NORTHERN ARIZONA UNIVERSITY

RESIDENTIAL RAINWATER HARVESTING **PROJECT**

NAU UGRAD CAPSTONE

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1.0 PROJECT DESCRIPTION

The purpose of this project is to design a rainwater harvesting distribution system to facilitate residential water use. The intent of the stored water will be to irrigate the client's vegetable garden, and to supply toilet flushing water. The purpose of the harvested rainwater is to reduce overall potable water usage from the Kachina Village Improvement District supply.

Figure 1 shows a simplified version of a rainwater harvesting and distribution system. The roof is used as the collection surface in order to convey the water through a gutter collection system to a subterranean cistern. The water flows through a pre-filtration device before entering the cistern to remove any dirt and debris from the roof area. The water from the cistern is pumped to a pressure tank inside the home. The pressure tank then distributes the water to the intended utility locations. This schematic provides a general concept of the applications and components of this project.

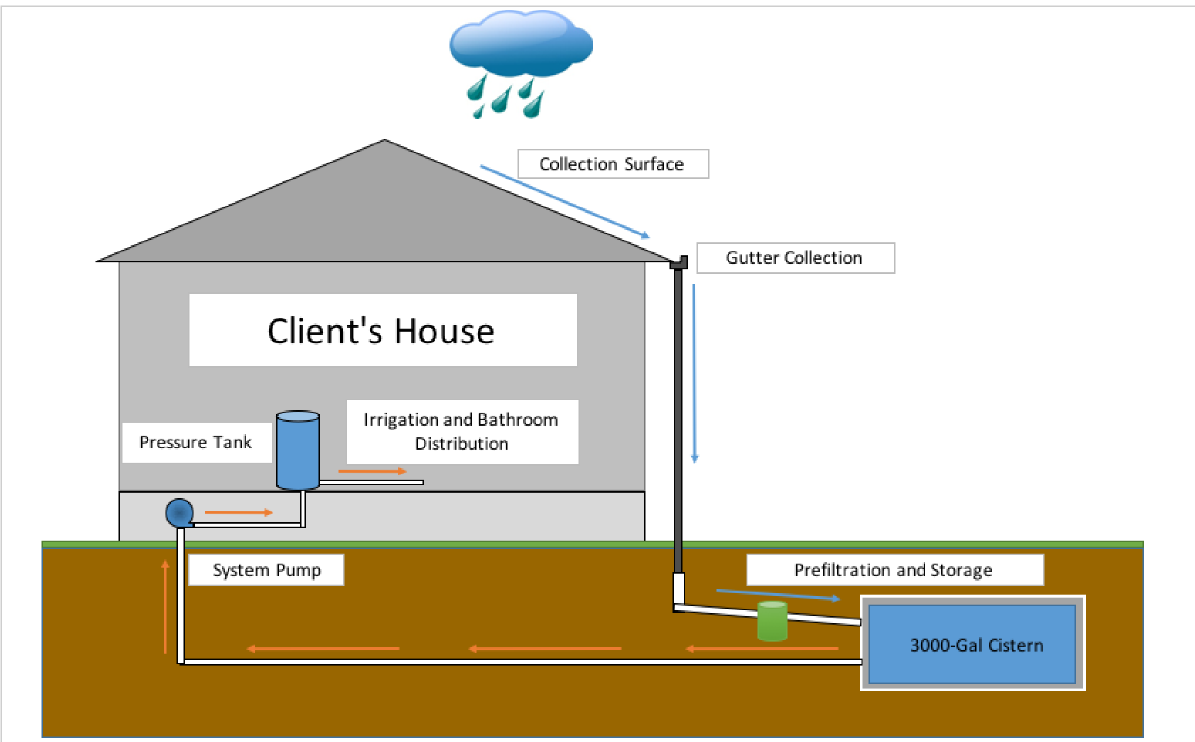

Figure 1: Rainwater Harvesting Schematic [1]

2.0 PROJECT BACKGROUND

This project site is located at 2156 Lohali Trail, in Flagstaff Arizona. Figure 2, shows where Kachina Village is located in reference to the City of Flagstaff. Kachina Village is approximately seventeen miles south of the City to Flagstaff limits. The property is located in the north region of Kachina Village.

Figure 2: Location of Kachina Village relative to the City of Flagstaff [2]

The client intends on making additions onto the home, which will be analyzed and incorporated during the design process. The home currently does not have any hydraulic infrastructure to convey roof runoff. The site has an existing storm drain composed of a shallow channel with a corrugated steel pipe that conveys surface runoff. The largest impervious surface type is the roof of the home, which will be used as the main catchment area. Figure 3 shows the existing property with a rendered model from AutoCAD of the proposed plan schematic on top. The proposed structures include a garage, and two decks located on the east and west side of the house. The decks also have a proposed roof overhang to provide cover. Figure 3 also shows the approximate location of the subterranean cistern that was specified by the client.

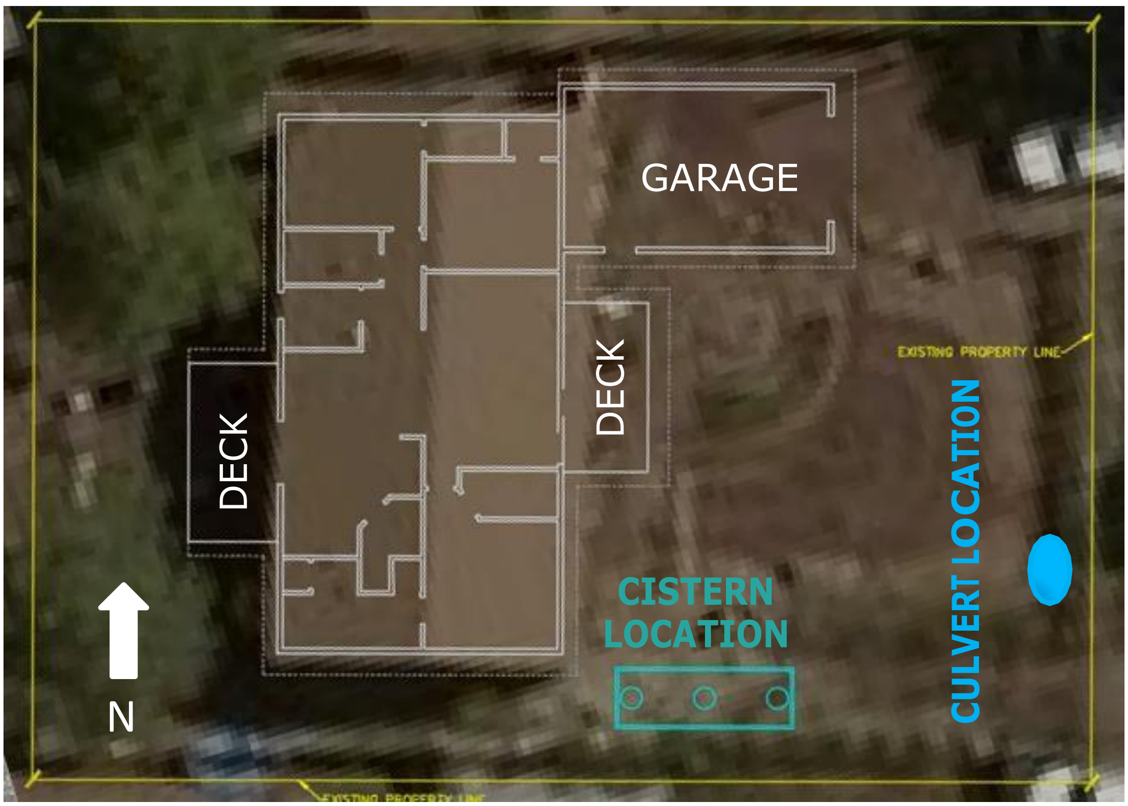

Figure 3: Aerial View of Proposed Property Layout [3]

3.1 TECHNICAL CONSIDERATIONS

3.2 FIELD EVALUATION

A field evaluation provided conditions of the existing site, and empirical data of property setbacks measurements. The property setback requirement of five feet was measured to ensure that the location of the cistern would not encroach in this distance. Pictures were taken of the roof in order to accurately determine gutter locations since the roof is designed as a gable roof. An existing storm drain is located in the front of the client's property adjacent to the road. The distance between the house and storm drain location was measured in order to determine the amount of pipe needed to re-route any excess runoff that will not be conveyed into the cistern.

3.3 DESIGN STANDARDS, SPECIFICATIONS, AND CODES

The Coconino County Drainage Design Manual, the City of Flagstaff Code, and the 2012 International Residential Code were used to find specific requirements that need to be considered for the design portion of this project. The Coconino County manual provided a frost depth of 3 feet to ensure subsurface water does not freeze. There were no restrictions or limitations on the quantity of water that can be collected by residential home owners. The drainage manual also stated that the sheet flow of the rainwater can be calculated using the Rational Method since the area of the project site is within the proper limitations of the equation.

The City of Flagstaff Code provided information about the Low Impact Design (LID) specifications and considerations. The LID manual provided more information about how to calculate the design volume, bug and pest prevention, overflow, filtration, and freeze prevention. The LID manual specified that if the roof of a structure is used as the main catchment area, the catchment efficiency is approximately between 80-90%. This means that approximately 80-90% of the available precipitation collected on the roof can be expected for harvest. Based on this design consideration, this project is based on the assumption of an 80% catchment efficiency.

The 2012 International Residential Code was used to determine the flow and pressure requirements to supply toilet fixtures. These code requirements included toilet tank type, flow rates depending on the number of supply fixture units within the home, required capacities at the point of outlet discharge, maximum flow rates, and consumption for plumbing fixtures and fixture fittings.

3.4 CATCHMENT SYSTEM DESIGN

The catchment system design consists of the components required to properly convey rainwater from the main catchment area to the cistern. The largest impervious area to be used as the main catchment area is the roof of the home. The proposed construction plans of the home were used to determine the roof runoff since this harvesting system will be implemented once existing conditions have been improved as proposed. Reference Appendix 9.0 for the proposed construction plans used to render each model created throughout the duration of the design process. A gutter collection and pipe network system will provide as adequate additions to the home to meet this design element.

3.4.1 ROOF RUNOFF

The amount of available water that can be conveyed through the collection site was first calculated in order to size the overall system. The roof catchment area was dimensioned by inserting the proposed roof framing plan into AutoCAD. The catchment area was then split into five separate sub-basins. Each sub-basin is separated by the ridgelines of the roof area. Figure 4 shows a REVIT model of the home with the proposed extensions with the corresponding sub-basin delineation.

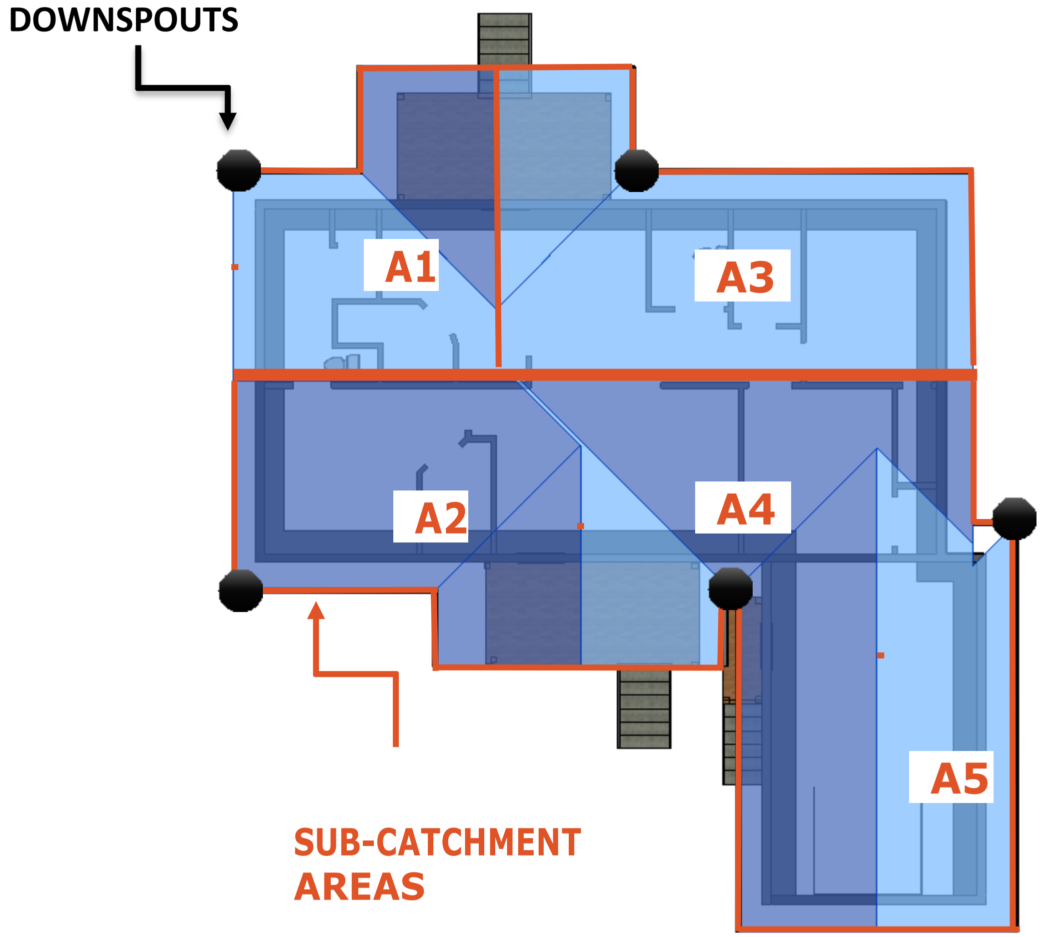

Figure 4: Top View of House with Proposed Extensions [4]

Table 1: Sub-Basin Catchment Area Results (ft^2)

A1	A2	A3	A4	A5
384.1	472.5	584.9	630.5	99.5

Area (total)	**2,172** (ft^2)

Equation A was used to calculate the flow amount each sub-basin would convey in cubic feet per second (cfs). The flow for each sub-basin provided a design capacity to size our gutters and downspouts accordingly. The downspout locations in Figure 4 were placed at the main drainage path of flow. Five downspouts in total are required to convey water for each catchment area. Since the catchment area incorporates a gable roof design, each sub-basin has separate gutter and downspout components. The total conveyance of the catchment area was used to size the required pipe size for the inlet of the cistern.

Equation A: Available Catchment Demand

$$\boldsymbol{Q}\ (\boldsymbol{cfs}) = (\boldsymbol{C_f})(\boldsymbol{C})(\boldsymbol{i})(\boldsymbol{A})$$

$$where C = antecedent precipitation factor C = runoff coefficient, f$$

$$i = rainfaill\ intensity\ (inch),\ A = roof\ area\ (acres)$$

Table 2 shows the values that were input into Equation A to yield the total roof runoff of 0.055 cfs. The runoff coefficient was determined based on the surface description listed in the Coconino County Drainage Design Manual [1]. NOAA Atlas provided rainfall intensity information for a 100-year storm, and 10-minute storm duration to calculate the amount of flow [2].

Table 2: Roof Runoff Results

Variable	Value	Units
Cf	**1**	**-**
c	0.95	-
i	1.08	in/hr.
A	2171.5	ft^2
Q (available)	**0.05**	**cfs**

3.4.2 GUTTER COLLECTION SYSTEM DESIGN

Roof gutters will convey the rain water from the roof to the subterranean cistern. The factors listed in Table 3 were used to determine the appropriate gutter size for the home. Various gutter manufacturing websites were used to calculate the proper size of 5-inch-wide gutters.

Table 3: Gutter Sizing Factors

Factor	Value	Units
Available Catchment Demand	0.05	cfs
Roof Slope	5:12	Horizontal: Vertical
Gutter Width	**5**	**inches**

Figure 5 shows the two type of shapes gutters are manufactured. U-shape and K- style gutters can be installed by any able home owner, and can be purchased at any local hardware store, like Home Depot. These types of gutters are also manufactured in sections, making for more accessible maintenance. Ultimately, the K-Style gutters were chosen as the most appropriate option due to cost, accessibility, and durability. Based on the 10 foot sections they are manufactured in, K-style gutters on average are 45% less expensive compared to U-shape gutters. K-style gutters also come in a wider variety of colors, sizes, and connections, making them more accessible. U-shape gutters are more likely to bend due to the weight of water, which increases the fatigue of the material. This increased fatigue shortens the life expectancy and durability of the U-shape gutter, making it more frequently replaced. This makes the K-style a more suitable option due to the longer life cycle.

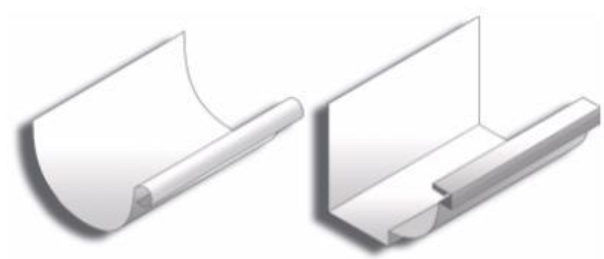

Figure 5: U-Shape and K-Style Gutters [5]

The local Home Depot in Flagstaff was referenced for available K-Style gutters to choose from for the design. These gutters are available in aluminum, copper, steel, and vinyl. Table 3 shows the decision matrix used to choose the most optimal gutter material. Each material is compared using various criterion. The cost refers to the price of the material, including start-up costs and part repair. The durability refers to the physical properties of the material, such as strength. The corrosion criterion refers to the resistance to weathering each material possesses. Maintenance refers to how frequently the gutter must be replaced due to material failure. The criteria were weighted based on importance out of a total of 100%; the higher the percentage, the more important the criteria are. The cost was weighted the highest at 40% due to the limited working budget set by the client. The durability of the material weighted second most important at 30% because the stronger material will last longer, which can increase the life cycle of the material. The third most important criterion is the maintenance because the less maintenance the client has to perform; the more convenience the system provides. Corrosion is weighted the least at 10% because there are maintenance techniques to mitigate weathering, no matter what gutter material is chosen. Each material is rated between a scale from 1-5; 1 being the most insufficient in meeting the criteria, and 5 being the most compatible. After rating each material carefully, the aluminum material was chosen as the most suitable option for the client. Even though the aluminum scored higher than the steel by only 6%, the team deemed the decision appropriate due to the availability of the aluminum versus steel. There are more aluminum gutter options in color, size, length, and connections locally available in town. Although the margin is still very small, the aluminum still met the criteria better than the steel.

Table 3: Gutter Material Decision Matrix

Criteria	Criteria Weight (%)	Gutter Material			
		Vinyl	Aluminum	Steel	Copper
Cost	40	5	3	5	1
Durability	30	1	5	3	3
Maintenance	20	2	5	3	3
Corrosion	10	2	4	3	1
Total	**100%**	**2.9**	**4.1**	**3.8**	**2**

3.4.3 CONVEYANCE SYSTEM DESIGN

Table 4 shows the estimated amount of gutter material and connections to convey the water from the roof to the cistern. A total of fifteen 10-foot sections will be required to collect roof runoff. In order to prevent ice dams from clogging the gutters, heat cables will be attached to the roof to prevent this issue. The water will travel from the roof and flow through the gutters into two downspout locations. Figure 6 shows the gutter locations with the corresponding sub-basin it will convey flow for. The gutters will convey water to each downspout location. Each downspout then distributes water to an underground pipe network. These pipes lead to one centralized location before entering conveying the water to the cistern.

Table 4: Gutter Components

Parameter (units)	Quantity
Gutter Slope (%)	0.02
Total Gutter Length (ft)	146
Outside Corner Piece	10
Inside Corner Piece	6
Downspout	2
10' Section	15
5" End Cap	4
Mounting Brackets	146
Downspout Filter	2

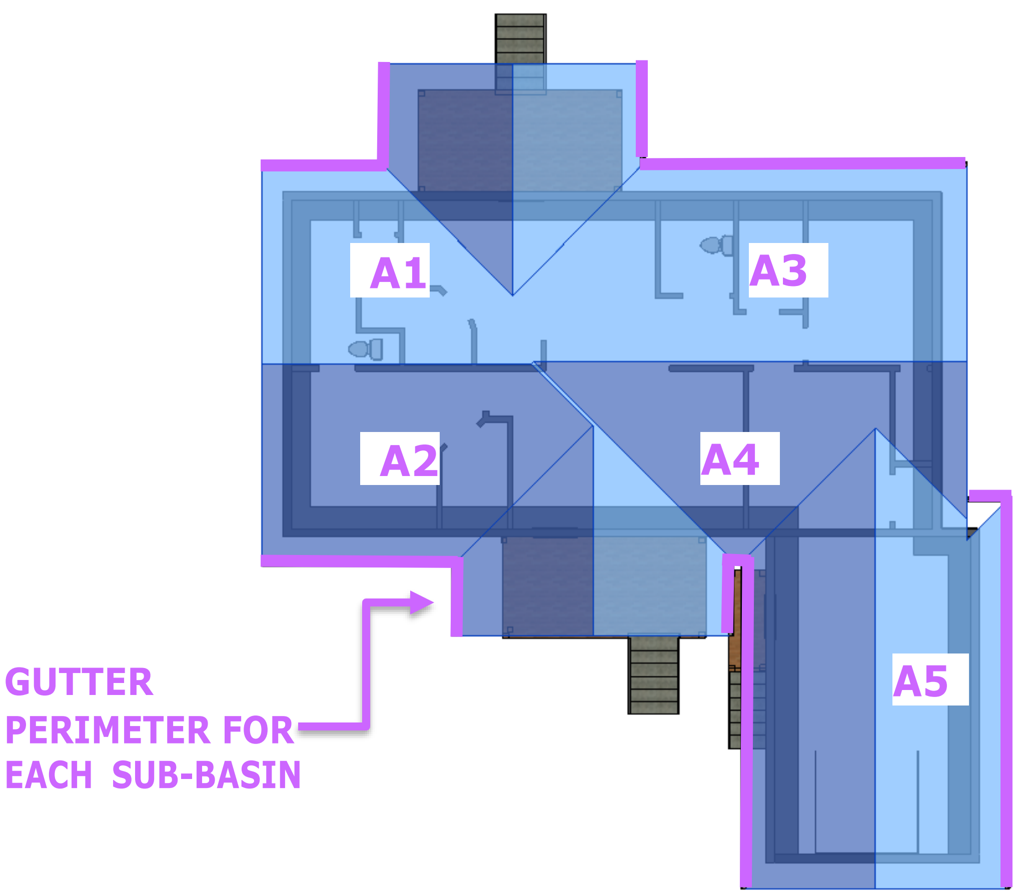

Figure 6: Gutter Locations [4]

3.4.4 FILTRATION SYSTEM DESIGN

The original scope of services included a first flush disinfection system. However, due to lack in efficiency, it was replaced with a filtration system instead. If the first flush disinfection system was implemented, the first inch of rainfall from the roof would have to re-routed to four rain barrels to store the contaminated water. The homeowner would then have to disinfect each rain barrel before draining them to make room for more precipitation. The cost of rain barrels was another issue due to the limited budget. Each 50-gallon rain barrel would cost up to approximately $200 dollars each. The location of these rain barrels was another issue because since the home is undergoing remodeling, the rain barrels would be a nuisance for large construction vehicles to navigate around. Also, if these rain barrels were in a permanent location, the client would have more limited space to renovate the home and the surrounding yard areas. Due to the inconvenient maintenance and cost of the first flush disinfection system, the team decided that it was too costly. To replace the first flush disinfection system, the team decided to implement a subterranean pre-filtration unit to filter the rainwater before it is conveyed to the cistern. Figure 7 shows the basket filter implemented in the final design. It is designed specifically for filtering rainwater, and removes debris and small particulate. Since the water will be disinfected by chlorination, the water will ultimately be safe to use for the client's intended purposes. The filtration device will be located 36-inches below the surface to ensure that the inlet and outlet pipes will not freeze during low temperature conditions.

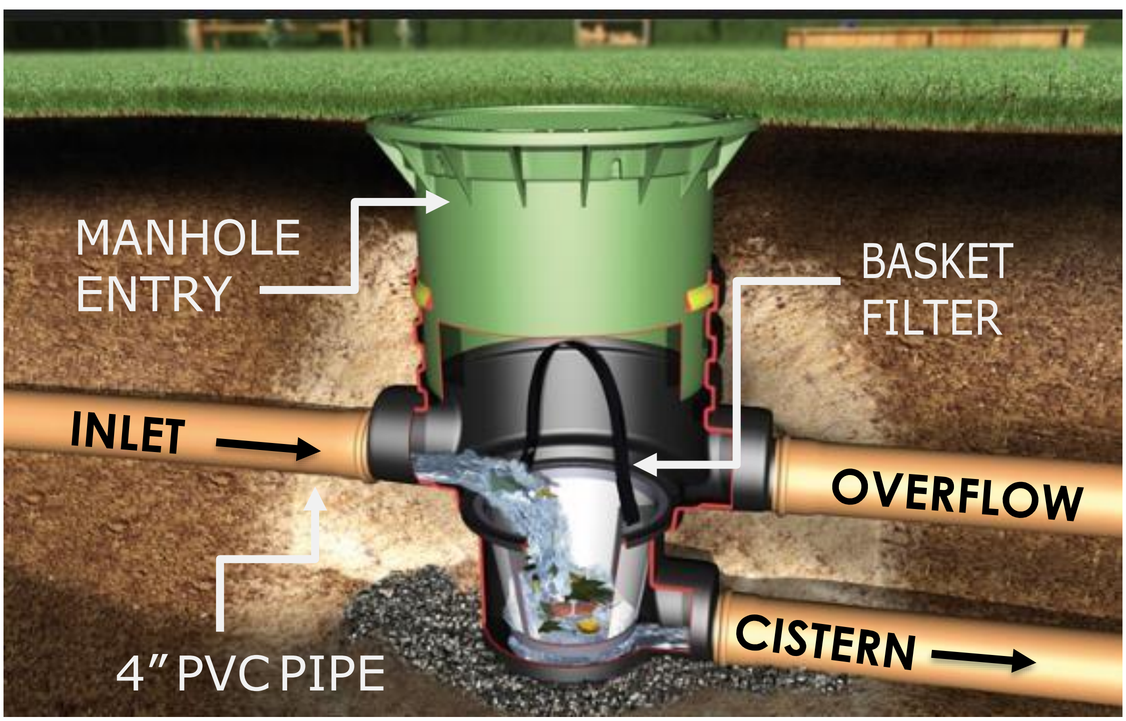

Figure 7: Pre-Filtration Unit for Rainwater Harvesting [8]

The rainwater flows from the inlet pipe on the left, as shown in Figure 7. This 4-inch inlet pipe will be conveying water through the basket filter from all downspout locations. The basket filter, composed of a 35 millimeter mesh, catches debris and dirt particles that flow from the roof [4]. The basket will need to be emptied as needed during various storm conditions for maintenance. The manhole cover on top of the device allows for easy access. The bottom-right 4-inch outlet pipe conveys the filter water directly to the cistern after it's been filtered. Once the cistern is at maximum capacity, the overflow pipe will convey any excess rainwater to the onsite storm drain location.

Figure 8 shows the external pipe layout that connects all downspout locations to the filtration device. Each pipe is composed of 4" PVC, and sloped at 1% to ensure the water is gravity fed to the intended locations.

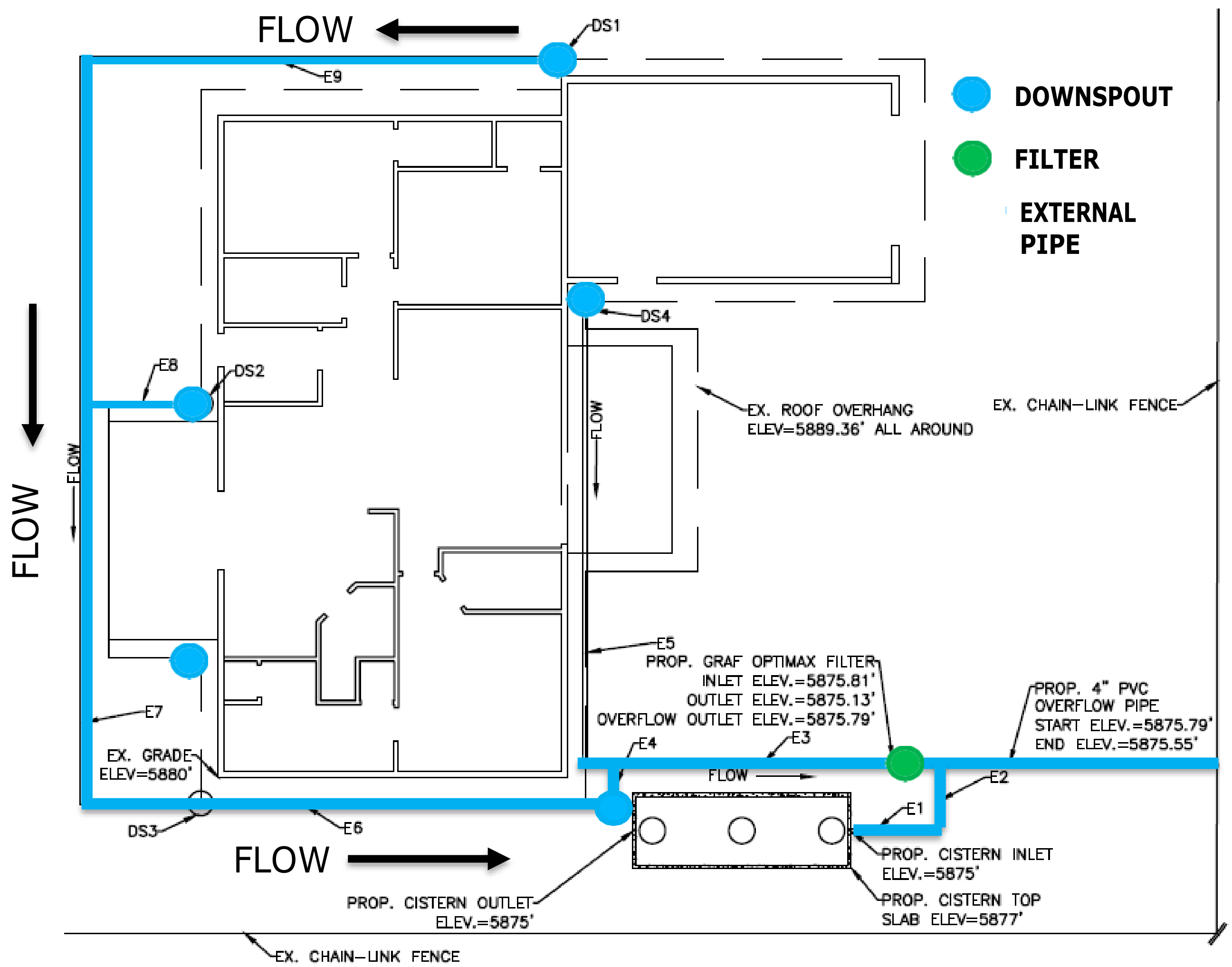

Figure 8: External Pipe Layout Schematic [9]

3.4 CISTERN SPECIFICATIONS

3.4.1 CAPACITY

The capacity of the cistern is in reference to the total amount of water the cistern will hold to meet demand requirements. The average annual precipitation data in the Flagstaff area was used to calculate the available amount of water the roof will collect during the year. Table 5 shows the precipitation data used for these calculations. The snow was converted into rainfall using a compaction ratio of 1:15, which means that every 1 foot of snow is equivalent to 15 inches of rainfall. The collection time was divided into a wet and dry season. A wet season is defined as consecutive months within a year that receive 2.5 inches per month or more of rainfall. The dry season are the consecutive months between these heavy precipitation months. For this project, the months between December-March, and July-August are the wet seasons. The months from July-August are considered to be the monsoon season during summer time. The dry season takes place between April-June, and October-November. The main collection period is within the wet seasons when there is the most precipitation occurring.

Table 5: Average Annual Precipitation Data in Flagstaff, AZ [7]

Month	Rainfall (in.)	Snow (in.)
January	2.13	18
February	2.32	17
March	2.24	15
April	1.26	7
May	0.63	0
June	0.43	0
July	2.36	0
August	3.46	0
September	2.56	0
October	1.89	2
November	1.81	7
December	2.05	11
TOTAL ANNUAL	**23.14**	**77**

Tables 6 and 7 show the amount of rainwater available for collection for the corresponding season. The precipitation values from Table 5 were used in Equation B to calculate the volume of water that will be collected from the roof area. The volume in cubic feet was then converted into gallons because cisterns are manufactured by the quantifiable gallons.

Equation B: Total Seasonal Volume

$$V(ft^3) = \Sigma P(ft.) X A(ft^2)$$

$$where\ V = Total\ Seasonal\ Volume,\ P = Precipitation,\ A = Catchment\ Area$$

Table 6: Wet Season Available Volume

Q(available) - WET SEASON			
	Available		Units
Total Precip./Snow	17.12	4.067	Inches
Total Rainwater	21.19		Inches
Wet Month Volume	**4,373**		**gal/month**

Table 7: Dry Season Available Volume

Q(available) - DRY SEASON			
	Available		Units
Total Precip./Snow	6.02	1.07	Inches
Total Rainwater	7.09		inches
Dry Month Volume	**205**		**gal/month**

In order to ensure that there would be sufficient water to supply the water demands, the team calculated the amount of water that is required to flush both toilet locations and supply irrigation based on the client's use. Table 8 shows the utility demands of each toilet, and the flow rate of the garden hose used to irrigate the vegetable garden. Table 9 shows the water demand based on the client's monthly use.

Table 8: Amount of water required to supply utilities

Utility Demands		
Utility	**Demand**	**Units**
Bathroom 1	1.6	gal/flush
Bathroom 2	1.6	gal/flush
Irrigation	6	gpm

Table 9: Monthly Utility Usage

Utility	Demand	Units
Bathroom 1	36	flushes/month
Bathroom 2	36	flushes/month
Irrigation	120	flushes/month

Tables 10 and 11 show the client's water demand based on utility usage in the wet and dry seasons. The usage is separated into two water demands because of the irrigation demand. The client will irrigate more heavily in the dry season months. The irrigation demand is still included in the wet season to account for the dry time before the monsoon season arrives. Since monsoons are high intensity rainfall with low duration, there will be an intermittent time for irrigation during summer.

Table 10: Wet Season Demand

Q (demand) - WET SEASON		
Utility	**Demand**	**Units**
Bathroom 1	57.6	gal/month
Bathroom 2	57.6	gal/month
Irrigation	38.6	gal/month
Q (demand)	**154**	**gal/month**

Table 11: Dry Season Demand

Q (demand) - DRY SEASON		
Utility	**Demand**	**Units**
Bathroom 1	57.6	gal/month
Bathroom 2	57.6	gal/month
Irrigation	720	gal/month
Q (demand)	**835**	**gal/month**

After reviewing Tables 10 and 11 and comparing them to Tables 6 and 7, it is evident that the amount of collectable rainwater in the wet season is greater than the amount demanded by the utilities. However, the amount of collectable of rainwater in the dry season is far below the amount demanded to supply the utilities. Therefore, in order to supply the utilities in the dry season, approximately 630 gallons of rainwater is required to be stored in the wet season in excess. Table 11 shows the amount of rainwater in each month that will be stored in the cistern based on the incoming available rainwater, and system demand requirements. Based on these utility demands, the highest volumetric demand that the tank will need to hold is approximately 2,700 gallons in the month of March. Equation C was used to calculate the total amount of gallons needed to supply the utilities, including excess rainwater stored in the wet season to supply the dry season. There were three assumptions built into this equation in order to accurately predict how much water would be in the cistern. The first assumption is that construction will end at the end of April. The second assumption is that the client will not use the harvested water for the first two months after construction (May-June). This will allow sufficient time for precipitation to be collected into the cistern before use. The third assumption is that the client will utilize the harvesting system in the third month after construction (July). Table 11 shows the amount of water that will be in the cistern based on the results from Equation C for one year after construction.

Equation C: Cistern Storage Volume

$$V_{cistern} = V_{total} - V_{demand} + \Sigma V_{storage}$$

$$where\ V_{cistern} = Cistern\ Volume\ \left(\frac{gal}{month}\right), V_{total} = Catchment\ Volume\ \left(\frac{gal}{month}\right),$$
$$V_{demand} = Demand\ Volume\ \left(\frac{gal}{month}\right), V_{storage} = Storage\ Volume\ \left(\frac{gal}{month}\right)$$

Table 11: One Year Analysis of Cistern Water Supply

Collection Month	Gallons/Month
May	682
June	994
July	2714
August	3000
September	3000
October	3000
November	3000
December	3000
January	3000
February	3000
March	3000
April	2321
May	2167

3.4.2 LOCATION

The cistern will be located 3-feet underground on the southeast portion of the property. This depth will ensure that the water does not freeze when temperatures drop below 32°. This 3-foot clear cover depth is measured from the surface to the top of the cistern. A manhole extension cover will be provided so the homeowner can perform routine maintenance.

3.4.3 CONSTRUCTION MATERIAL SPECIFICATIONS

The selected cistern is composed of concrete material. Figure 9 shows a cross-sectional view of the cistern selected for the final design. This model can store approximately 3,000 gallons of water with a 1-foot freeboard surface. There are two manhole entries located at the top of the cistern for maintenance. The inflow pipe will receive the filtered rainwater, and the outflow pipe will distribute the water to the pressure tank. The original scope of services specified a concrete slab design to provide a foundation for the cistern. The cistern manufacturer, Jensen Precast, specified a 6-inch aggregate base instead in order to provide appropriate structural support.

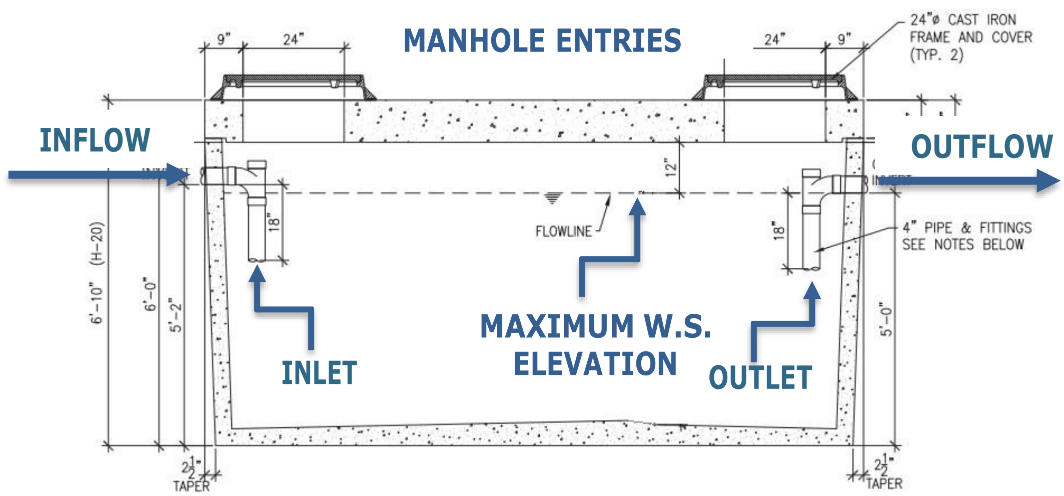

Figure 9: Concrete Cistern Section View [10]

3.4.4 DISINFECTION

3" chlorine tablets are required to provide sufficient disinfection for the cistern. In order to disinfect the water appropriately, one tablet of chlorine is necessary per 1,000 gallons. The water level will need to be checked by the client to determine how much water is in the tank. Pool pH strips are also an available option to check the pH levels in the water. This will ensure that the water is not over, or under, chlorinated.

3.4.5 GEOTECHNICAL EVALUATION

A soil analysis was performed to analyze the on-site soil surrounding the proposed location of the subterranean cistern. A dry sieve analysis was completed to classify the soil, and to create a distribution of grain sizes. It was determined through the Unified Soil Classification System (USCS) method that the composition of soil is a well-graded gravel with silt and sand. This soil classification provided a more comprehensive understanding of the site characteristics. These results can be found in Figure 10. A proctor compaction test was performed to determine the unit weight of the soil as well. The unit weight of the soil was necessary in order to determine the bearing capacity of the slab foundation. These results can be found in Table 12.

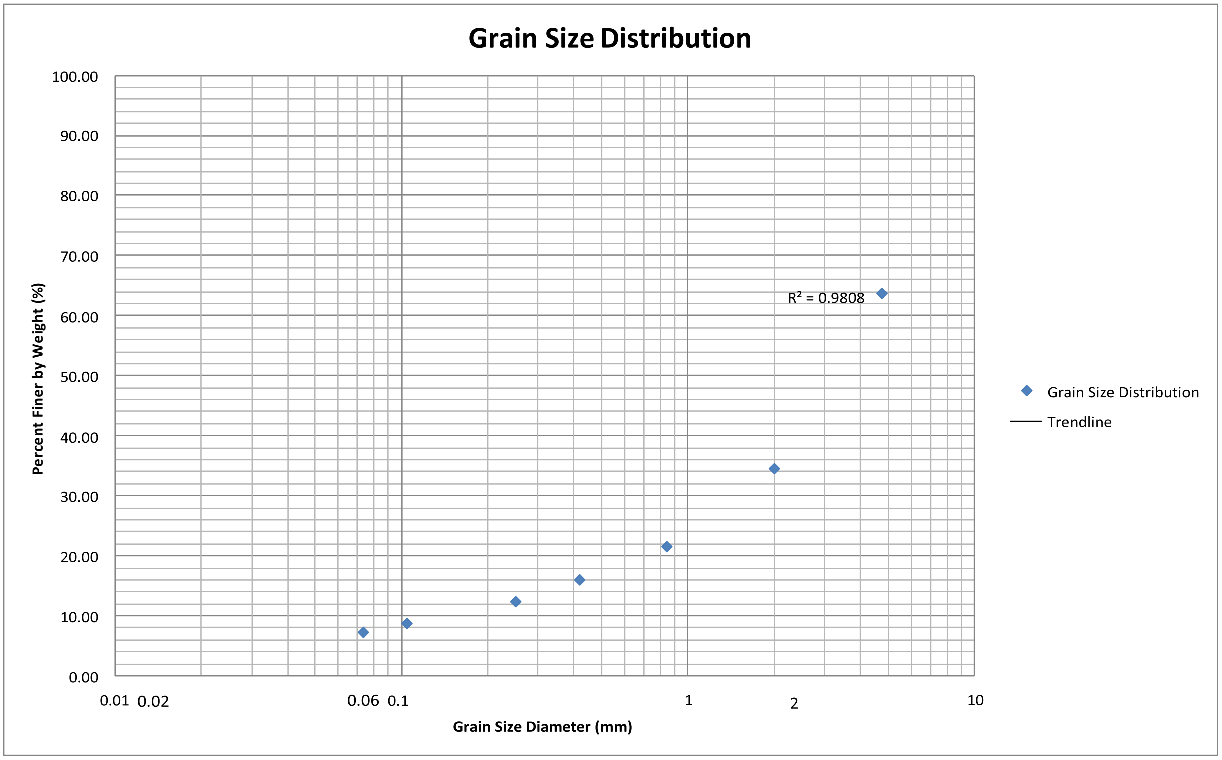

Figure 10: Grain Size Distribution Results

Table 12: Tabulation of Sieve Analysis Raw Data and Results

Sieve #	w_{sieve} (g)	$W_{sieve \& soil}$ (g)	Retained Weight (g)	Percent Retained (%)	Cumulative Retained (%)	% Finer by Weight	Sieve Size (mm)
4	774.39	1102.25	327.86	36.24	36.24	63.76	4.76
10	438.84	703.20	264.36	29.22	65.47	34.53	2
20	393.55	510.36	116.81	12.91	78.38	21.62	0.841
40	384.40	435.64	51.24	5.66	84.04	15.96	0.42
60	541.39	573.23	31.84	3.52	87.56	12.44	0.25
140	339.94	373.64	33.70	3.73	91.29	8.71	0.105
200	320.63	333.32	12.69	1.40	92.69	7.31	0.074
pan	370.65	436.75	66.10	7.31	100.00	0.00	0
Σ	3563.79	4468.39	904.60	-	-	-	-

The results from these tests were originally intended for the slab design calculations, as well as soil pressure analysis. The slab design would have incorporated different failure modes of overturning, and bearing capacity, which requires the results from the geotechnical evaluation. However, these results were not necessary for completing the scope of services outlined in the proposal. This was due to the fact that Jensen Precast, the cistern manufacturer, specified an aggregate base for a structural foundation for the cistern. This is further described in Section 3.4.7 of this report.

3.4.6 PUMP SELECTION AND SPECIFICATION

In order to select an appropriate pump to supply the pressure tank from the cistern, the team utilized the 2012 International Residential Building and Plumbing Code to determine minimum pressure requirements for toilet and irrigation use in residential sites. Toilets require a minimum of 20 psi from the 2012 IRC Table P2903.1, and Table P2903.6 specifies a minimum flowrate of 5.3 gpm is required [3]. This was set as design criteria for selecting a pump; a 6 gpm pump with operating pressure range of 30-50 psi was selected.

Since PVC piping will be utilized for distribution from the cistern to the pressure tank, the Swamee-Jain and Energy equation were used to calculate the friction factor and required total dynamic head of pump, respectively [4] [5]. Equation D was used to calculate the friction factor. This value was then used to determine the headloss due to friction and minor losses in the pipe. Equation E shows the equation used to calculate the headloss due to friction, and Equation F shows the equation used to calculate the headloss due to minor losses. These headloss results were then applied to the energy equation (Equation G) to calculate the head of pump required to operate the system, as well as the minimum pressure that will supply the furthest toilet location in the home.

Equation D: Swamee-Jain [11]

$$\frac{1}{sqrt(f)} = -2\log\left(\frac{\varepsilon}{(3.7D_h)} + \frac{5.74}{R_e^{0.9}}\right)$$

$$where\ f = frisction\ factor, \varepsilon = pipe\ roughness\ coefficient,$$

$$D_h = hydraulic\ radius\ (ft), R_e = Reynold's\ Number$$

Equation E: Headloss Due to Friction [11]

$$h_{lf} = (f)\left(\frac{L}{d}\right)\left(\frac{v^2}{2g}\right)$$

$$where\ f = friction\ factor, g = gravity\ \left(\frac{ft}{s^2}\right), L = pipe\ length\ (ft),$$

$$d = pipe\ diameter\ (ft), velocity = \left(\frac{ft}{s}\right)$$

Equation F: Headloss Due to Minor Loss [11]

$$h_{lm} = \Sigma(\xi \frac{v^2}{2g})$$

$$where\ \xi = pipe\ fitting\ loss\ coefficient, v = velocity\ \left(\frac{ft}{s}\right), g = gravity\ (\frac{ft}{s^2})$$

Equation G: Energy Equation [11]

$$z_1 + \frac{p_1}{\gamma} + \frac{v_1^2}{2g} + h_p = z_2 + \frac{p_2}{\gamma} + \frac{v_2^2}{2g} + h_t + h_{lf} + h_{lm}$$

$$where\ z = elevation\ head\ (ft), p = pressure(psi), \gamma = unit\ weight\ of\ water\ \left(\frac{lb}{ft^3}\right),$$

$$v = velocity\ \left(\frac{ft}{s}\right), g = gravity\ \left(\frac{ft}{s^2}\right), h_p = head\ of\ pump\ (ft),$$

$$h_t = head\ of\ turbine\ (ft), h_{lf} = friction\ losses\ (ft), h_{lm} = minor\ losses\ (ft)$$

The results for the required head of pump and toilet pressure from these equations can be seen in Tables 13 and 14, respectively. According to these results in Table 13, the pump will need to operate at 6 gpm and 112 feet of total dynamic head to meet system demand requirements. In order to supply sufficient pressure to the furthest toilet location from the pressure tank, a pressure of at least 20 psi must be supplied to meet IRC code requirements. Table 14 shows that according to the energy equation results, the toilet will be supplied at 27.8 psi, which exceeds the minimum requirement.

Table 13: Energy Equation Results for Required Head of Pump

Variable	Symbol	Units	Value
Cistern Elevation	z_1	feet	5871.5
Cistern Pressure	P_1	psi	11.2
Cistern Velocity	v_1	ft./s	0
Head of Pump	$\mathbf{h_p}$	***ft.***	***112***
Tank Elevation	z_2	feet	5887.5
Tank Pressure	P_2	psi	50.0
Toilet Velocity	v_2	ft./s	0
Friction Loss	h_{lf}	feet	2.31
Minor Losses	h_{lm}	feet	4.18

Table 14: Energy Equation Results for Toilet Pressure

Variable	Symbol	Units	Value
Tank Elevation	z_1	feet	6883.5
Tank Pressure	P_1	psi	30.0
Tank Velocity	v_1	ft./s	0
Toilet Elevation	z_2	feet	6883
Toilet Pressure	$\boldsymbol{P_2}$	***psi***	***27.8***
Toilet Velocity	v_2	ft./s	0
Friction Loss	h_{lf}	feet	2.11
Minor Losses	h_{lm}	feet	3.44

In order to meet the system demand requirements, a 1 horsepower (HP) irrigation pump was selected for the final design [12]. Figures 11 shows a schematic of the selected pump. The rainwater from the cistern enters a 1-inch inlet pipe, which is then pumped to the pressure tank through a 1-inch outlet.

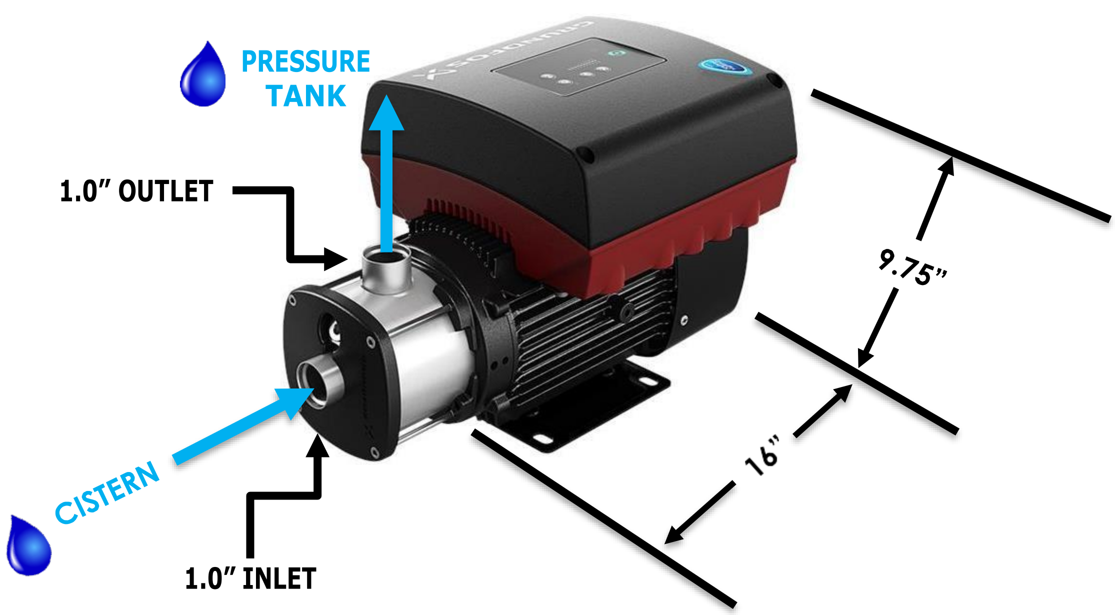

Figure 11: Schematic of Selected Pump [12]

Figure 12 shows the operating curve of the selected pump. It operates at 62% efficiency at 112-feet of total dynamic head at 6 gpm [12]. The net positive suction head available that this pump can produce is 16.52-feet, and the distribution system only requires approximately 9-feet of net positive suction head [12]. Therefore, this pump is adequate for the intended use of this system.

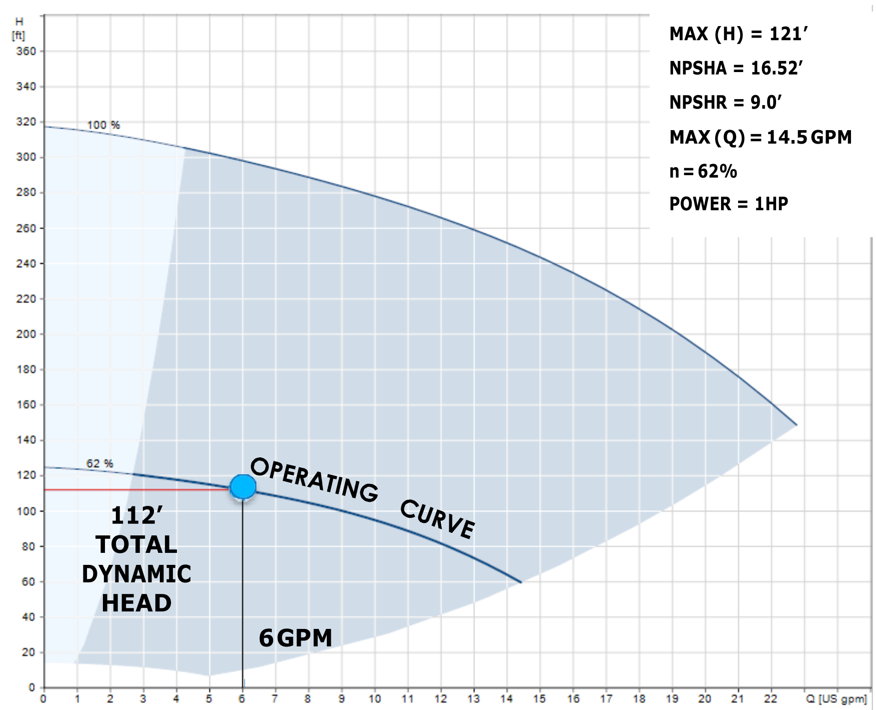

Figure 12: Operating Curve for Selected Pump [12]

3.4.7 SLAB DESIGN

A slab design is not necessary since a concrete cistern with a 6-inch aggregate base will provide as a structural foundation. This was a design specification from Jensen Precast, the cistern manufacturer.

3.5 PRESSURE TANK

3.5.1 DESIGN COMPONENTS

The intended use of the pressure tank is to distribute water to the two toilet locations, and existing irrigation spigot on the side of the home. The IRC for single-family homes specifies that 6 gpm of flow at a minimum of 20 psi of pressure must be supplied to toilet outlets per section P2903.1 [13]. For these reasons, a bladder-type pressure tank operating between 30 and 50 psi was selected. It operates at a flowrate between 6-8 gpm, which meets the minimum IRC flow requirement [14]. There were not any codes for specifying pressure at an irrigation outlet, but conditions will be equal to or greater than the designed toilet outlet flowrate and pressure, and are adequate for the client's utilization. The current irrigation system operates at approximately 40 psi, and operates at 6 gpm. When irrigating, the client may experience a reduction in pressure due to length of garden hose utilized. This system is designed for a standard 100-foot garden hose, with a 1-inch orifice.

A bladder-type pressure tank, was selected for this design element. Figure 13 shows a simple schematic of how the pressure tank will operate. The pressure tank is connected to the pump that supplies the water to the tank from the cistern. Stage A of the schematic shows the pressure tank empty and the pump turned off. At this stage the tank is charged to a minimum pressure of 30 psi. Stage B shows water filling into the bladder bag inside the pressure tank when the pump is turned on. When the water fills the bladder bag, the pressure inside the tank increases. Stage C shows the pressure tank at maximum pressure of 50 psi, when the bladder bag is at maximum capacity. At this point, the pump will automatically turn off. Stage D shows the pressure tank distributing water from the bladder bag. At this point, the pressure within the tank will decrease as water leaves the system. The pressure will continue to decrease until a minimum of 30 psi is reached, then the pump will turn back on to continue the operating cycle.

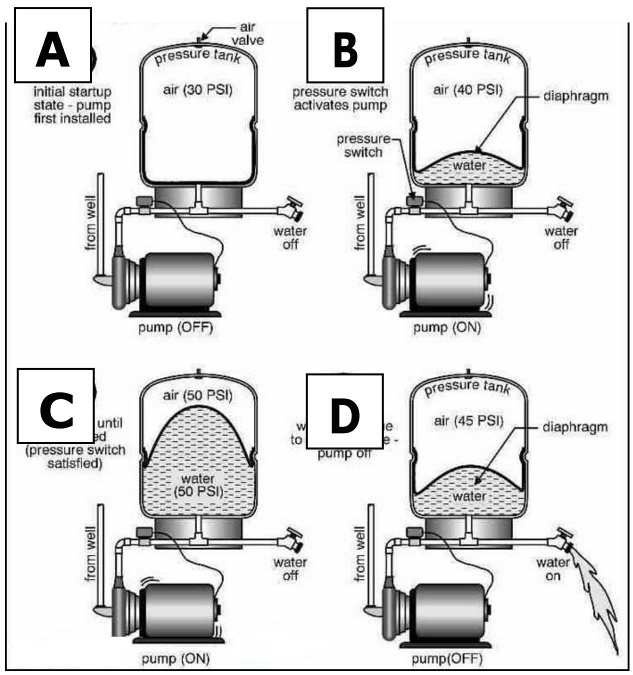

Figure 13: Bladder-Type Pressure Tank Schematic [15]

Additionally, the tank should hold between 20 to 35 gallons, to ensure that the pump is able to supply the tank at a rate equal to, or greater than, the rate of water usage for irrigation and toilet flushing. It is recommended that a 30-50 psi pressure switch is installed with the pump and pressure tank to ensure that operating pressures are constantly supplied. The switch ensures that the pump turns off once 50 psi is reached in the tank, and turns on when the tank pressure decreases to 30 psi. A pressure relief valve is required by municipal code to prevent excess pressure from building within the system; if this were not installed, the diaphragm in the pressure tank could break and cause the tank to require replacement. A check valve is required to prevent backflow from the pressure tank to the pump. A pressure gage is recommended so that a visual representation of the operating pressure of the tank can be observed.

Finally, a drain valve is recommended so that water from the pressure tank can be removed in case the pump, piping, or tank components are required to be inspected, maintained, or replaced, which are not including in the approved scope of services, and therefore is at the discretion of the client to perform himself or by a separate contracted agency or company.

3.5.2 LOCATION

The pressure tank will be located within the utility closet in the client's home. Placing the pressure tank inside the home has advantages against frost and freezing, and corrosion due to weathering. Figure 14 shows the internal pipe layout schematic, which also includes the location of the pressure tank, pump, two toilet locations, and irrigation spigot. The internal pipes connect to the back of the toilets at each location. A gate valve is also recommended at each toilet location in order to ensure that the client can switch the toilets supply back to municipal if needed.

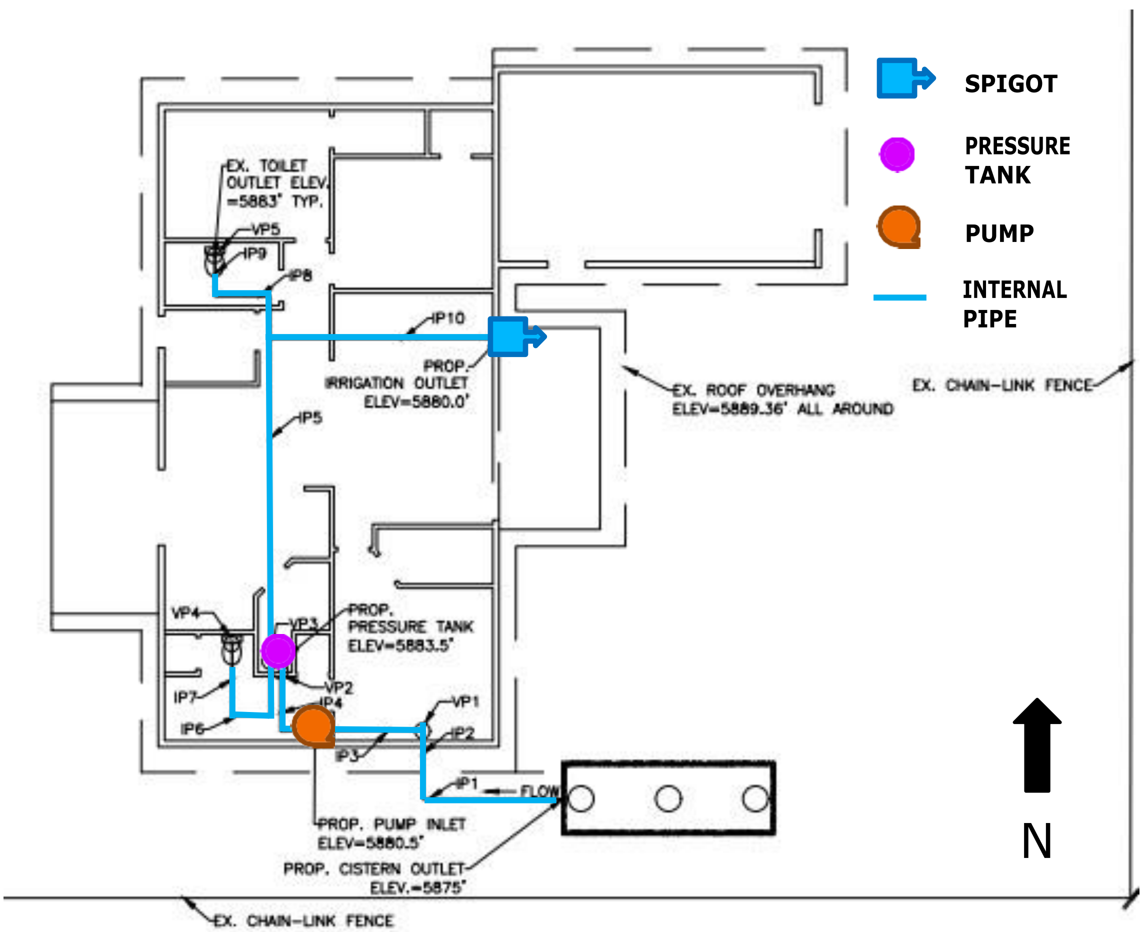

Figure 14: Internal Pipe Layout Schematic

3.5.3 DISINFECTION

Water in the cistern will be chlorinated, deactivating most bacteria that will be present in roof runoff. This water supplies the pressure tank upon usage, so at this time, it is expected that daily operation of the tank is adequate to prevent harmful bacteria from growing past the outlet of the cistern. Therefore, no separate disinfection method is required for the pressure tank component.

3.6 BATHROOM DISTRIBUTION DESIGN

3.6.1 DISTRIBUTION SYSTEM

The distribution system within this task refers exclusively to the design of the required pipe network layout connecting the pressure tank to both toilet outlet locations within the client's house. From the outlet of the pressure tank, a single pipe will connect to a brass t-splitter, from which the piping will lead to each individual toilet outlet. 90-degree elbow fitting are to be used where vertical pipes or direction changes are required to fulfill this design. At the toilet outlet, brass dual-splitter connections with built-in check valves are required to connect the existing potable line and the proposed design line to the toilet. These shall be installed such that the client has easy and reasonable access to operate the valves in order to operate the toilet flushing water using potable water when cistern water is unavailable, or when construction is underway. It is required that the check valve of the source not being utilized for supplying the toilet lines is turned off in order to prevent cross-contamination of source water, especially to avert cistern-provided water from flowing into the municipal supply.

3.6.2 CONSTRUCTION MATERIAL SPECIFICATIONS

The piping and connections within the bathroom distribution network shall be constructed from 1" PEX material. The connection from the cistern shall be a 4"-to-1" contraction of either brass or PEX material, and can be eccentric or concentric in design. Lines running into and out of the pump and pressure tank shall be 1" PEX material as well. All required fittings and bends shall be made of a PEX material, or another compatible material.

3.7 IRRIGATION DISTRIBUTION DESIGN

3.7.1 RAIN BARREL SELECTION

This section refers solely to the required calculations and verification of any applicable codes to irrigation distribution networks for residential sites; however, no codes were required to be met, and therefore no calculations were necessary to ensure compliance with associable agencies. However, as previously described in section 3.5.1, similar flow and pressures to the toilet outlets can be expected at the spigot location; however, hose length and respective outlet elevation respective to the spigot outlet will alter the pressure experienced by the outflow end of the hose during irrigation.

3.7.2 PIPE NETWORK DESIGN

This section refers to the 1" PEX pipe that will be connected to the proposed bathroom distribution line running from the pressure tank to the toilet located in the north portion of the client's house, as shown in Figure 10. The outlet shall be selected in accordance to a compatible fitting with respect to the proposed 1" PEX line and the existing spigot material and size. A dual-splitter connection with built-in check valves are required in order to prevent backflow when one source, either the cistern supply or municipal supply, is not being used for irrigation. This connection shall be installed similarly to that described in section 3.6.1 in regards to the ease of access for the client's manual operation of this system. The internal and external pipe network design schematics can be found in Figure 8 in Section 3.3.4, and Figure 14 in Section 3.5.2 of this report, respectively.

3.7.3 DISTRIBUTION SYSTEM

This section refers solely to the required calculations and verification of any applicable codes to irrigation distribution networks for residential sites; however, no codes were required to be met, and therefore no calculations were necessary to ensure compliance with associable agencies. However, as previously described in Section 3.5.1, similar flow and pressures to the toilet outlets can be expected at the spigot location; however, hose length and respective outlet elevation respective to the spigot outlet will alter the pressure experienced by the outflow end of the hose during irrigation.

4.0 SUMMARY OF PROJECT COSTS

Table 15 below displays the cost of the aluminum gutter components required to implement this design [16]. The total cost of the aluminum gutter components came out to $798, whereas the total project cost of components came out to $9,674 as shown in Table 16. This total project cost does not include the cost of engineering services required by this project, excavation, or construction. It was additionally estimated from this project's proposal that a total of 453 hours would be required to complete this project based on the previous scope of services, as shown in Table 17. The hours from this estimate were based on the required tasks of a multidisciplinary engineering and management team, including a senior engineer, an engineer II, an engineer I, a geotechnical lab technician, as well as an administrative assistant. However, the number of hours distributed through these positions varied throughout the actual design of this project due to a change in scope of services. Because a slab design was not necessary, rain barrel selection was removed, and the pressure tank design was added, many design hours were reallocated. The pressure tank component was the main source of the decrease in hours because it replaced various components that did not need design work. Table 18 shows that an estimated 412 hours of design were completed throughout this project. Because of this difference of approximately 40 hours of labor between the proposed and completed design, the cost of engineering services was reduced from $32,771 to $30,578. In total, the cost of engineering services with the project component cost came out to $40,252, which does not include the cost of required construction or excavation.

Table 15: Aluminum Gutter Costs [16]

Parameter (units)	Quantity	Cost/Unit ($)	Cost ($)
Heat Tape (160 ft. Section)	2	112	224
Outside Corner Piece	10	84	84
Inside Corner Piece	6	8	50
Downspout	5	22	110
10' Section	15	10	141
5" End Cap	5	3	15
Mounting Brackets	146	0.98	143
Downspout Filter	4	8	32
TOTAL			***798***

Table 16: Project Component Costs

Parameter (units)	Quantity	Cost/Unit ($)	Cost ($)
Gutter Components (LS)	1	798	798
CME3-7 Pump (LS)	1	2,000	2,000
Concrete Cistern (LS)	1	5,550	5,550
PEX Piping (LF)	110	0.45	50
PVC Piping (LF)	282	2	494
Pressure Tank (LS)	1	324	324
Graf Filtration Device (LS)	1	459	459
TOTAL			***9,674***

Table 17: Proposed Cost of Engineering Services

Classification	Hours	Billing Rate, $/hr	Cost, $
SENG	13	170.00	2,210
ENG II	117	100.00	11,700
ENG I	265	65.00	17,225
GTECH	13	22.00	286
AA	45	30.00	1,350
TOTAL	***453***	***32,771***	

Table 18: Actual Cost of Engineering Services

Classification	Hours	Billing Rate, $/hr	Cost, $
SENG	26	$ 170.00	$ 4,420
ENG II	105.5	$ 100.00	$ 10,550
ENG I	210.5	65.00	13,683
GTECH	20	22.00	440
AA	49.5	30.00	1,485
TOTAL	***411.5***	***30,578***	

5.0 PROJECT IMPACTS

Our project has impacts that can affect economics, society, health, and the environment. For the economics part, the budget of a rainwater harvesting project really determines what type of materials will be used for the different aspects of the project. This budget would influence the final design of a rainwater harvesting project because the designers would mainly focus on getting quality material that would work for the design but also to try and get the material as cheap as possible. This project would also have the potential to lower the user's water bill [17]. The client would end up using less water from the municipality because most of the water would come from the rainwater that is being collected. For the society aspect, our client would be able to educate others about how this system works and how it is beneficial for people to use. The client would be able to talk to his co-workers, students, family and neighbors. For the health aspect, the rainwater that is collected is usually cleaner than water that is distributed by the municipality because it is free of salts, minerals, and natural and man-made contaminants [17]. However, if the user does not properly filter the rainwater, the rainwater could get added contaminants from the gutter collection system. For the environmental aspect, rainwater harvesting systems save ground water sources, could help with climatic changes, excess water can recharge ground water and can reduce floods and soil erosion. Since rainwater harvesting systems use rainwater, ground water sources could potentially rise by a slight amount because one less household will be using water from the ground. Since less water from the ground will be used, this could help keep climatic changes more stagnate. Any water that will not be used to supply water to the household could potentially recharge the ground water supply. Even though the amount of ground water that will be saved through the use of a rainwater harvesting system is small, this amount of water over time may make a big difference, especially in an area that is currently in a drought, such as the south western states. By collecting rainwater, flooding in low lying areas can be prevented. Rainwater harvesting systems also reduce soil erosion and contamination of surface water with pesticides and fertilizers from rainwater run-off. This can result in cleaner lakes and ponds, which is good for the planet, and climate change [17].

6.0 ACKNOWLEDGEMENTS

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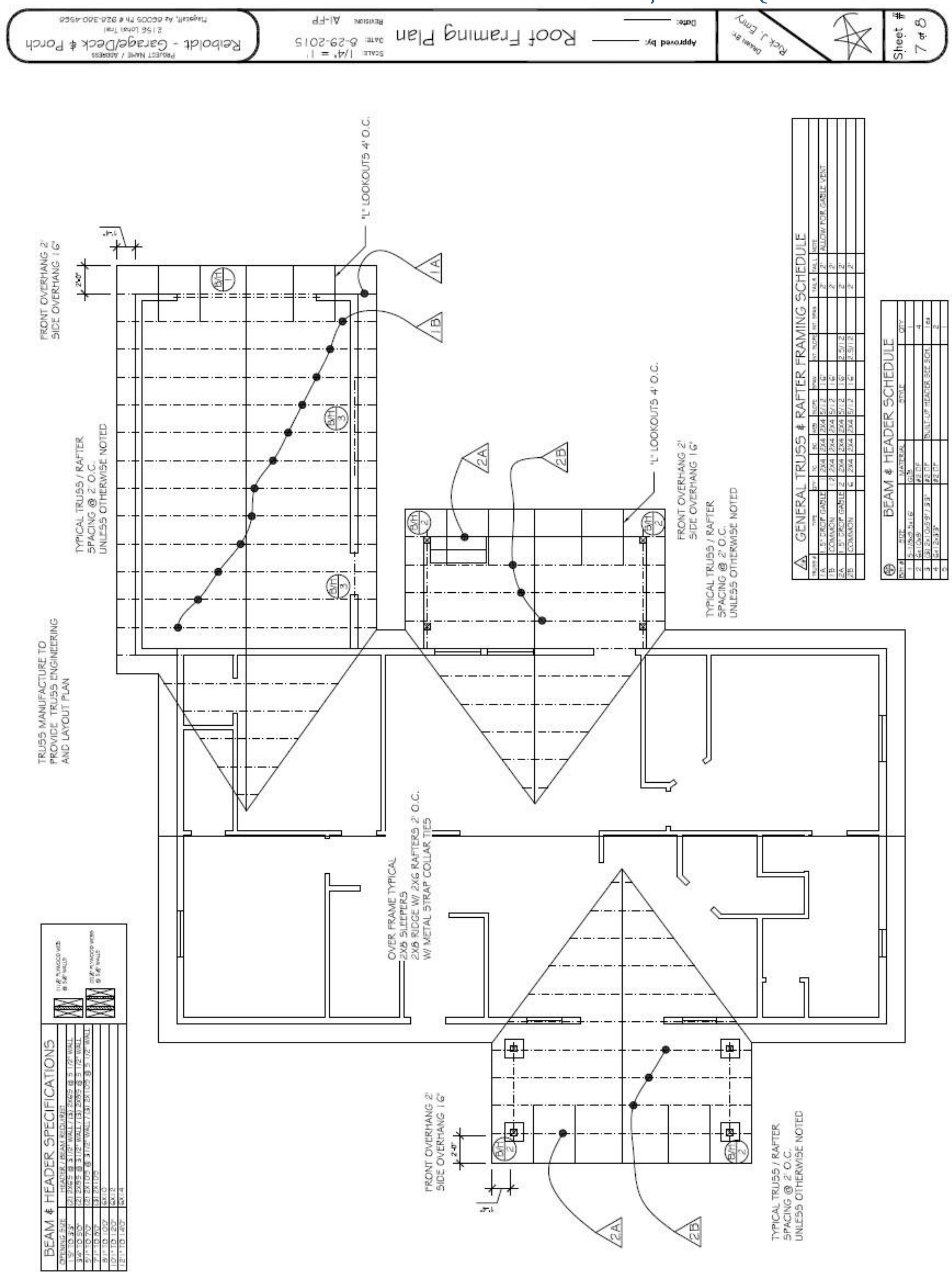
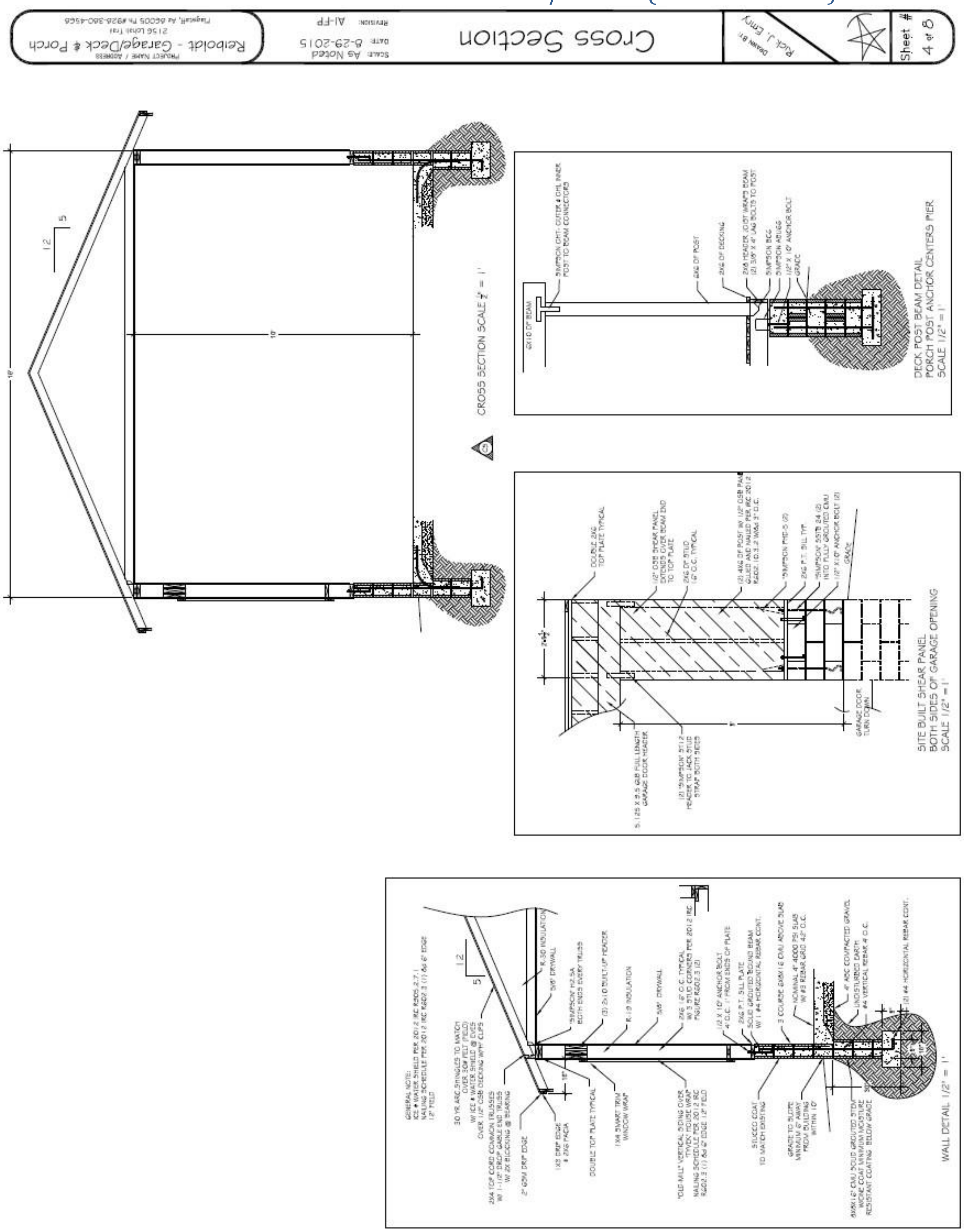
8.1 APPENDIX

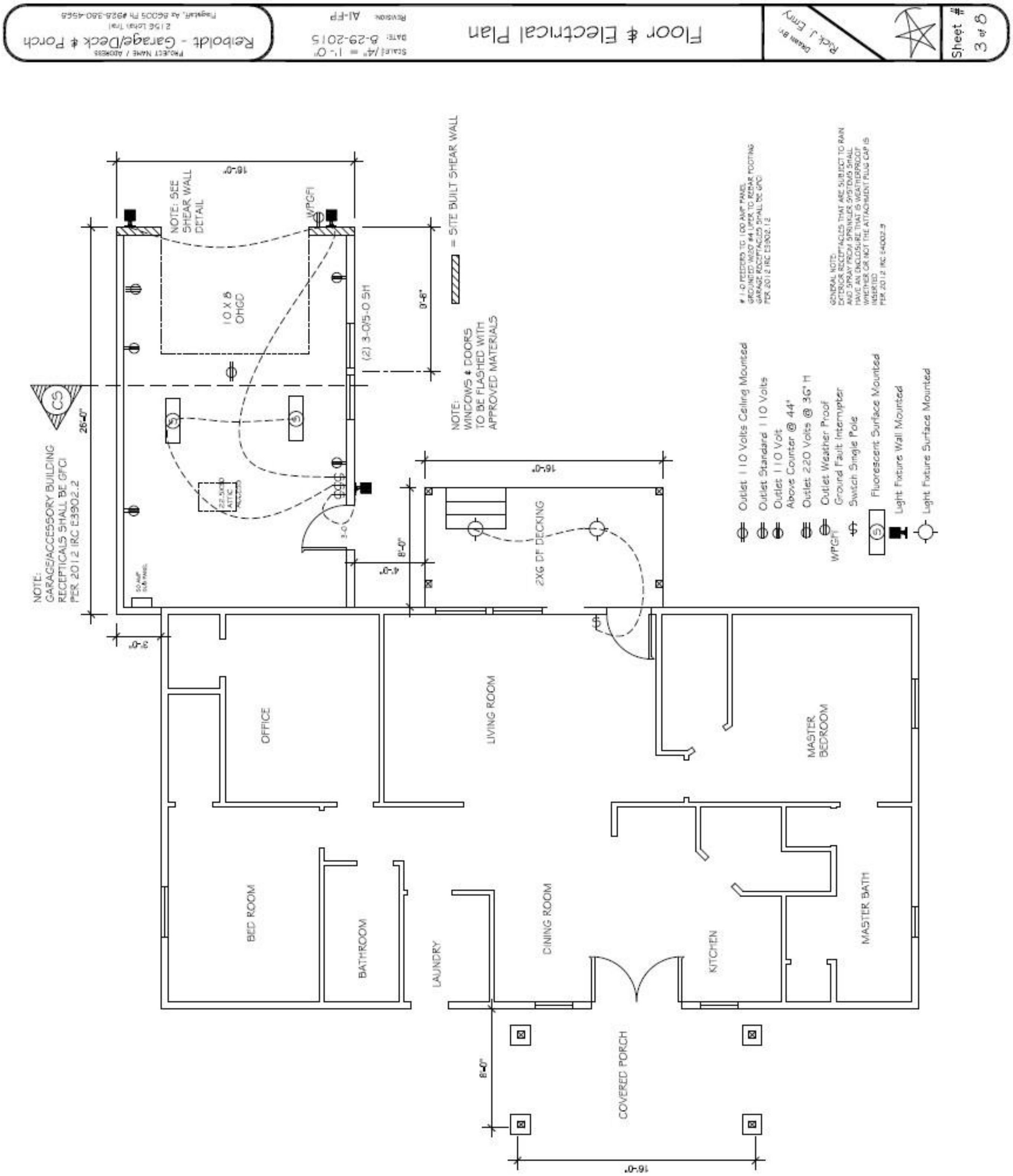
8.2 APPENDIX A: ROOF FRAMING PLAN FOR GARAGE/DECKS (NOT TO SCALE)



8.3 APPENDIX B: CROSS SECTION OF GARAGE/DECKS (NOT TO SCALE)



8.4 APPENDIX C: ELECTRICAL PLAN FOR GARAGE/DECKS (NOT TO SCALE)



8.5 APPENDIX D: DECK FRAMING PLAN (NOT TO SCALE)