the RHS is an excellent method to implement as explained earlier. A more extensive design will be discussed more with its relevant details later in this report.

3 Objective

The primary purpose of this project is to review and analyze the best way to mitigate the use of city water in a traditional family house. Based on multiple chosen houses, designs of systems that allow family members and other current residents consume water directly from the rain will be proposed. In other words, the design should make the house less dependent on water brought from the drinking water utility per year.

4 Location Information

In this section, three different locations are chosen and discussed for the purpose of the project. There will be a primarily, secondary, and a tertiary location where New York, Ecuador, and Texas will be used respectively. More details will be discussed in the following section of this report.

4.1 Primarily Location (Port Washington)

For this project, a house located in Long Island, particularly in Port Washington, was chosen. The figure below displays the location of the house. The address of this house is 2 Spitler Pl. It is a one-story house with a garage attached to the house and a front and a backyard with a total of 92 m^2. It is estimated that this house was built around 1960. Since the house was built during the early '60s, it has three small bedrooms, one kitchen (with one dishwasher), a living room, one complete bathroom, and a basement. This house's interior characteristics are plaster walls/wood paneling, steel pipes for incoming water supply and cast-iron drainpipes, slab-on-grade foundation, the roof of medium slope (40 deg) with gutter attached, brick exterior walls, along with wood shingle siding. The number of habitats is 4.

In this location, the road is private, meaning that the town does not make any repairs if needed. The owners of the houses that belong on Spitler Pl never decided to change a dirt/gravel road to one with concrete. Therefore, it will be challenging to deal with the road water runoff since most of the water will infiltrate in the dirt. Only the roof will be helpful in this project since nothing intervenes the water from landing on the house's roof.

Figure 3: Aerial View of selected house in New York

Figure 4: House at 2 Spitler Pl

Due to this location's landscape and the piping system underground, the RHS with the tank above the surface will be implemented for more convenience. The best location for the rainwater harvesting system can be done inside the garage since it is mainly used for storage and not for vehicle parking.

4.2 Secondary Location (Cuenca)

Another location that will be used for this project is in Cuenca, Ecuador (South America). The purpose of having a separate location is to investigate the effect of moderate environmental changes on rainfall. Typically, in Ecuador, rainfall occurs very often. This indicates that the RHS will potentially be more efficient in residential buildings.

The chosen location is at 177 Buganvilla St, Cuenca as seen in the figures below. It shares similar characteristics as the primary location such as the steepness of the roof. This location is a three-story house with only one small front yard of roughly 60 m^2. The house has a total of three bathrooms. Two complete bathrooms are located on the second floor and one small bathroom on the first floor. Lastly, a kitchen is on the first floor as well. Similarly, to location one, it uses steel pipes for incoming water supply. In addition, the total number of residents is three.

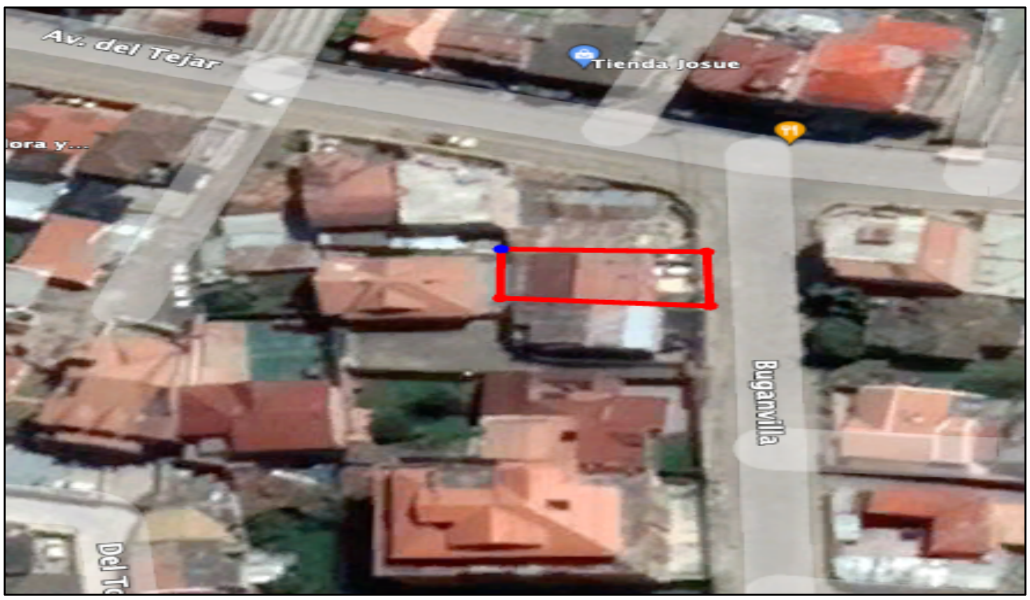

Figure 5: Aerial View of Secondary Location (Ecuador)

Figure 6: House at 177 Buganvilla St

4.3 Tertiary Location (Texas)

Since it has already been mentioned a location that has a changing climate throughout the year, and another that has a consistent climate, it would now be interesting to analyze a third location that only deals with a hot climate which involves a lot less rain than the other two previous locations. For the purpose of this project, a random house in Travis County, Austin, Texas has been chosen.

The following single-story house can be found at 3609 Cookstown Dr, Austin, Texas. This house is very similar structurally to location one (Port Washington). However, this third location has 2 full bathrooms, two garages, and four bedrooms with a total of 1396 ft^2 (130 m^2). For simplicity, some assumptions will be made for this particular area such as the angle of the roof and the total number of residents which will be used in the next section of this report.

Figure 7: Aerial View of Third Location (Texas)

Figure 8: House at 3609 Cookstown Dr

4.1 House Water Consumption Analysis

In this section, a description of all type of water uses will be mentioned along with a total price and amount of water that each utility and each member of the house would typically consume.

4.1.1 Water Use in Port Washington

An important thing to know is how much city water the family consumes monthly and how much money is spent. The fastest way to obtain this data is by simply looking at the water consumption bills. In this case, the bill comes from the Port Washington Water District. The bill is being counted for 97 days (3 months of meter readings). An example of how much water is being consumed in this household during the months of January, February, and March for the current year 2021, the total amount was 31,500 gallons (4,210 ft^3). The volume is relatively high since four people are living in the house. To know the daily consumption, simply divide 4,210 ft^3 by the number of meter reading days (97 days). For this billing period it was determined that 43 ft^3 (267 gallons) was consumed daily (based on different charges). Since there are different charges that range from $0.10 to $0.50, the total charges for this period were $1.04. The total daily charge is being multiplied by the total number of reading days (97 days); $100 is obtained, which would be $33.33/month.

In the summer months, where the water is being consumed more frequently, the bill had values of 72 ft^3 (538 gallons) consumed per day and a total amount to pay of $148 for July, August, and September or $50/month. All these values are counted for the use of cooking, showering, and landscaping.

Another thing that must be known is how much water these utilities use. For example, in the bathroom area, the most common utility used is the toilet and the bathroom sink. It can be estimated that 1.6 gallons of water is used per flush in the toilet. If assumed that the toilet is being flushed 20 times a day, the total consumption of water is 32 gallons. Now, consider the bathroom sink, which is used to brush teeth, after using the toilet or to simply wash face and hands at random times of the day. It can also be estimated that 2.2 gallons of water are being used per minute when the faucet is fully open. Assuming that each resident in this house uses the bathroom faucet for 10 minutes throughout the whole day, 22 gallons are used for one single person in a day. The total for the four people is 88 gallons/day using the bathroom sink. The total bathroom consumption will be 120 gallons/day (30 gallons per person), excluding the shower due to the project's complexity since a simple, fast, and economical design is wanted.

Another prominent place where the water is consumed is in the kitchen. On average, the kitchen faucet can use anywhere between 1-3 gallons per minute. Of course, these values can depend on factors such as the available water pressure and the age of the pipes used. Although not every family member uses the sink, the water consumption can be equivalent to the number of gallons used one in the bathroom sink. Washing dishes, fruits, vegetables, and other tasks can take up to 20 gallons per day.

Lastly, landscaping requires a lot of water. This is usually done during the weekends. Since the family uses a typical water hose, the average flow rate is 9 to 17 gallons/min. Assuming again the actual flow of the current hose used, 15 gallons/min are into play. Typically, the hose is only used from April-October (7 months) for 30 minutes. So, 15 gal / min *15 min = 225 gallons total for landscaping in a day.

In general, the overall total daily consumption of water by the four-member family is roughly 365 gallons/day including while going landscaping. These calculations will reflect on the design of the RHS explained later in the report.

4.1.2 Water Use in Cuenca

Follow the same logic for the house in Cuenca. However, some assumptions must be for some calculations due to the lack of information that cannot be gathered. To start, most people in the city usually pay less than $10/month for water consumption. In this household during the months of January through June for the current year 2021, the total amount was 81m^3 (21397 gallons) with a monthly consumption average of 14 m^3 (3698 gallons). For this billing period of one month, it was determined that 0.33 m^3 (87 gallons) was consumed daily. Since there is only one fixed charge for water consumption of $0.416/m^3, the total charge for a month can range from $5 to $10.

In the summer months of July, August, and September, where the water is being consumed more frequently, the monthly bills had values of 16^3, 17 m^3, and 20 m^3 respectively (14001 gallons total) with a total of $19 for these three months ($6/month). All these values are counted for the use of cooking, showering, and landscaping. Meanwhile the rest of the year is very similar to the values of January through June.

The same logic can be followed of how much utilities consume as mentioned in the primarily location (excluding shower time). It can be estimated that 1.6 gallons of water is used per flush in the toilet. If assumed that the toilet is being flushed 15 times a day, the total consumption of water is 15 gallons. Similarly for the bathroom sink, it can also be estimated that 2.2 gallons of water are being used per minute when the faucet is fully open. If each resident in this house uses the bathroom faucet for 10 minutes throughout the whole day, 22 gallons are used for one single person in a day. The total for the three people is 66 gallons/day using the bathroom sink. The total bathroom consumption for the whole family will be 81 gallons/day or 27 gallons/person. For the kitchen water consumption, use the same value of 20 gallons/d

Lastly, landscaping requires some water but not as much as the primarily location since the house in Cuenca has a very small front yard of roughly 20 m^2 (225 ft^2). This is usually done during the weekends. Since the family uses a typical water hose, the average flow rate is 9 to 17 gallons/min. Assuming again the actual flow of the current hose used, say that 15 gallons/min are into play for 8 minutes. So, 15gal / min *8 min = 120 gallons total for landscaping in a day.

In general, the overall total daily consumption of water by the three-member family is roughly 221 gallons/day during a weekend or while wetting the front yard.

4.1.3 Water Use in Austin

For the house located in Travis County, the bill comes from Travis County Water Control District 17. The bill is being counted for 31 days. For this particular house, it will be assumed that the number of people living there is 3. Water consumed in the summer and spring months (April-September), where the water is being consumed more frequently, the bill had values of 1043 ft^3 (6500 gallons) consumed per month giving a daily average consumption of 210 gallons with an average cost of $1.40/day and a total amount to pay of $43 for a typical spring/summer month. All these values are counted for the use of cooking, showering, landscaping (mainly) and other fees such as customer, tiered fixed charge (charged by volume for every 1000 gal) and other services that can range from $1 to $8 a month.

During the months of October through March are surprisingly low with an average consumption of 2000 gallons (321 ft^3) a month, giving an estimated total of 13,000 gallons (2,087 ft^3) for the winter and fall seasons. The volume is relatively lower than the New York location since three people are living in the house. To know the daily consumption, simply divide 321 ft^3 by the number of meter reading days (31 days). For this billing period it was determined that 10.35 ft^3 (64.5 gallons) was consumed daily (based on different charges). Since there are different charges that range from $1 to $8, the total charges for a monthly period during one of the fall/winter seasons can be up to $35/month.

Following the same procedure as location one, the total consumption for three people using the bathroom sink only is 66 gallons/day which would add to the overall bathroom usage with 81 gallons/day for the whole family excluding the shower due to the project's complexity. Similarly, use the same values for the kitchen with 20 gallons/day. Lastly, landscaping is also assumed to be 300 gallons for a typical day (when needed). In general, the overall total daily consumption of water by the three-member family is roughly 401 gallons/day for a sunny day to water the front and backyard.

5 Design Approach

In this section, data gathered from multiple sources such as NOAA, USGS and a third-party site were used to analyze rainfall. With the help of these sources, it will be possible to estimate how much water is needed to come up with the RHS design which will be discussed later in this report.

5.1 Rainwater Analysis Based on Chosen Locations

Since not all locations are near each other, there will be differences in weather, which indicates a potential change in rainfall for all of them. First, it is needed to know how much precipitation and/or snow there is to see how much water can be obtained for an efficient design. Below, a more detailed analysis is explained.

5.1.1 Rainwater in Port Washington

In order to start with the design, it is required to know how much rain Port Washington gets. According to the USGS, the average number of rainy days is 116 days. It has an average total annual rainfall of 47 inches (1190 mm). Since it is complicated to predict how many inches of rain a rainy day will provide, some assumptions need to be made. The following figure shows data from NOAA containing daily rainfall in Port Washington from each day starting from January 1, 2020, until December 31, 2020. During this timeframe, it can be noted that rain in this area is somewhat consistent. However, the months with the least heavy rain seem to be January, February, April, May, and October with no more than 0.6 inches (12.7 mm) of rain. Meanwhile the rest of the year mostly go beyond 0.9 inches (22.86 mm) of rain.

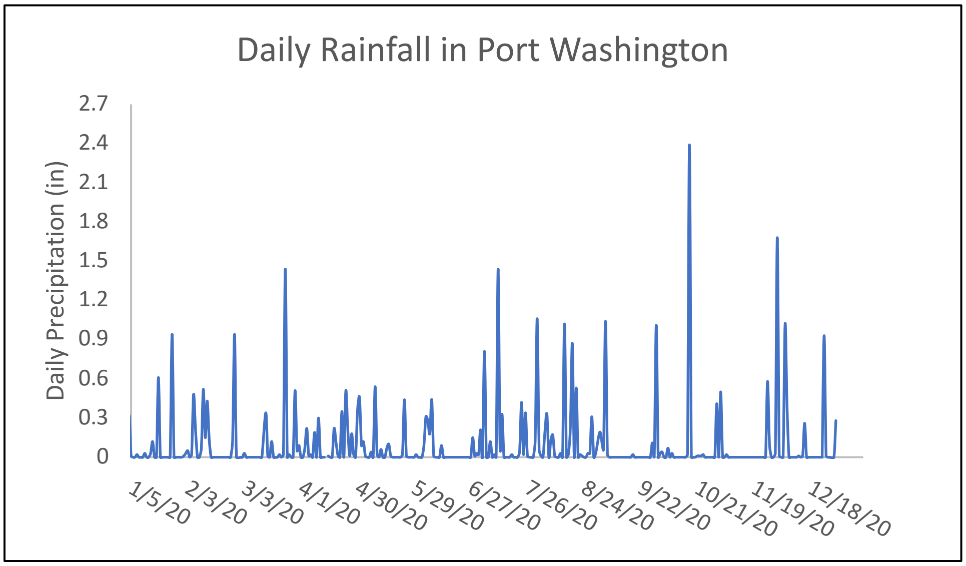

Figure 9: NOAA data on total rainfall in Port Washington (2020)

Throughout the year, the sensor has detected a total of 35 inches (889 mm) of rain which escalates at a consistent rate as time goes as seen on the figure below.

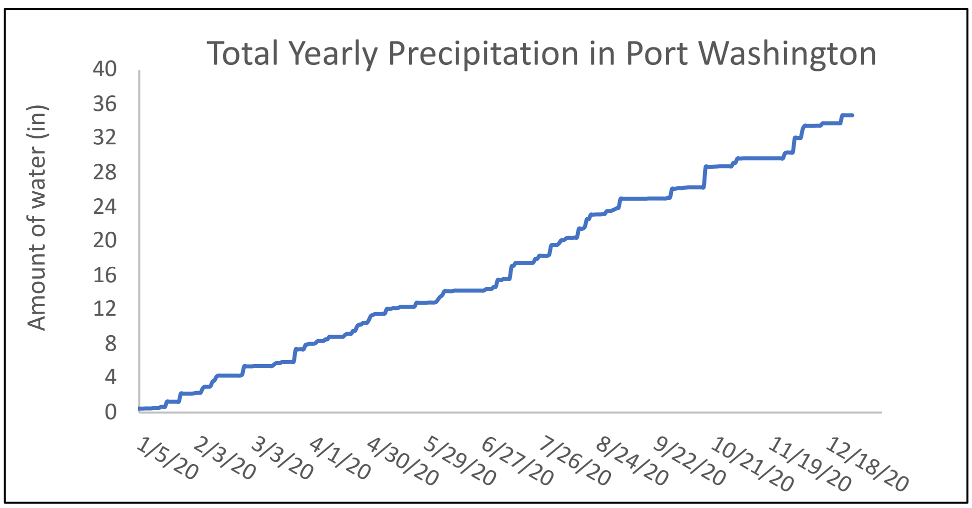

Figure 10: Total Precipitation amount in Port Washington (2020)

The duration of rain must be known to understand better how much rain can be collected. However, the periods can be unpredictable. Therefore, another assumption must be made: the time that the rain takes from start to end. It can be said that most rains occur for one hour, and since it is known that the annual average rate is 47 in/yr (1190 mm/yr) with 117 days of rain, it can be estimated 0.40 in/d (10.1 mm/d) during that one hour. Another assumption can be made that in worst-case scenarios such as tropical storms, the total amount can be up to 7 inches (170 mm) of rain.

On the other hand, snow should also be considered. In Port Washington, the total annual average snowfall is 24 inches (600 mm). Based on the "rule-of-thumb," 10 inches (254 mm) of snow can potentially give up to 1 inch (25 mm) in water. Of course, this can always change because the snow will depend on characteristics involving texture and weight.

Some small calculations need to be made to get an estimate of how much water the house can collect from rainfall. To figure out the size of the water tank, the rainfall collected in the rainwater harvesting system would need to be stored; it is crucial to know how large the roof is. It is also known that the majority of rain events are 1 inch or less.

First, measure the length and the width of the roof but check where the downspouts are to find what part of the roof drains to each downspout when there is more than one downspout. For example, if the roof is pitched in 2 directions and only the downspout on one side can be used, then just measure the part of the roof that drains to the downspout that will be used. In this case, use both sides.

Second, some further analysis needs to be made such us how much water can the residents actually benefit from the roof. The RHS is expected to collect about 75% of the actual rainfall to account for losses and inefficiency, so; all the annual values should be multiplied by 0.75 to get a new total precipitation value. In the case of the year 2020 where the total precipitation was 35 in (889 mm), it now will go down to 26.25 in (666 mm). This new value will be 26.25 in x 1 ft^2 per year of water that one square foot area which can support relying entirely on precipitation. To make things simple, assume that the accumulated water use in this household is roughly 0.072 in/d (1.8288 mm/d) which will be an equal amount at the end of the year to the new accumulated rain amount. This is helpful because it demonstrates how much water is being used and how much could potentially be stored. In the figure below, the water consumption is slightly higher than the collected rainwater. On the other hand, the third curve indicates the reservoir storage which will depend on the days that rain. For instance, the peak reservoir storage will be during mid-July to mid-August because there were rainy days that happened more frequently with more heavy rain and house consumption is lower than the collected rain.

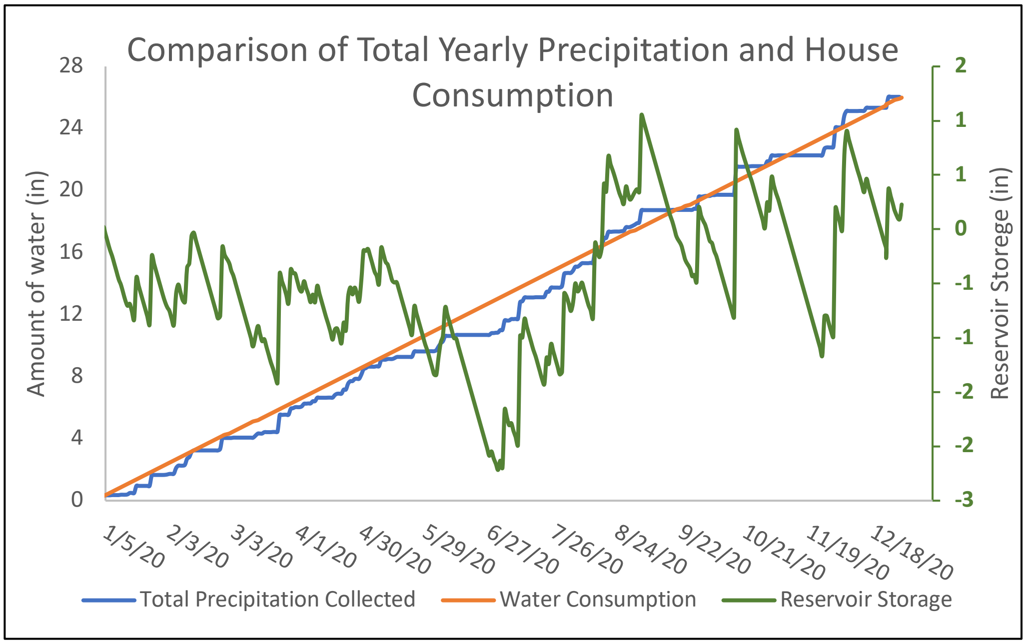

Figure 11: Yearly Water Collection, usage, and Storage in Port Washington

Considering that 7.48 US gallons is equal to 1 ft^3 from 1 ft^2 roof surface, 17 US gallons of rainwater can potentially get collected. Since in the previous sections of this report discussed about house water consumption, the primarily location had an estimated value of 30 gal/person for bathroom use, this is 120 gallons for the whole family per day which translates to 43800 gallons per year. With this value, and the known yearly collected amount from roof surface, the needed square footage can be obtained by dividing both giving a total of 2576 ft^2 (239 m^2). However, the surface area to satisfy the water needs is 1.7 times smaller than the desired roofing area. The length of the actual roof is 52 ft (15 m), and the width is 29 ft (8.8 m) giving a total area of 1508 ft^2 (140 m^2).

Lastly, looking at the reservoir storage in this case, the proper capacity is up to 1 inch. Because 26.25 in is the overall rainfall, 3.80% (1 in/26.25 in) of the annual effective precipitation should be collected if the residential building were to have 2576 ft^2 of roof surface. Then, the 3.80% of the collected rainwater gives 1664.4 gallons. This volume is crucial for our tank decision because this is what the household would need at least to collect the desired rainwater amount which will be discussed in the structural composition portion of this report.

5.1.2 Rainwater in Cuenca

In this area in the World, rainfall can happen very often or sometimes very rarely. In Cuenca, a wet day is one with at least 0.04 inches (1 mm) of liquid or liquid-equivalent precipitation. The chance of wet days in Cuenca varies significantly throughout the year. The wetter season lasts 3.9 months, from January 16 to May 12, with a greater than 34% chance of a given day being a wet day according to Weather Spark. The month with the most wet days in Cuenca is March, with an average of 16.5 days with at least 0.04 inches (1 mm) of precipitation. The drier season lasts 8.1 months, from May 12 to June 16 as seen on the figure below with data from NOAA. The month with the fewest wet days in Cuenca is August, with an average of 4.2 days with at least 0.04 inches (1 mm) of precipitation. Among wet days, distinguish between those that experience rain alone. Overall, an average annual rainfall in Cuenca is estimated to be 64 inches (1620 mm) according to Weather Spark. This would exclude tropical storms and snow days because the city has never experienced any of these environmental phenomena. However, during the year 2020, Cuenca seemed to experience a drier period than usual since the total amount of rainfall was roughly 20 inches (508 mm).

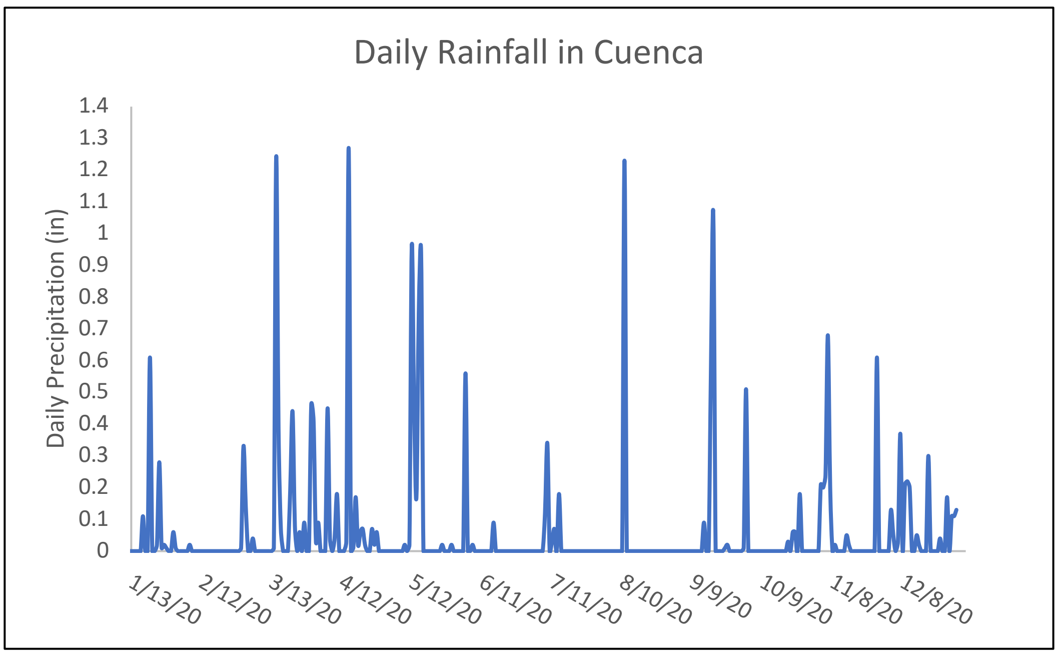

Figure 12: Daily Rainfall in Cuenca (2020)

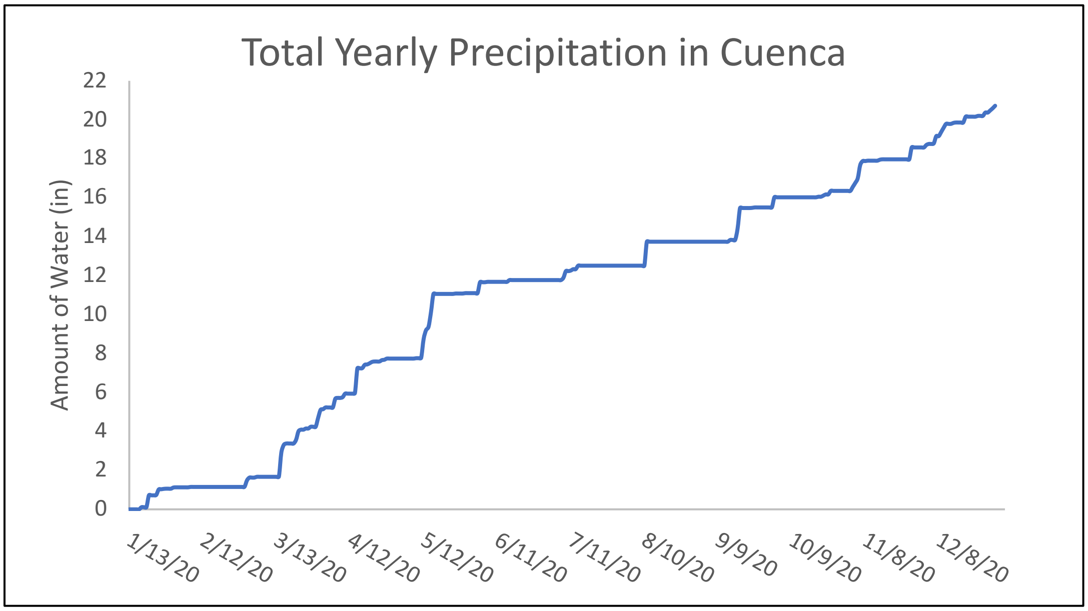

Figure 13: Total Precipitation in Cuenca (2020)

Similarly, to accomplish the purpose of the project, it is necessary to analyze more in detail so the actual amount of water that the residents will be used can be obtained using the same assumptions as from the primarily location. Additionally, know the tank size, and which will be the most suitable for this house. Again, the dimensions of the roof must be known for further calculations. For this location, the roof on the third floor and the smaller left roof from the second roof will be used since these will be the most suitable for the design. Once the area of the roof has been obtained, the same steps as the previous case can be followed. The length of the top roof is 32 ft (10 m), and the width is 20 ft (6 m) giving a total area of 640 ft^2 (60 m^2), meanwhile for the smaller roof is 3 ft (0.9 m) wide and 13 ft (4 m) long with a total area of 39 ft^2 (3.6 m^2).

On a separate step of this process, evaluations from the figure below can be made. The total precipitation was 20 in (508 mm), it now will go down to 15 in (381 mm) because of the 75% water collection efficiency. This new value will be 15 in x 1 ft^2 per year of water that one square foot area which can support relying entirely on precipitation. Assume that the accumulated water use in this household is roughly 0.042 in/d (1.0668 mm/d) which will be an equal amount at the end of the year to the new accumulated rain amount. This is helpful because it demonstrates how much water is being used and how much could potentially be stored. The water consumption is slightly higher than the collected rainwater in some periods of the year. The third curve indicates the reservoir storage which will depend on the days that rain. The peak reservoir storage will be during mid-March to mid-April because there were rainy days that happened more frequently with more heavy rain and house consumption is lower than the collected rain.

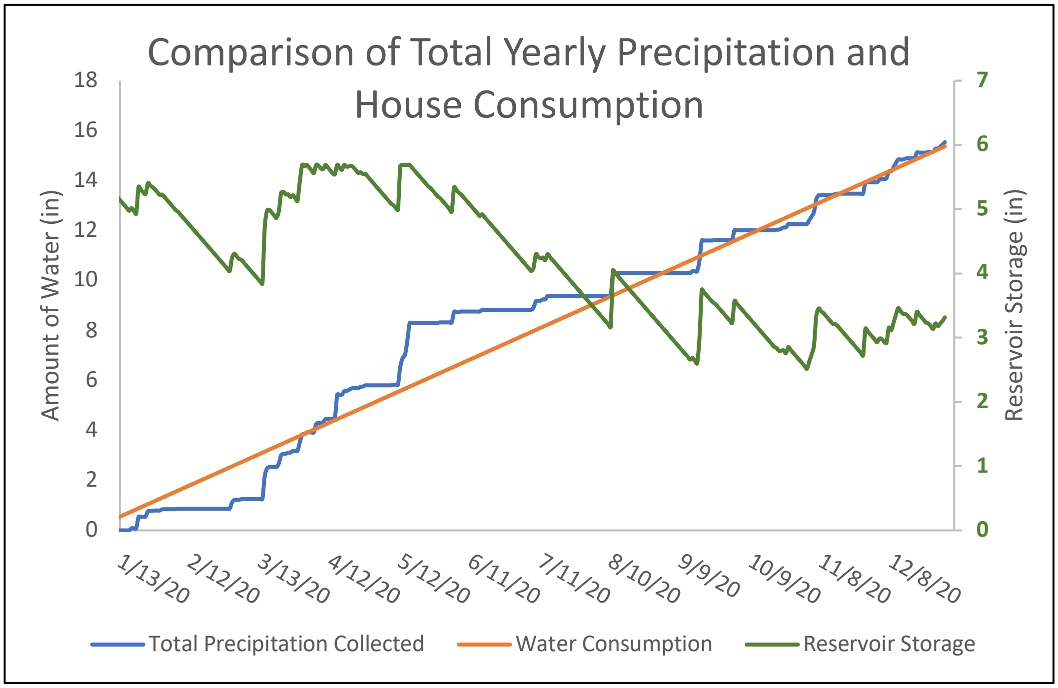

Figure 14: Yearly Water Collection, usage, and Storage in Cuenca

Following the same steps as before, consider the amount of water that the family consumes for bathroom use. This is roughly 30 gal/person giving 90 gallons in total for the whole family per day. This amount is converted into yearly consumption which is 32850 gallons per year. With the total volume obtained and the estimated 17 gallon collected from roof surface, the needed area for the desired water storage should be 1932.35 ft^2 (179.5 m^2). This area is far beyond the actual area of the house because to collect more than 30000 gallons, the area of the roof should be almost 3 times bigger than what it is now.

Looking at the reservoir storage in this case, the proper capacity is up to 6 inches. Because 15 in is the overall rainfall that can possibly be collected, 60% (9 in/15 in) of the annual effective precipitation should be collected if the residential building were to have 1932.35 ft^2 of roof surface. Then, the 60% of the collected rainwater gives 19710 gallons. This volume is valuable for the tank sizing later in the composition section of this report.

5.1.3 Rainwater in Austin

According to the USGS, the average number of rainy days is 79 days in Travis County. It has an average total annual rainfall of 36.6 inches (863 mm). The following figures show 2020`s rainfall data containing daily and the total amount in inches of rain from each day starting from January 2020, until December 2020. The year had a total of 35 inches of rain (914 mm). The figures also indicate the wettest seasons which in this time of the year, it rains more frequently during January through July and the rest of the year has almost zero rainy days.

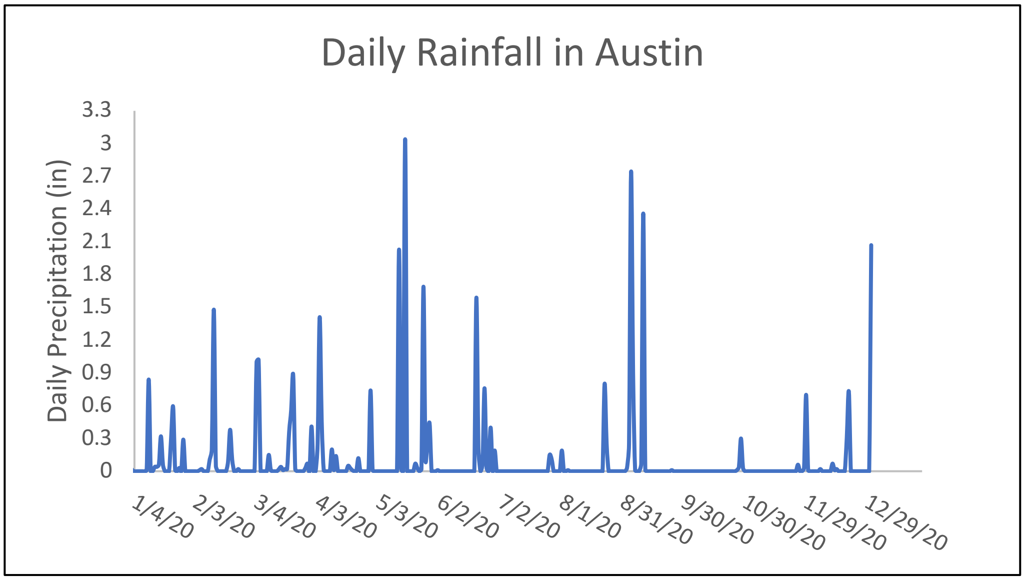

Figure 15: Daily Rainfall in Austin (2020)

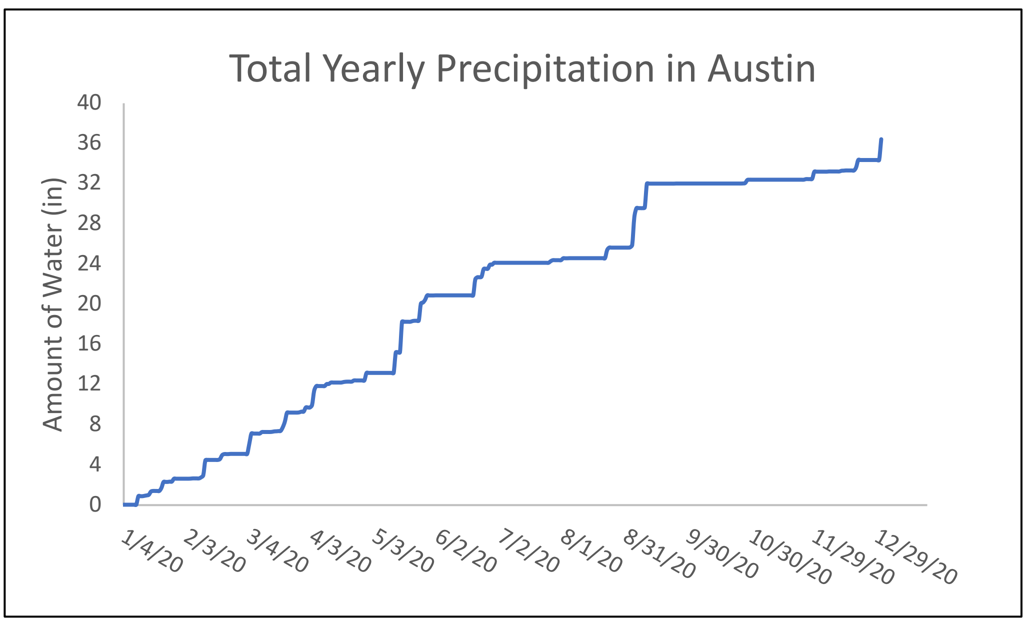

Figure 16: Total Precipitation in Austin (2020)

The same assumptions can be applied from location one and two. It can be said that most rains occur for one hour, and since it is known that the annual rate is 47 in/yr with 97 days of rain, it can be estimated 0.40 in/d during that one hour. It can be also assumed that in worst-case scenarios such as tropical storms, the total amount can be up to 7 inches (178 mm) of rain. On the other hand, snow can be neglected since the amount of snowfall is almost zero in Austin (Travis County).

For this house, both sides of the roof will be used since architectural characteristics are very similar to the primary location. In terms of calculations, the same steps will be followed. The length of the roof is 50 ft (15.2 m), and the width is 32 ft (9.7 m) giving a total area of 1600 ft^2 (148 m^2) in addition to an extra area covering the garage entrance of roughly 70 ft^2 (6.5 m^2) giving an overall 1670 ft^2 (155 m^2) of roofing area. Knowing the area that will be used, looking at the comparison of total yearly precipitation and house consumption is also needed. The figure below demonstrates that roughly 27.31 in (685 mm) of rain can be collected from the RHS due to 75% efficiency (in the case of the year 2020). This new value will be 27 in x 1 ft^2 per year of water that one square foot area which can support relying entirely on precipitation. Similarly, to the Port Washington location, 0.074 in/d (1.82 mm/d) can be assumed for daily house consumption which will equate to the total amount of rain collected at the end of the year. Since the water consumption is always consistent (assumed), in the figure provided shows that the rain collected curve is higher than water consumption curve almost every time. This is due to rainwater keeps accumulating. On the other hand, the reservoir storage curve is also consistent during the times that most rain events occur such as from the months of January and July. The curve then drops dramatically because of dry seasons.

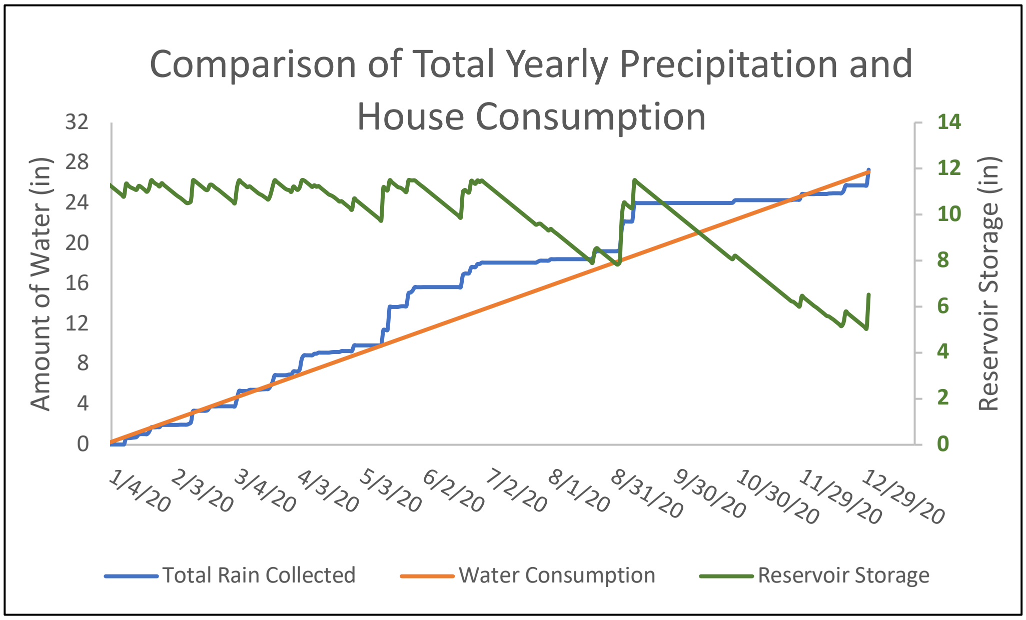

Figure 17: Yearly Water Collection, usage, and Storage in Austin

Once again, considering that 7.48 US gallons is equal to 1 ft^3 from 1 ft^2 roof surface, 17 US gallons of rainwater can potentially get collected. With the assumption mentioned earlier about the number of residents and the water consumption per person, 90 gallons for the whole family per day which translates to 32850 gallons per year. With this value, and the known yearly collected amount from roof surface, the needed square footage can be obtained by dividing both giving a total of 1932.35 ft^2 (179.5 m^2). However, the surface area to satisfy the water needs is 1.1 times smaller than the desired roofing area since the actual area is 1670 ft^2 (155 m^2).

Lastly, looking at the reservoir storage in this case, the proper capacity is up to 12 inches. Because 27.31 in is the overall rainfall, 43.9% (12 in/26.25 in) of the annual effective precipitation should be collected if the residential building were to have 1932.35 ft^2 of roof surface. Then, the 43.9% of the collected rainwater gives 14421.15 gallons. This volume will help decide tank sizing in the next section.

5.2 Structural Composition

In this section, a method of where to install the water tank will be discussed based on space availability along with other crucial components that will be part of the piping system to deliver the rainwater to the residential building. All these methods will be recommended for each household.

5.2.1 Method Used in Port Washington

As explained in the previous sections, it was determined that the best location for the system would be best inside the garage, which will be isolated before the installations. The idea is to have water tanks inside the garage, which can collect the rainwater from the gutters from the front and the back of the house. One of the main reasons the containers will be inside is that the garage has insulated walls to keep it relatively warmer during the winter season, potentially preventing the water from freezing. The back of the house has no interruptions for transportation of the water through the gutter, unlike the front by the main entrance, which has a different roof to cover the person from the rain or sunlight. Since it will have two separate sections for the gutter in the front (right side of the house), the best solution to collect water as much as possible is to place a vertical PVC pipe all the way at the right end of the gutter and have other additional pipes connected (on the ground) so that they can reach the water containers. The figure below shows a better interpretation of the method where the black straight lines around the roof represent the pipes that would be placed to transfer all the water inside the garage. The gutter system in the front is almost identical except that it does not have the entrance roof, indicating that the water travels only in one direction until it meets with the other pipe coming from the front of the house, as seen on the side view image below.

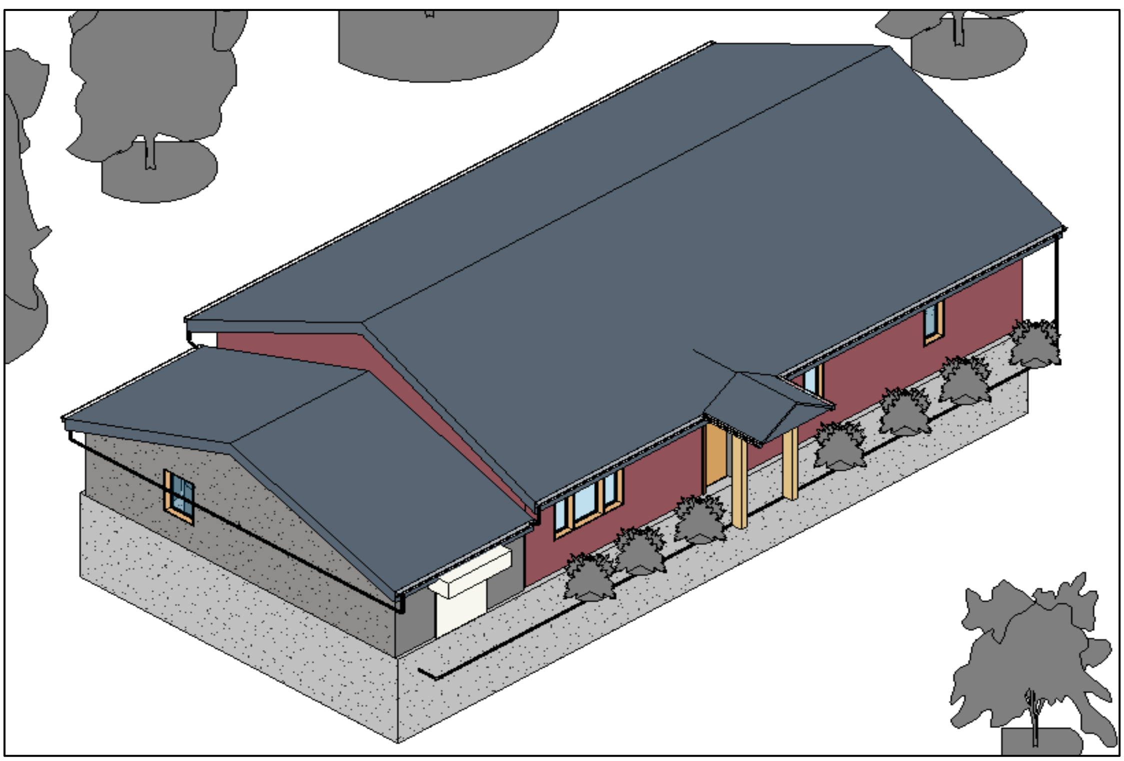

Figure 18: Aerial view of exterior pipe system

Figure 19 shows a closer look at how the PVC pipes and the gutters would be connected since the house has two separate roofs. The pipe below is the one that comes from the right side of the house because there is an interruption with the gutter on the main roof. This pipe will go underground since it will need to go through the main entrance. Once the pipe is near the garage, a hole could be made between the garage floor and the basement ceiling and then another inside the garage floor to go upwards so it makes a connection with the other two main pipes. Of course, to prevent the water from the main two pipes from the side go to the third inlet (front of the house), the tee will be placed at an angle, so all the water goes directly to the tank and not somewhere else. Figure 20 below shows a side view of the house and where the pipes are lined up. The first two could go through the center of the wall at the height of 6-7 feet (2 m) from the ground, so it is quicker to reach the tank's opening leading directly inside the garage. Two wooden supports will hold these pipes to keep them balanced, and the third goes under the garage (inside the basement) and then goes up to reach the garage; however, the water would take more time to reach the top of the tank due to its vertical distance. In addition, if there is an overflow, the main conducting pipes of rainwater will have an opening at a higher point so that the extra water leaves the pipes as if it were acting like a typical gutter exit path. Of course, all these gutters will have a leaf filter at each exit to prevent large particles from entering the main pipes.

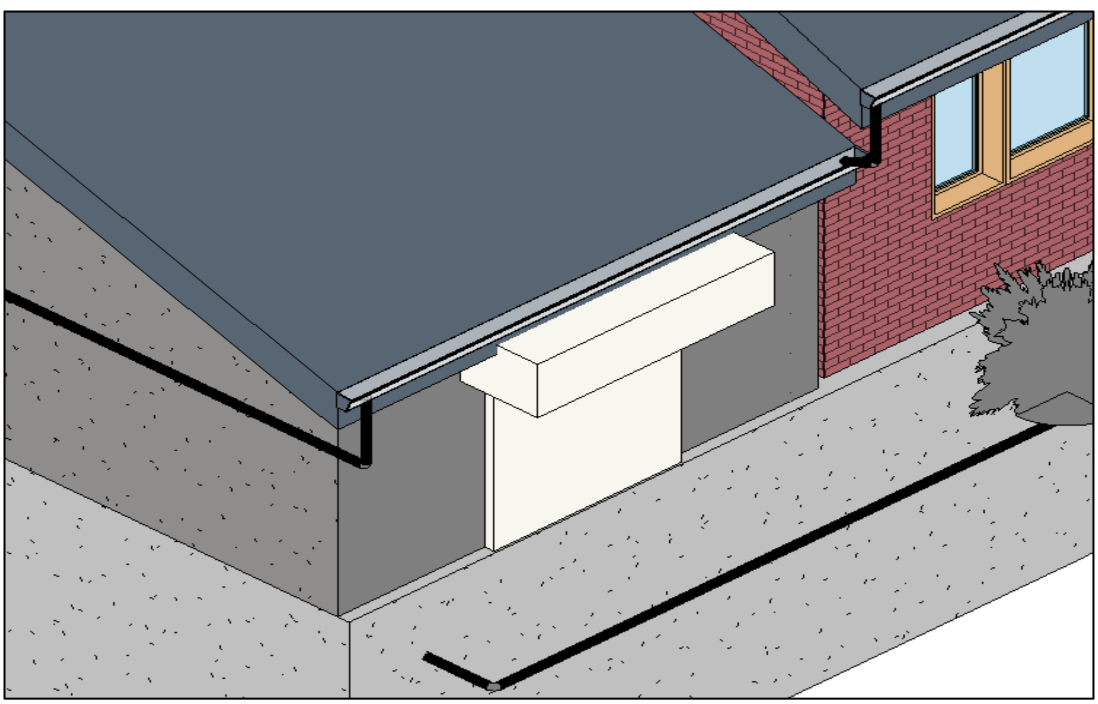

Figure 19: Closer Look of connection of pipe and gutter

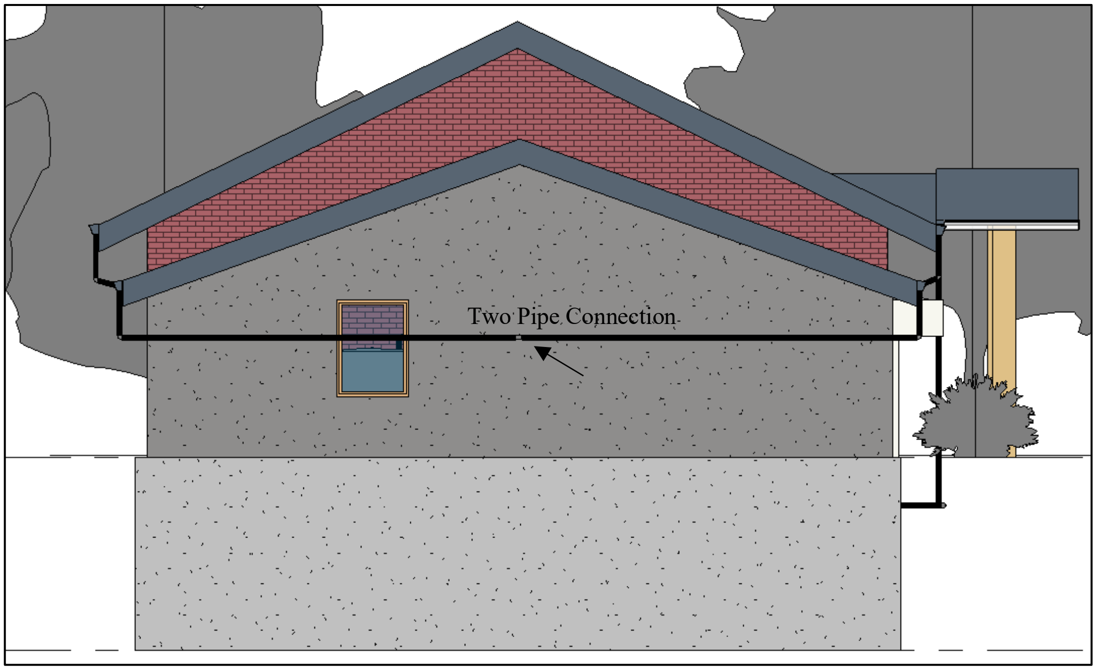

Figure 20: Side View of house and exterior pipe alignment

This will be an easy step since the gutters are already placed and not much needs to be changed in these areas.

Once the exterior design is completed, the project can then move to the interior design, which involves many house adjustments. First, before the water reaches the containers, a filter (5-micron water filter) must be placed to catch microparticles such as dust and other sediments. To better understand how the system is being designed, the figure below shows a view inside the garage once all the pipes are connected.

At the intersection of all the pipes, which is located at the center of the wall, there will be a tee making this possible. To the left side, a 5-micron filter will be placed before the water reaches the tanks. For this design, since before it was mentioned that there could an estimated rainwater collection up to 1664.4 gallons; therefore, it can be chosen two 1000-gallon tanks. This is also ideal because a tank with this volume will just fit through the entrance of the garage which has dimensions of 7'H x 7'W and the tank would have 6.3'H x 5.3'W If there is an overflow, then the water can be discharged from the overflow exit pipes.

After the water is being cleaned, the water will first go to the tank placed on the right of the figure below. It will then immediately move to the tank to the left. The tank on the left will be the leading tank. There would be three different outlets. One will be connected to a small water pump (as seen in figure 22) which will lead to the bathroom (toilet only) and kitchen sink, another outlet will be for another sink which is placed in the basement near the laundry room, and the third will be used for landscaping/outdoor purposes.

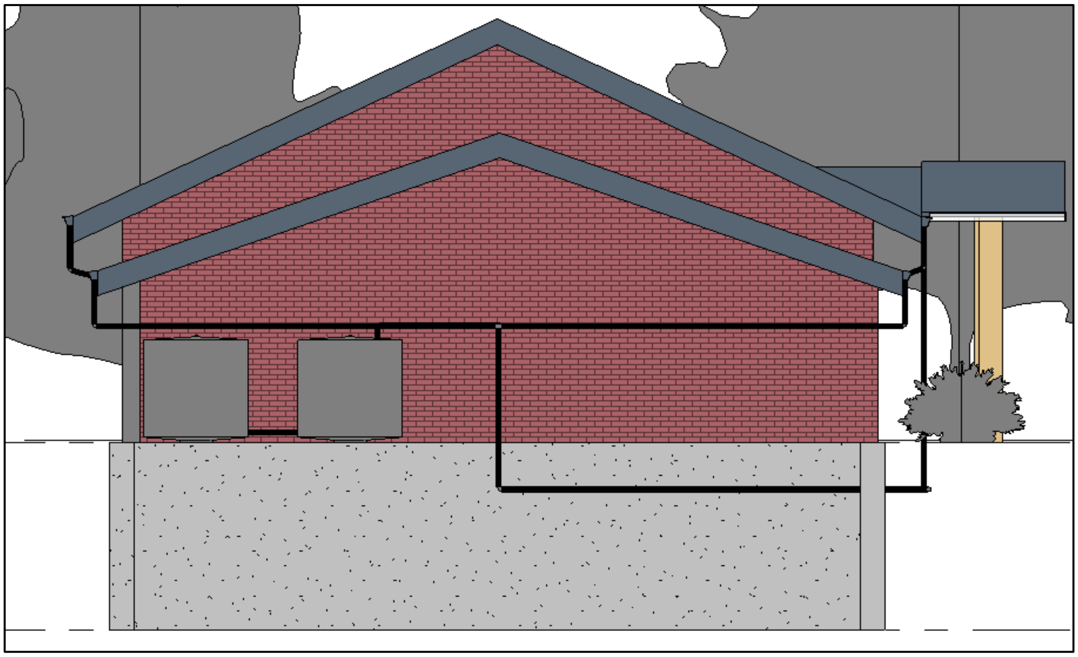

Figure 21: Side View of interior of garage with pipe system and tanks

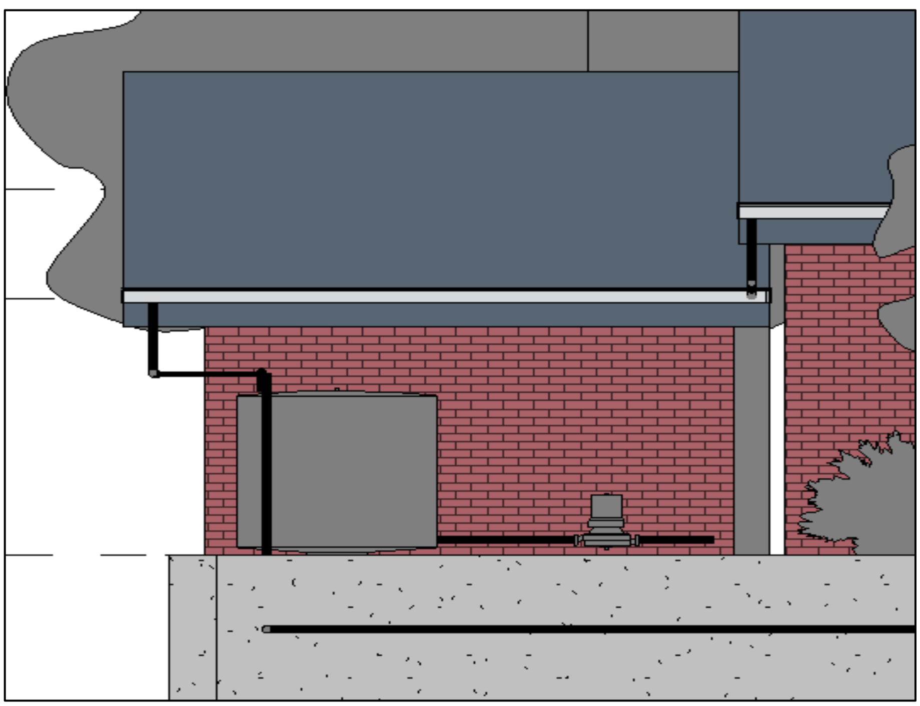

Figure 22: Front view of pump connection

The image below shows a floor view for the first level. The piping system is shown in this view. However, the pipes will be located under the first floor (ceiling of the basement). On the first floor, all the bedrooms, the kitchen, and the bathroom are located. As seen in the image, there are two lines of PVC in the second half of the house. A tee will connect both. The line above (kitchen area) leads to the kitchen sink; the second line leads to the toilet. Whenever a person wishes to use either utility, there will be a sensor that will detect the movement of the sink's faucet or the lever of the toilet. For instance, if an occupant finishes using the toilet, a water sensor will detect that the toilet tank will need water. This will involve a switch that will trigger the water pump and let the water run until the toilet tank gets full. To know that the tank is full, the ballcock, also known as the float valve, will touch another switch, turning off the pump.

Similarly, this applies to the kitchen sink. To avoid overflow in the bathroom when the kitchen sink, an automatic lid will cover the pipe. Both utilities should be able to use simultaneously.

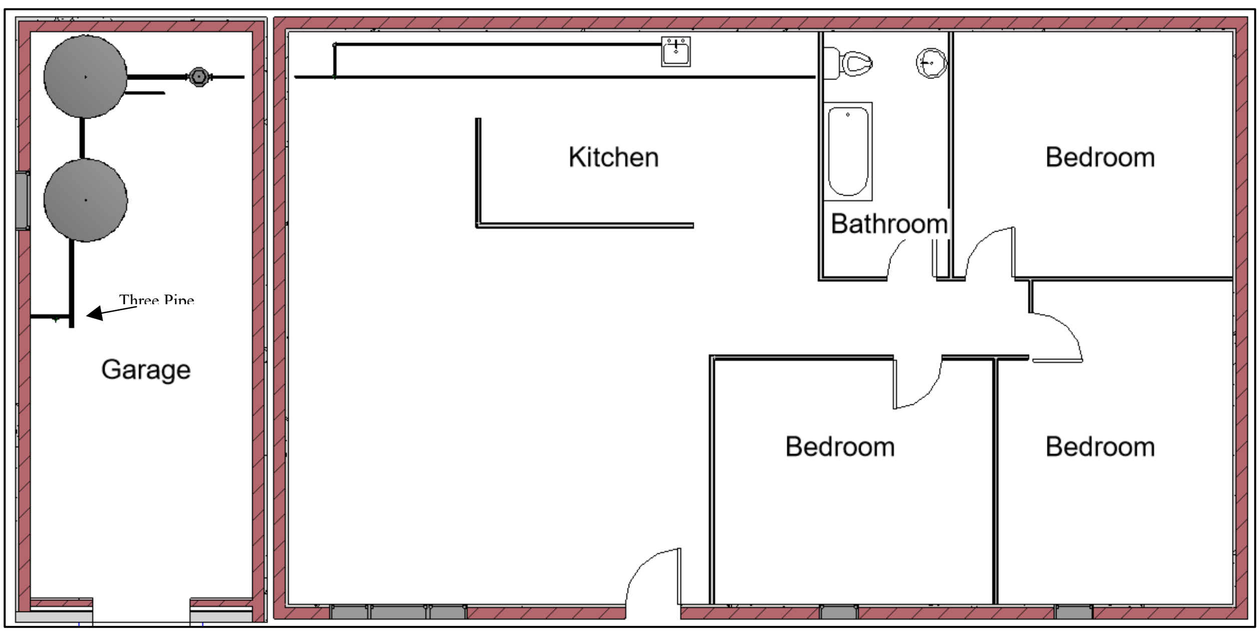

Figure 23: Top view of first floor

On the other hand, a second pipe coming from the tank which will only be used for a small sink near the laundry room. This sink can be used more often since the only energy source in this case will be coming from gravity because the sink is under the RHS. As shown in the following figure, the pipe will also be attached on the ceiling of the basement, but this time, it will reach to the only sink in this area.

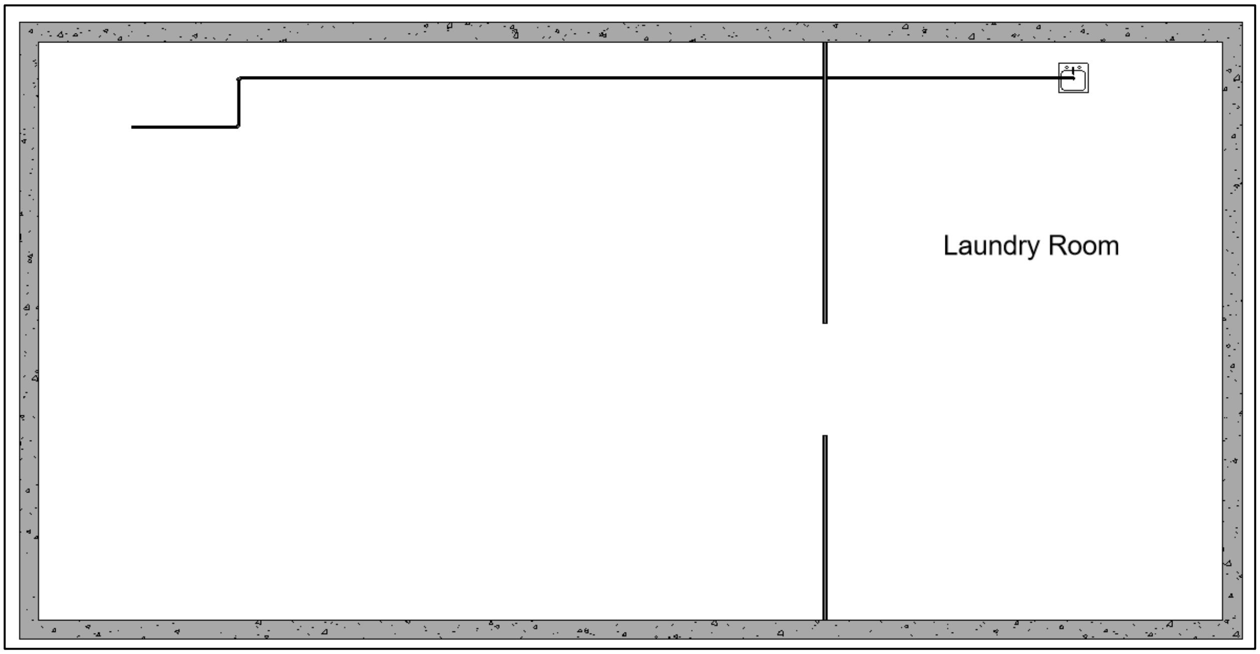

Figure 24: Basement top view

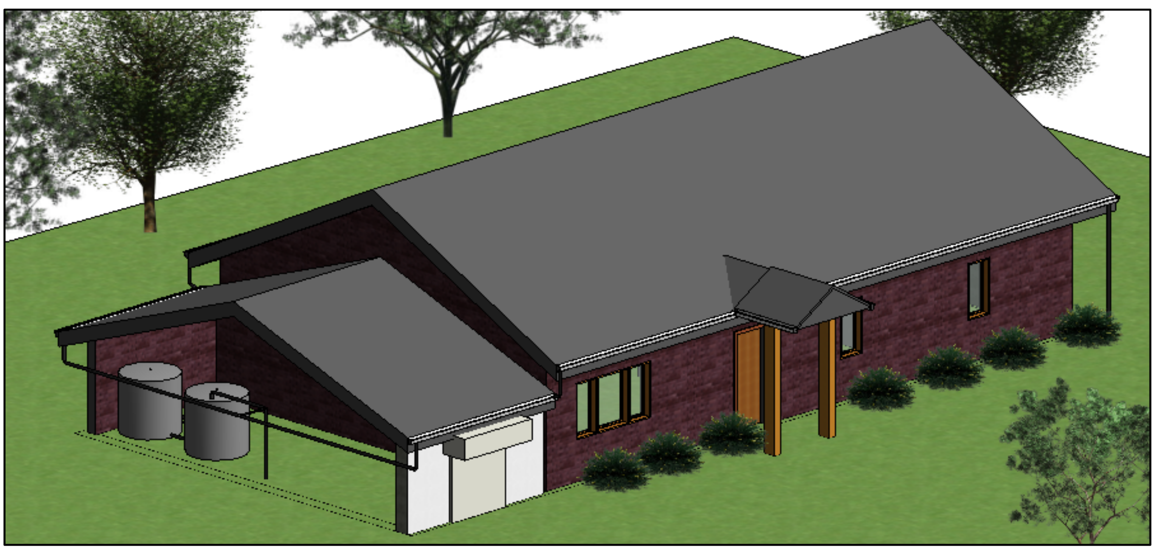

Figure 25: Final representation of completed system (Garage)

Figure 26: Front view of House in Port Washington

5.2.2 Method Used in Cuenca

The only available places to put the water tank will be in the front yard or third floor. However, after further investigations, because the house is mainly made from concrete and to prevent a compromise with the integrity of the house, it is best to only use the third floor for water storage.

Luckily, if the tank is being put on the third floor, the main bathroom located on the second floor will be the most benefited from the tank since the storage tank will be right above the bathroom. The figure below is a raw representation of where the tank could potentially go.

Figure 27: Potential Design for house in Cuenca

Because the water tank will be at a high elevation, there will be no need to have a pump to transfer the water to its destination. In this case, since the tank is closer to a shower, it can be recommended to include a gas water heater if desired. In any case, a simple design will be taken into consideration. It will only consist of the main pipe that comes from the roof, connected to a primary filtration system which catches large debris like plastic or leaves. To transfer the water from the tank to the bathroom, it should go through an additional filtration system which will clean the water even more at a microscopic scale. The clean water will then move to the tank for storage. The main pipe will then go through a small window already installed on the third floor making a connection with the bathroom. Other additional installations should be made for hot and cold water. If hot water is needed, and with the help of a water heater, a separate pipe should be installed along with the water heater. If only cold water is needed, then only one piping system will be installed. Assume that both hot and cold water will be used. For this reason, the cold one will go to the sink, toilet, and shower, meanwhile the hot pipe will only be applicable for the sink and shower. The following schematic will give a better visual of the given description.

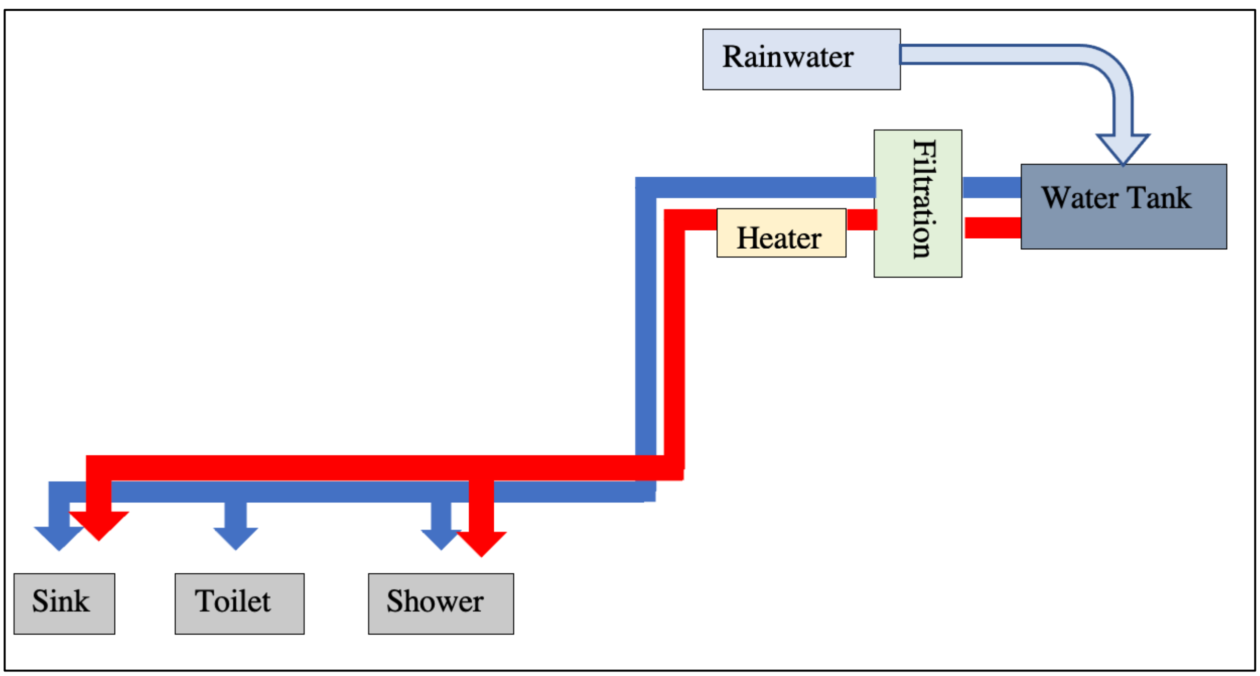

Figure 28:Potential Pipe System Design for Cuenca`s Location

Since the pipes will be connected to each utility, multiple valves will be needed to open and close when there is a use of water. This will be additional installation because the original piping system already implemented for water consumption must be kept untouched since the residents cannot always rely on just the tank.

In terms of the tank sizing, since the calculations estimated that 19710 gallons of rainwater could be collected throughout the year, then a very large physical size tank is required. However, this would only apply if the house had a roof area of 1932.35 ft^2 (180 m^2) which is three times larger than the actual roof surface area. Because of this, the amount that the roof can collect is an estimated 6528 gallons. With this new volume, it can be recommended that two 3500-gallon tanks could be used because that is the amount that the tank could store a year worth of rainwater using the current roof area. This is considering that the smaller roof from the second floor is no longer part of the design.

Although two 3500-gallon tanks seem ideal for the design, the allowable space on the third floor needs to be taken into account. By this, it means that the opening of the windows should be big enough to introduce the tanks since the doors will be tiny for these structures. The exterior windows on the third floor are only 5'H x 5'W which is a negative impact for the project due to the large tank size needed to meet water consumption. One alternative is to minimize the water collection and leave the rest for overflow and order a custom size water tank. If ordering a custom size water tank is available, then have 3 tanks that support 1000 gallons each with dimensions of 4.5'H x 4.5'W x 6.5'D. This will at least meet half the total water collection for the house.

5.2.3 Method used in Austin

Due to the lack of property information for accurate measurements, there will be some assumptions for the design in the location in Austin. First, the only proper available place to put the tank will be at ground level. Since this house has a large backyard, it will be ideal to place the tank in that area.

This house in Austin shares some architectural characteristics as the location in Port Washington, therefore the design concepts will be similar. Two 6000-gallon tanks could be placed behind the house to meet 12463 gallons of rainwater collection by the current roof area as opposed to 14421.15 gallons from the theoretical square footage of the roof obtained in earlier calculations. Regardless of tank sizing, these tanks can be placed particularly on the left side since it seems to have enough empty space and because there is an open path to make a connection with the water that will be falling from the front side. The figure below shows a better look of the back of the house.

Figure 29: Back of 3609 Cookstown Dr. House

Following the same methodology from the Port Washington location, the system will be very similar, but some portion of the roof might not be able to contribute to the water storage system. In the figure below, a drawing of a potential design of water storage and gutter system in this location can be demonstrated as the following with the drawn arrows.

Figure 30: Planned Gutter System at 3609 Cookstown Dr

In the figure shown, the majority of the roof will be used except for the left front because it could be far from the tanks which would involve large pipes that could also interfere with entrances, or it will simply make the house have a bad aesthetic. The arrows represent the direction of the water flow. The blue arrows indicate the water in the gutter and the green is the pipe that will be transferring all the water from the front to the back. Assuming that one bathroom and the kitchen are next to each other, then it can have a similar system as the first location which also deals with a kitchen and a bathroom,

6 Material Specifications and Costs

In this section, costs and materials will be discussed for the designed systems for each location. These are estimates since changes could be made in the future and because each location is in different region.

6.1 Costs and Materials for Port Washington`s Location

Many of the following tools/equipment were chosen from the Home Depot and National tank websites for the tank. For the exterior pipes, 2” (5.08 cm) diameter PVC will be used. For all interior pipes, 1” (2.54 cm) PVC pipes are being used for higher water pressure.

- Exterior Total Length Pipes (2” – 50.8 mm): ~ (85 ft (26 m) large underground pipe, 9 ft (2.7 m) vertical on right end of the house, 10 ft horizontal on the side of the house, 6 ft (1.8 m) gutter connection, 10 ft inside garage) = 120 ft (36.5 m). Cost: $1.167/ft → 120 ft * $1.167/ft = $140
- Interior Total Length Pipes (1”- 25.4 mm): ~ (45 ft in basement, 31 ft from pump to kitchen, 39 ft (9.4 m) for toilet tank line, 10 ft for extra turns) = 125 ft (38 m). Cost: 1.046/ft → 125 * 1.046 = $130.75
- PVC Tee socket: 2 * $2 =$4
- PVC 90 deg elbows: 14 * $1.52 = $21.28
- Gutter filters: 7 * $7.30 = $51.10
- 5-micron sediment filter: $90 for apparatus and $15/cartridge (can be changed every 6 months) = $105 total
- Water meter (can be installed after filtering process): $40
- Float switch for toilet water tank: $25
- 12-volt transfer water pump: $60
- 12-volt battery: $90
- Snap action switch: 2 * $5 = $10
- Automatic motor with lid (close overflow in toilet): $24
- 1000-gallon Water tanks: 2 tanks * $859/tank = $1718
- The total cost for this project will be approximately $2419.10.

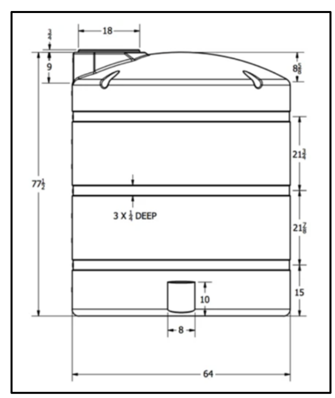

Figure 31:Tank Used for Pt Washington

6.2 Costs and Materials for Cuenca`s Location

Pipe sizing will be the same as the primarily location. However, the prices of these pipes and other components will be different since it comes from other stores called MegaHierro and Mercado Libre in Ecuador.

- Exterior Total Length Pipes (2" – 50.8 mm): from end of gutter to tanks gives a total of ~16 ft (5 m). Cost: $10/10ft → 16ft * $10/10ft = $16
- Interior Total Length Pipes (1"- 25.4 mm): ~ 30 ft (9.1 m). Cost: $7.78/10ft * 30 ft = $23.34
- PVC 90 deg elbows: 2 * $1.07 = $2.14
- Gutter filters: 1 * $2.60 = $2.60
- 5-micron sediment filter: $399
- Water meter (can be installed after filtering process): $75
- 1000-gallon Water tanks: 3 tanks * $1300/tank = $3900
- Gas Water Heater: $526
- The total cost for this project will be approximately $4944.

Figure 32: Gas Water Heater for Cuenca

6.3 Costs and Materials for Austin`s Location

For this location, measurements are estimated. Similarly, to location one, the following prices are from HomeDepot.com and NationalTank.com.

- Exterior Total Length Pipes (2" – 50.8 mm): ~ Cost: $1.167/ft → 200 ft * $1.167/ft = $233.40
- Interior Total Length Pipes (1"- 25.4 mm): ~ Cost: 1.046/ft → 150 ft * $1.046/ft = $157
- PVC 90 deg elbows: 5 * $1.52 = $7.60
- Gutter filters: 4 * $7.30 = $29.20
- 5-micron sediment filter: $90 for apparatus and $15/cartridge (can be changed every 6 months) = $105 total
- Water meter (can be installed after filtering process): $40
- Float switch for toilet water tank: $25
- 12-volt transfer water pump: $60
- 12-volt battery: $90
- Snap action switch: 2 * $5 = $10
- Automatic motor with lid (close overflow in toilet): $24
- 6000-gallon Water tanks: 2 tanks * $5680/tank = $11360
- The total cost for this project will be approximately $11984.

7 Summary

In conclusion, although the total costs of the RHS in Port Washington, Cuenca, and Austin are 72, 824, and 342 times higher than residents would pay regular municipal water in a month, it needs to be kept in mind that this will be helpful for the long term, which eventually helps decrease the water costs depending on how much the tanks collect. However, the system wouldn't be feasible to Cuenca, and Austin since the prices are extremely high and would technically be paid off after many years although the tanks can potentially save up to 40% of the city water. Of course, since there could be risks to the system, residents cannot 100% always rely on the RHS. All utilities will still need to be connected with the main city water line to avoid any problems but only use it when needed.

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