Final Design Report

Entusi Model Farm Irrigation Initiative

EDNS 491 – Group F20-16-01

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Project Review

Lake Bunyonyi, located in Southwestern Uganda, is situated below a vast expanse of hilly terrain. Climate change has made rainfall patterns in the area incredibly unpredictable and thus unreliable for farmers whose livelihood depends on their crops. This project is sponsored by the Global Livingston Institute (GLI), a non-profit organization whose goal is to educate students and community leaders on innovative approaches to international development and empower awareness, collaboration, conversations, and personal growth. In order to help solve the problem of unreliable rainfall, GLI has tasked our team with designing an irrigation system for the farmers of the Lake Bunyonyi community. The main constraints for this project are the cost of the design, lack of resources such as electricity or fuel in the area, the accessibility of materials, constructability, the amount of maintenance required, and the ability to serve the greatest number of community members.

This report details the team's progress in designing a low-cost irrigation system which is tailored to the unique geography and landscape of the community area surrounding Lake Bunyonyi. Initially, our team began the project by doing extensive research on the community, the lake, and existing solutions that could be applied to the Lake Bunyonyi region. Our research, along with conversations with GLI sponsors and local engineers, allowed us to gain a better understanding of the scope of the project and what was needed. This led to the first milestone of the Preliminary Design Report, in which the team presented many possible solutions falling into one of three subsystems: Water Transportation, Water Storage, and Water Delivery. A design matrix was developed with weighted selection criteria corresponding to the project's main design constraints. The steep terrain combined with the lack of electricity and access to fuel in the Lake Bunyonyi region caused our team to focus the bulk our research on various human and solar powered pumps that can be used to transport water from the lake to the model farm. These pumps have an overall output of approximately 10-15 meters. From the design matrix, a mechanical pump seemed to be the best option.

At the beginning of the second semester, GLI stressed the importance of the proposed solution being applicable to all of the members of the community. After learning that the majority of the community members live higher that 15 m in elevation from Lake Bunyonyi, it became apparent that the use of a human powered or solar pump would not be applicable for the bulk of the community due to their limited output. To serve as much of the community as possible, our team collaborated with Team 2 to discuss the possibility of creating different design solutions for community members living at different proximities to the lake. This idea was well received by GLI, and our team elected to take the challenge of creating a design solution for community members living above 15 m in elevation from Lake Bunyonyi, outside the range of the proposed pump solutions. Therefore, the team decided to transition into designing a rainwater catchment system. After analyzing rainfall and crop data and learning that the terrain begins to flatten higher in the hills, the team proposed a combined retention pond and siphon system that could be used to store and transport the largest volume of water at the given price point. However, after water quality and seismic concerns, combined with the fact that the retention pond was not received well by the community, our team decided to discard the retention pond aspect of the design and began researching alternative water storage methods. Originally, this solution consisted of a buried tank and siphon pump to store and transport water to the farmers. The use of a water storage tank was then redesigned to work in tandem with farmers' roofs. A gutter will be fastened onto farmers' roofs which will guide water into a nearby tank. As this rainwater catchment system utilizes available materials and is relatively low-cost, the team has found this to be the final design. This will make water more easily accessible for farmers located up on the nearby hills during the dry seasons. The rainwater catchment solution that our team has designed will allow future engineers working on the project to refine and begin its implementation. An operations and maintenance manual will need to be made to educate farmers and community leaders on how to use and upkeep this system.

Figure 1: Entusi Model Farm, Sponsored by GLI [1]

Application of Design Methodology

As we have seen over the past two semesters, engineering problems never have a direct solution. With the influx of information, the problem has the ability to evolve and change. As a team, what we can agree is the proposed solution in this report is the best solution with the given requirements and will best impact the Lake Bunyonyi community. At the start of this project, the team was excited to learn about the ins and outs of the community and determine how best to fix its current water shortage problem. Since the partnership with GLI has been ongoing, we were fortunate to have a team before we do a project and research which we used heavily to make assumptions in the initial phases of designing our solutions. Using their research allowed us to save time or dive deeper into the information that had found to find clear answers and ask deeper technical questions to our project advisors and the client. Allowing each team member to research their topics allowed the information to be more valued when designing the solutions or asking the question since each one of us was an expert in different fields.

During the initial phases, our team decided to identify restrictions, exclusions, and assumptions for the scope of the project and keep referring to them as we got along so that the client understood clearly where our efforts were going towards and that if changes needed to be made the entire project team was made aware of them. This allowed the team to stay focused for the entirety of the two semesters and designing the best solution. As part of the humanitarian department, this project was heavily focused on making an impact on the individuals who live in the Lake Bunyonyi community, and therefore understanding their needs, style of living, daily life activities, and future made a huge impact on how we approach this problem. As a team, we decided to design a stakeholder map (See figure 2 below) which outlines how a simple change can make an impact on the local economy, environment, and the lives of people. This map allowed the team to understand needs and get the local context of what the solution needs to look like and perform.

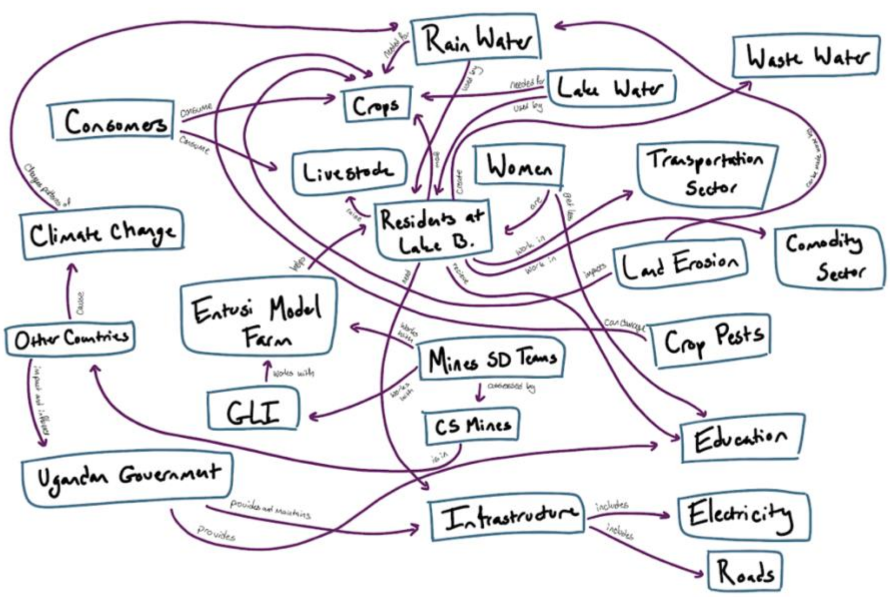


Figure 2: Stakeholder Map

The greatest tool we used across the project was our biweekly meetings with our project advisors and our client. Communication was crucial to this project due to the large amount of information needed to design the solution and understand the local needs. During these meetings, questions were asked by team members about project-specific information but during some meetings, questions were asked to find out more information about how the client initially got involved with this community and their efforts to make this world a better place. The team was also fortunate to talk to a local engineer during a meeting which allowed us to get some more context of how engineering projects are run and built. Once solutions were drawn up based on feedback, research, and calculations, the team used decision matrices. These matrices allowed the team to dive deeper one solution at a time and find its weaknesses on construction, use and meeting the project problem to better design them later. This also allowed the client to understand what we believe was the best solution based on the teams' assumptions. As a team we decided to propose an array of solutions to the client because we didn't know how the community was going to react to our initial designs. By doing this, the team was able to create a survey for the community to take and give us feedback on what solution they think they would use and best fit their needs. The information the team gathered from these surveys heavily influenced our final solution design.

Once solutions were narrowed down to a couple of designs. Risk matrices were performed, exploring the environmental impact, human safety, and potential failure modes of the solutions. As a team, we made it a priority to make sure that the proposed it design solution was safe in all aspects. At this time, risks were either declined to be too dangerous, therefore, needed redesign or they were accepted to be safe and needed no further explorations. A mitigation plan was the outcome leading to another round of redesign and calculation analysis. Additionally, the team explored how sustainable the solutions were in terms of using local materials, lasting more than 5 years, and the need for repairs or redesigns once constructed. As current Mines's students and engineers in training, our brainstorms were based on knowledge we have collected throughout the range of classes we have taken. Getting advice from our project advisors and technical advisors allowed the team to explore new ideas and research its possibilities with the proposed solutions. We say thank you to all of them because we believe this solution will impact the community for the greater good. Once our final solution was designed for the first time, the team explored all parts of the system by running calculations to figure out its structural integrity. Decisions were made with materials or orientation of parts to improve the efficiency of the solution. Criticism was given from advisors and the client which allowed the team to redesign the solution.

Working in a developing country across the globe was the hardest part of this project due to not being able to travel there or see what it is like to live there. One of the biggest constraints the team and client agreed upon in the initial phases was to maintain a low project budget. Every time a solution was design or redesigned, a project material analysis was performed outlining the cost of materials with local prices, so the team was aware of where the solution stood at meeting this goal. Lastly, and the tool that was used mostly was the need for calculations. As a team, we took the extra measures to understand the flow of water at every point in the designs and explore how little changes could impact the price, the outcome, and the construction of the designs. What we found out early on was that some solutions were proposed were physically impossible or our designs needed complete rethinking. As engineering students, we love calculations as it makes sense to us but to our client and the community, these were just numbers so the team explained what the numbers meant in terms of outcome or risks mitigated or how the solution solved the problem.

Overall, our approach to this problem was not settling for our first solution but to strive to find the best solution that the community would implement immediately and impact for the greater good.

Tools + Techniques Used

- Last year's project + research
- Identifying restrictions, exclusions and assumptions
- Stakeholder map
- Individual research on local area + topics + GLI
- Biweekly meetings with client with question on project or client advisor
- Decision matrices
- Risk matrices (environmental + human safety + failure modes)
- Technical advisor advice
- Design criticism
- Survey with community input
- Material cost budget analysis
- Sustainable design critique
- Calculations

Engineering Analysis

After reviewing common roof types and materials used in the community, a traditional rainwater catchment using roof gutters would not be applicable for every house. As shown in Figure 3 below, common roof materials are straw and sheet metal.

Figure 3: Common Roof Types in Lake Bunyonyi Community

Straw roofs will not support a mounted gutter system; however, community members still have the opportunity to facilitate rainwater catchment by incorporating the funnel catchment system proposed during the intermediate design phase. This design is freestanding and impartial to site specific conditions. The design calculations are divided into two sections: Funnel Catchment Calculations and Roof Catchment Calculations. Additional analysis on water supply and sustainable design are provided.

Funnel Catchment Calculations

Reservoir Calculations

As stated in the risk analysis section, the team determined that the safest and most cost-efficient reservoir is a storage tank. The premise of the design is extremely cost-driven. With an average budget of $100-200 USD, we have decided to select the 1000L Gentex tank priced 191,000 UGX or roughly $52 USD.

Since the team is designing a solution for community members living above 15m in elevation from the lake, we have moved outside the confines of the model farm, and thus, there is not a specific site selected for this design solution. For this reason, our team does not want to make any site-specific assumptions such as roof size and overall layout. Therefore, our team is designing a stand-alone rainwater catchment system that can function independent of site-specific features. Accompanying the storage tank will be a harvesting funnel that acts to increase the surface area of the tank inlet, ultimately maximizing the amount of rainfall collected. For ease of constructability, the funnel will be square shaped, lined with a plastic tarp, and supported by a simple wood frame. The square shape also makes the funnel impartial to the direction of rainfall, ensuring effective rainwater catchment.

The purpose of this calculation is to determine the design length of the top of the square funnel in order to completely fill the 1000L tank during the first rainy season of a calendar year (March-May). The harvested water can then be used at the farmers' disposal during the dry season (June-

August). The nearest city, Kabale, has an average accumulated rainfall of 370mm during the first rainy season. [1] An assumed 90% efficiency of the funnel system is used to mitigate any water losses that may occur. Included in Appendix C is the design length table for the various tank sizes to accommodate farmers with differing budgets than expected, or if several community members feel it best to combine finances for a larger tank. Also included in Appendix D is the cost and overall value (Liters/$) of each tank size to better assist in the farmers' decision making.

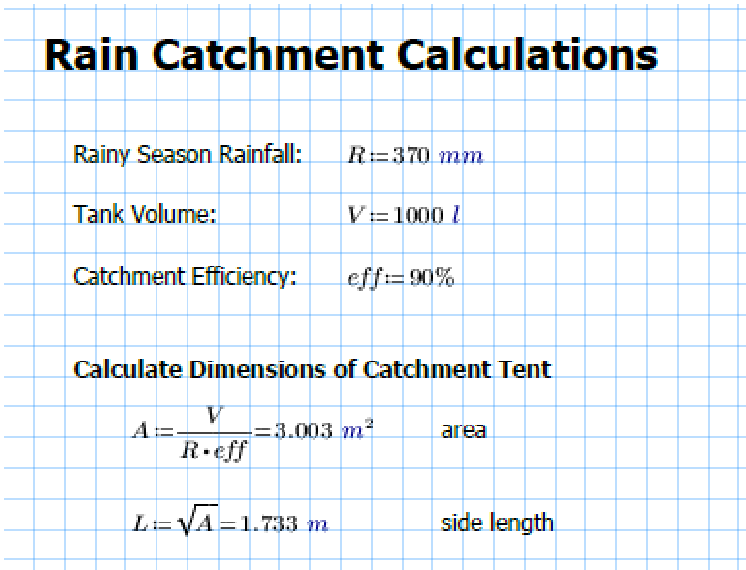


Figure 4: Excerpt of Catchment Calculations Created in Mathcad

This calculation shows that in order to completely fill the 1000L tank during the rainy season, the square funnel should have the dimensions of 1.73m x 1.73m or 5.69ft x 5.69ft. As stated in the risk analysis section, the tank will be buried to mitigate seismic concerns and to remove the reservoir from direct sunlight, mitigating the risk algae and aquatic plant growth as well. However, the tank will be partially buried (approximately 10 inches of the top of the tank will be above the ground surface level) to reduce the risk of runoff impurities entering the tank.

In order to facilitate this design logic, the following calculation will determine if the 1000L tank is adequate to bury. Essentially, using a factor safety of 1.5, this calculation will determine if one of the empty 1000L PVC tank walls be able to withstand the lateral earth pressures that the soil imparts on the tank. Listed below is a table of assumptions made. Tank dimensions are provided by Gentex [2]. The 1000L tank will be analyzed in this calculation. Appendix E uses the same procedure to the determine the adequacy for all of the available Gentex tanks.

It is important to note that the following calculations use only typical soil data and specific in-situ soil testing will have to be performed to know the site-specific soil properties. In addition, under normal conditions, only active earth pressures would be present on the tank. However, due to seismic concerns, the team will analyze the worst-case scenario and include passive earth pressures in the analysis. Since the earth pressures increase with depth in which the tanks are buried, the calculations analyze a completely buried 1000 Gentex tank, further adding to the applied factor of safety. Per a local engineer, the steep terrain means that the groundwater table is at a depth greater than that in which the various tanks will be buried. As a result, effects of groundwater table will not be included in this analysis.

Table 1: Soil and Tank Assumptions

Soil Classification in Lake Bunyonyi Region	Primarily Sandy Loam Soil [3]
Typical Dry Unit Weight of Sandy Loam Soil	15 kN/m^3 [4]
Typical Internal Friction Angle of Sandy Loam Soil	35° [4]
Typical PVC Tank Flexural Strength	78 kN/m^2 [5]
Projected Shape of Cylindrical Tank Wall	Rectangular with the dimensions: height x tank diameter

Is the tank safe to bury?

Typical PVC tank flexural: $f := 78\ \frac{kN}{m^2}$

Soil surrounding Lake Bunyonyi is classified as Sandy Loam

Soil properities for sandy loam:

Unit weight: $\gamma := 15\ \frac{kN}{m^3}$

Internal failure angle: $\alpha := 35\ ^\circ$

Earth pressure constants:

Active: $K_A := \left(\tan\left(45\ ^\circ - \frac{\alpha}{2}\right)\right)^2 = 0.271$

Passive: $K_P := \left(\tan\left(45\ ^\circ + \frac{\alpha}{2}\right)\right)^2 = 3.69$

Tank dimensions (1000L):

Height: $h := 1.33\ m$

Diameter: $d := 1.08\ m$

Tank Area Profile: $A := d \cdot h = 1.436\ m^2$ assume rectangular profile

Factor of safety: $FS := 1.5$

Adjusted Flexural Capacity: $P := \frac{f}{FS} = 52\ \frac{kN}{m^2}$

Max Flexural Force: $F := P \cdot A = 74.693\ kN$

Active Earth Pressure

$$P_A := \frac{1}{2} \cdot \gamma \cdot K_A \cdot h^2 = 3.595\ \frac{kN}{m}$$

$$F_A := P_A \cdot d = 3.883\ kN \qquad < 74.7 \text{ (adjusted flexural capacity)}$$

Passive Earth Pressure

$$P_P := \frac{1}{2} \cdot \gamma \cdot K_P \cdot h^2 = 48.957\ \frac{kN}{m}$$

$$F_P := P_P \cdot d = 52.873\ kN \qquad < 74.7 \text{ (adjusted flexural capacity)}$$

The adjusted flexural capacity of the tank is greater than both the active and passive earth pressures, therefore the 1000L tank is safe to bury.

Figure 5: Excerpt of Tank Adequacy Calculations Created in Mathcad

Since the adjusted flexural capacity is larger than the demands that the active and passive earth pressures impart on the tank, the 1000L tank is deemed safe to be buried. Note that in Appendix E, all of the tanks have flexural capacities larger than their demands from active earth pressures. However, since passive earth pressures due to seismic loads are being considered, tanks larger than 2500 L are deemed unsafe to be buried.

Siphon Calculations

As detailed in previous sections, the buried storage reservoir will be located at a terrace above the intended farm and the siphon system will be used to draw water from the tank to the farm. Since a specific site is not chosen for this design solution, a scenario in which the reservoir is located 3.8m above the farm is chosen.

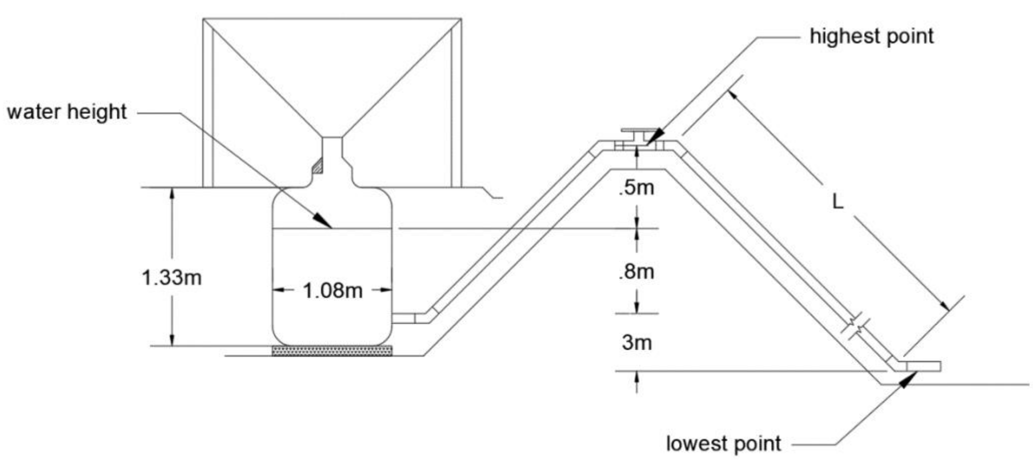


Figure 6: Siphon Problem Statement with Sample Dimensions Shown (Not to Scale)

The purpose of the calculation is to aid in selecting a standard diameter of PVC pipe that is readily available in community hardware stores. From the continuity equation, we know that the flow rate is directly proportional to the cross-sectional area of flow and the flow velocity.

$$Q = AV$$

Where Q = Volumetric Flow Rate (m^3/s)
V = Fluid Velocity (m/s)
A = Cross-Sectional Area of Flow (m^2)

Figure 6 shows a very idealized situation, in which the siphon discharge line flows in a straight line from the top of the reservoir to the discharge point. In actuality, there will most likely be small hills and bumps in the terrain as the discharge line passes from the storage tank to the farm. as shown in the extreme case of figure 6 below. Previous experience afforded the team the knowledge to know that in its current configuration, having a flow velocity too slow will result in the air lock effect as the pipe travels over bumps in the terrain, while having a flow velocity too fast will result in the water hammer effect, potentially damaging the PVC pipe.

At the top of each bump or hill, dissolved air bubbles will come out of solution and will fill the top of the pipe, decreasing the cross-sectional area of flow and ultimately decreasing the overall energy profile of the fluid. This phenomenon is known as cavitation, and if there is an excess amount of air in the pipe, the entire cross section can become filled with air and impede the flow of water. [6] In order to determine the precise minimum flow velocity, the exact topography of the site must be known. In this calculation, a conservative estimated minimum flow velocity of 1.5 m/s (equal to one-half of the effective head between the reservoir and outlet (3m)) will be used.

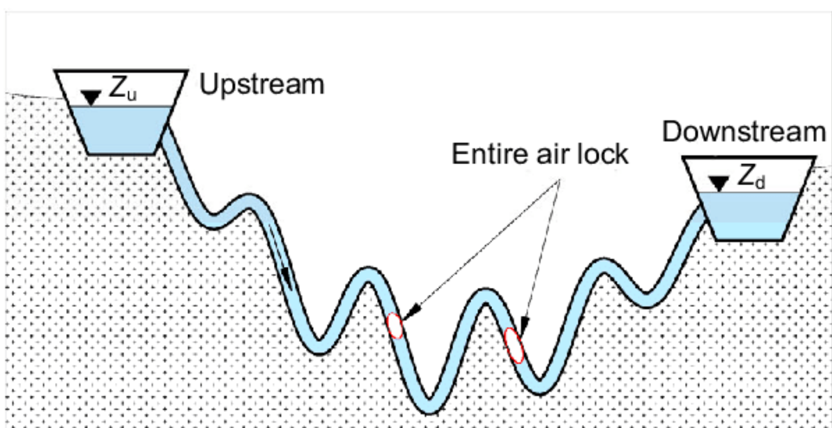


Figure 7: Schematic of Air Lock Effect [7]

The water hammer effect is caused by pressure waves induced by an abrupt change in the velocity of a flowing liquid in a pipe. [8] A standard PVC ball valve will be located at the outlet of the siphon to allow farmers to stop the water flow after irrigating their crops. The use of this ball valve will have the potential of inducing the water hammer effect, since the flow of water will be abruptly stopped. In order to mitigate this risk, the water must flow at a velocity slower than the velocity in which the water hammer effect will occur. A web-based Pipe-flow engineering tool from PipeEng was used to determine the maximum allowable flow rate for PVC pipe in its current configuration. [9] The complete flow report is provided in Appendix F. From this report, it is estimated that a flow velocity of 19.29 fps or 5.88 m/s will induce the water hammer effect when the flow of water is abruptly stopped by the ball valve.

Note the following:

- Based on the report, if the water hammer effect were to occur, the induced surge pressure on the system would be equal to 158.4 psi. The pressure rating of standard schedule 40 1" PVC is equal to 270 psi. [10] This means that that in the worst-case scenario that the water hammer effects does occur, the pipe is still safe from busting. However, lateral movement caused by the water hammer can still damage the pipe and the system will be designed against this phenomenon occurring.
- This report is simply a tool to estimate the presence of the water hammer effect, and specific flow velocities will vary with site dimensions, temperature, and pipe material.

Now that it has been determined that $1.5 m/s < V < 5.88 m/s$, we can begin the design calculations. Note that all referenced tables are provided in Appendix G.

Solve for v_2 using Darcy

First iteration:

Constants:

$\nu := 9.44 \cdot 10^{-7} \frac{m^2}{s}$ — kinematic viscosity of water based on average air temperature in Kabale, Uganda (22.5C)

$\varepsilon := 3 \cdot 10^{-7}\ m$ — roughness of PVC

$g := 9.81 \frac{m}{s^2}$ $\quad D := 1\ in$ $\quad L := 6.8011\ m$

$K_L := .5$ — squared-edged inlet [Motts Table 10.3]

$f_T := .008$ given: $\frac{\varepsilon}{D} = 1.181 \cdot 10^{-5}$ — [Motts Table 8.2]

$L_e := D \cdot 16$ — [Motts Table 10.4]

$K := \frac{L_e}{D} \cdot f_T = 0.128$

$R_e := \frac{v \cdot D}{\nu}$ — reynolds number

$f := \frac{64}{R_e}$ — assume laminar flow

Points of Head Loss:

Entrance Loss $\quad h_{LEnt} := K_L \cdot \frac{v^2}{2 \cdot g}$

Elbows (3x45°) $\quad h_{LElb} := K \cdot \frac{v^2}{2 \cdot g}$

Exit Loss $\quad h_{LExt} := 1.0 \cdot \frac{v^2}{2 \cdot g}$

Major Losses $\quad h_{Lmajor} := 1.9 + f \cdot \frac{L}{D} \cdot \frac{v^2}{2 \cdot g}$

Total Losses $\quad h_L := h_{LEnt} + h_{LElb} + h_{LExt} + h_{Lmajor}$

Combine equations

$$z_1 := \frac{v_2^2}{2 \cdot g} + h_{LEnt} + h_{LElb} + h_{LExt} + h_{Lmajor}$$

$$z_1 := \frac{v_2^2}{2 \cdot g} + K_L \cdot \frac{v^2}{2 \cdot g} + K \cdot \frac{v^2}{2 \cdot g} + 1.0 \cdot \frac{v^2}{2 \cdot g} + 1.9 + f \cdot \frac{L}{D} \cdot \frac{v^2}{2 \cdot g}$$

$$z_1 := (2 + K_L + K) \cdot \frac{v^2}{2 \cdot g} + 1.9 + \frac{64 \cdot \gamma \cdot L}{D^2 \cdot 2 \cdot g} \cdot \frac{v}{2 \cdot g}$$

Use equation solver to find v_2

$v_2 := 3.5485 \frac{m}{s}$ Now check if flow is laminar or turbulent

Second iteration:

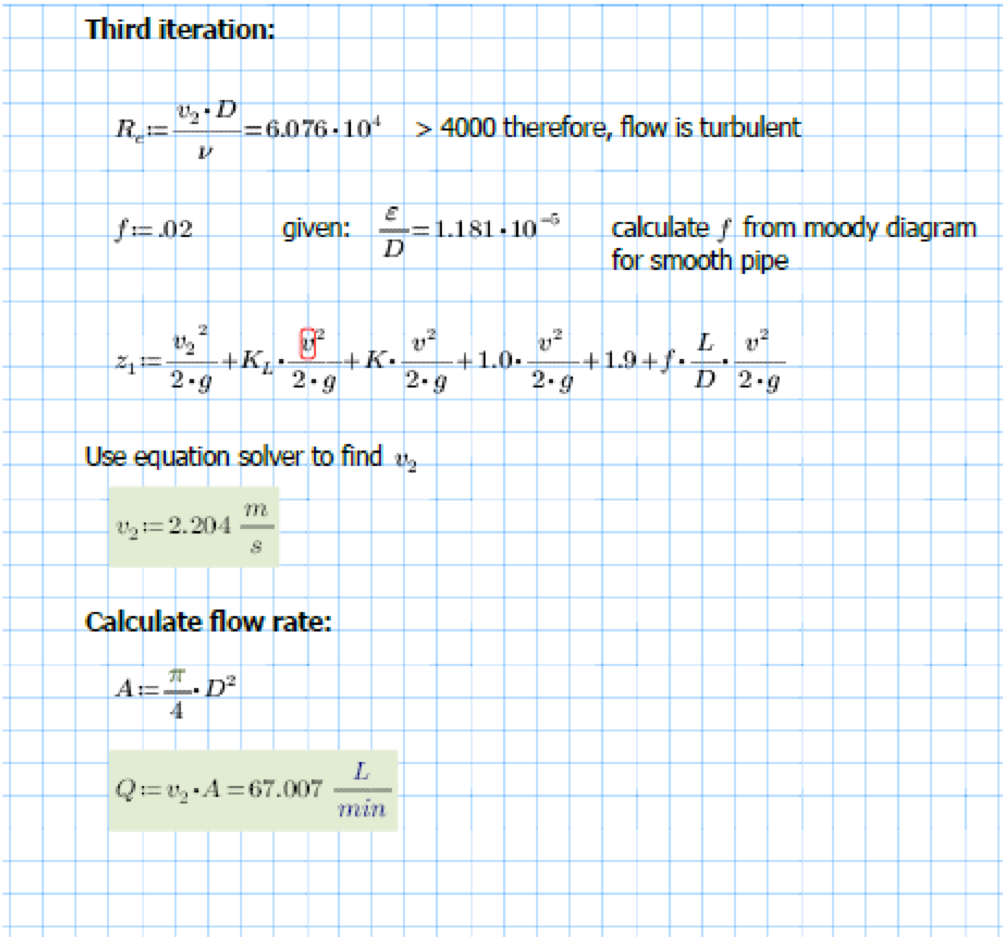
$R_e := \frac{v_2 \cdot D}{\nu} = 9.548 \cdot 10^4$ > 4000 therefore, flow is turbulent

$f := .0185$ given: $\frac{\varepsilon}{D} = 1.181 \cdot 10^{-5}$ calculate f from moody diagram for smooth pipe

$$z_1 := \frac{v_2^2}{2 \cdot g} + K_L \cdot \frac{v^2}{2 \cdot g} + K \cdot \frac{v^2}{2 \cdot g} + 1.0 \cdot \frac{v^2}{2 \cdot g} + 1.9 + f \cdot \frac{L}{D} \cdot \frac{v^2}{2 \cdot g}$$

Use equation solver to find v_2

$v_2 := 2.258 \frac{m}{s}$



Third iteration:

$R_e := \frac{v_2 \cdot D}{\nu} = 6.076 \cdot 10^4$ > 4000 therefore, flow is turbulent

$f := .02$ given: $\frac{\varepsilon}{D} = 1.181 \cdot 10^{-5}$ calculate f from moody diagram for smooth pipe

$$z_1 := \frac{v_2^{\ 2}}{2 \cdot g} + K_L \cdot \frac{v^2}{2 \cdot g} + K \cdot \frac{v^2}{2 \cdot g} + 1.0 \cdot \frac{v^2}{2 \cdot g} + 1.9 + f \cdot \frac{L}{D} \cdot \frac{v^2}{2 \cdot g}$$

Use equation solver to find v_2

$v_2 := 2.204 \ \frac{m}{s}$

Calculate flow rate:

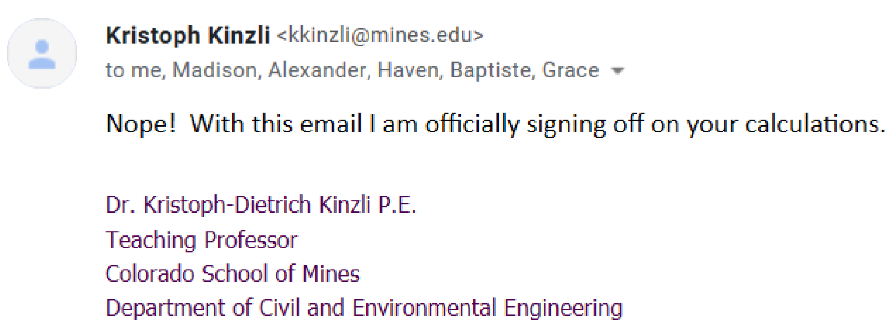
$A := \frac{\pi}{4} \cdot D^2$

$Q := v_2 \cdot A = 67.007 \ \frac{L}{min}$

Figure 8: Excerpt of Siphon Calculations Created in Mathcad

The first shows that by using 1 inch (DN25) PVC pipe, the flow velocity will fall within the acceptable range, properly mitigating the air lock and water hammer effects detailed above. In addition, a favorable flow rate of 67 Liters per minute ensures that farmers can draw an adequate quantity of water without extended operation of the siphon, ultimately promoting the longevity of the system.

Technical Advisor: Dr. Kristoph Kinzli P.E.
Technical Advisor Signature:



Kristoph Kinzli <kkinzli@mines.edu>
to me, Madison, Alexander, Haven, Baptiste, Grace

Nope! With this email I am officially signing off on your calculations.

Dr. Kristoph-Dietrich Kinzli P.E.
Teaching Professor
Colorado School of Mines
Department of Civil and Environmental Engineering

2/8/2021

Roof Catchment Calculations

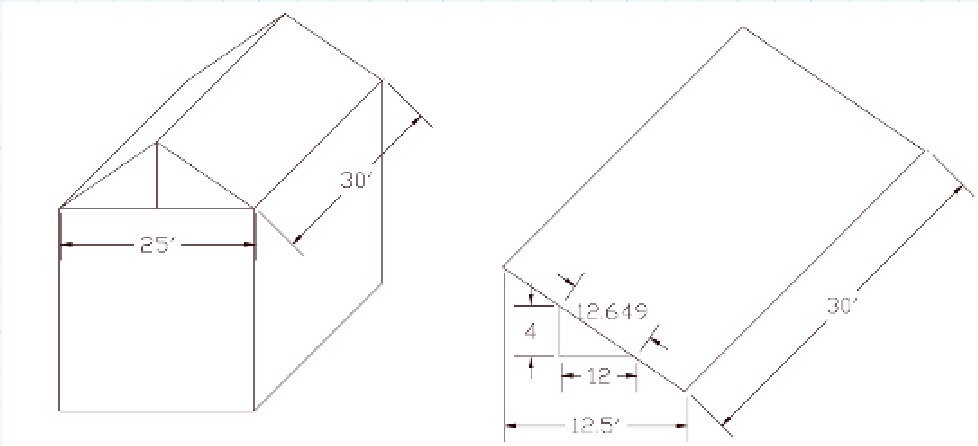
First Flush Pipe Calculations

The roof catchment system uses a gutter to collect runoff from a roof, which is then directed through a series of pipes until finally being deposited into the storage tank. Since rain events can be intermittent, dust, dead leaves, bird feces, and other pollutants can accumulate on a roof in the time between storms. These pollutants will be washed off of the roof via the gutter during new storms. In order to ensure that these harmful contaminants do not enter the storage tank, a vertical section of PVC pipe will be used to collect this polluted water before it enters the tank. The volume of water contained in this section of pipe will be equal to the area of catchment (in this case one roof panel) multiplied by 0.4mm of rain (adequate to effectively wash pollutants off the roof). [11]

The calculation below determines the length of 3" PVC pipe needed to contain the volume of water for the first flush of the roof. The standard roof dimensions of 25 ft. x 30 ft. were provided by GLI and used for this calculation. A ceiling height of 9 ft. and roof slope of 4/12 was assumed as these are standard building practices.

First Flush Calculations

Roof Dimensions



Typical Roof Dimensions: $W := 25\ ft$ $L := 30\ ft$
(top down)

Width of Roof Panel: $x := \frac{12.5}{12} \cdot 12.649\ ft = 13.176\ ft$

Roof Pannel Area: $A := x \cdot L = 36.723\ m^2$
(one side)

Calculate Water Volume for First Flush

Rainfall Depth: $d := .4 \cdot mm$

First Flush Volume: $V := d \cdot A = 14.689\ L$

Calculate First Flush Pipe Length

Selected Pipe Diameter: $D := 3\ in = 76.2\ mm$ (DN 75)

Pipe Area: $A_P := \frac{\pi}{4} \cdot D^2 = 0.005\ m^2$

Pipe Length: $L_P := \frac{V}{A_P} = 10.568\ ft$

$L_P = 3.221\ m$

Figure 9: First Flush Calculations

This shows that 3.211m (approximately 11 ft.) of 3" (DN75) PVC pipe will be needed to accommodate the 14.69 L of first flush volume. The 1000L Gentex tank has a manufactured height of 1.33 m (approximately 4.4 ft.). For ease of construction, the first flush pipe will consist of a 5 ft. vertical section of 3" PVC pipe, followed by a 3" 90-degree PVC elbow, and a final 6 ft. horizontal section of 3" PVC pipe with a ball valve at the discharge point to equal 11 ft. total of first flush length. During a storm event, place the ball valve in the closed position to allow the first flush pipe to fill with water. After the 11 ft. section has completely filled with water, clean water will then be directed through the PVC tee and gravity fed into the tank as shown in the figure 10 below. Please see the Appendix L section for further details.

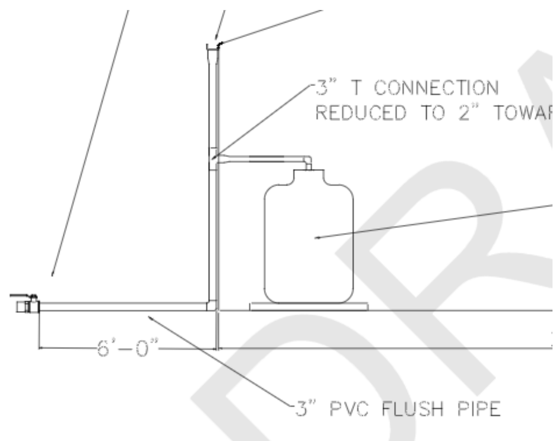


Figure 10: Illustration of First Flush Pipe

As illustrated in the calculation above, the volume of water and the length of 3 in PVC pipe needed are dependent on the roof dimensions. To better accommodate the community, a table of various roof dimensions and subsequent first flush pipe lengths is provided in Appendix H.

Tank Foundation Calculations

As shown in the calculation below, a 1000L tank completely full of water will weigh approximately 2200 lb. Evenly distributing this weight over the 1.08 m (3.54 ft) diameter base will result in a bearing pressure of 622.12 psf. The typical bearing capacity of the sandy loam soil in the region is roughly 2,000 psf. [12] However, given the steep slopes and moderate seismic activity of the lake Bunyonyi region, our team recommends that the tank sits upon a stable foundation. The following calculation follows ACI-318 guidelines to determine the adequacy of a slab on grade.

Tank Foundation Calculations

Tank Properities

Volume: $V := 1000\ L$

Diameter: $D_T := 1.08\ m$

Height: $h := 1.33\ m$

Water Weight: $W_W := V \cdot \frac{1\ ft^3}{7.48\ gal} \cdot \frac{62.4\ lb}{ft^3} = 2203.8\ lb$

Slab Properities

Dimensions: $L := 4\ ft$ (4' x 4')

Pressure on slab: $DL := \frac{W_W}{L^2} = 137.737\ \frac{lb}{ft^2}$

round to: $DL := 140\ psf$

Stress and Strength Properities

Yield Stress: $fy := 60000\ psi$ (grade 60 rebar)

Compressive Strength: $fc' := 4000\ psi$ (concrete)

Find height (h) of Slab

Slab Height: $h := \frac{L}{20} = 2.4\ in$

round to: $h := 3\ in$

1ft Section of Slab:

Base: $b := 12\ in$

Clear Cover: $c := \frac{3}{4}\ in$

Rebar Diameter: $d_b := \frac{3}{8}\ in$

Rebar Placement Depth: $d := h - c - \frac{1}{2}\ d_b = 2\ in$

Calculate Mu for Slab

Distributed Live Load: $W_L := 0$

Distributed Dead Load: $W_D := 140\ \frac{lbf}{ft}$

Self Weight: $S_W := 150\ \frac{lbf}{ft^3} \cdot \left(\frac{3\ in}{12\ \frac{in}{ft}} \cdot \frac{12\ in}{12\ \frac{in}{ft}} \right) = 37.5\ \frac{lbf}{ft}$

Factored Distributed Load: $W_U := 1.2\ (W_D + S_W) = 213\ \frac{lbf}{ft}$

Factored Moment per Load: $M_U := \frac{W_U \cdot L^2}{8} = 5112\ (in \cdot lbf)$

Want ϕMn>Mu

Tensile Strain: $\varepsilon_t := .005$ (assumed)

Strength Reduction Factor: $\phi := .9$ (therefore)

$R_N := \frac{M_U}{\phi \cdot b \cdot d^2} = 111.27\ psi$

Assume: $\rho_{min} := .0018$ for slabs (temp & shrinkage)

From Table A-13 $R_N := 117.1$

$\rho_{min} := .002$

Rebar Spacing

Area of Steel: $As := \rho_{min} \cdot b \cdot h = 0.072\ in^2$

Rebar Diameter: $d_R := .375 \cdot in$

Rebar Area: $Ab := \frac{\pi}{4} \cdot {d_R}^2 = 0.11\ in^2$

Rebar Spacing: $s := \frac{12\ in \cdot Ab}{As} = 18.408\ in$

Max Spacing: $3 \cdot h = 9\ in$ or $18\ in$

Actual Area of Steel: $As := \frac{12}{18} \cdot Ab = 0.0736\ in^2$

Calculate ϕM_N for Actual As

$$a := \frac{fy \cdot As}{.85 \cdot fc' \cdot b} = 0.108\ in$$

$$\beta := .85 \qquad \text{(at 4,000 psi)}$$

$$c := \frac{a}{\beta} = 0.127\ in$$

$$\varepsilon_t := \frac{.003 \cdot (d - c)}{c} = 0.046 \quad >.005$$

$$\phi M_N := \phi \cdot fy \cdot As \cdot \left(d - \frac{a}{2}\right) = 7.985\ in \cdot kip$$

$$\phi M_N := \phi M_N \cdot \frac{1000\ lb}{kip} = 665.45\ ft \cdot lb$$

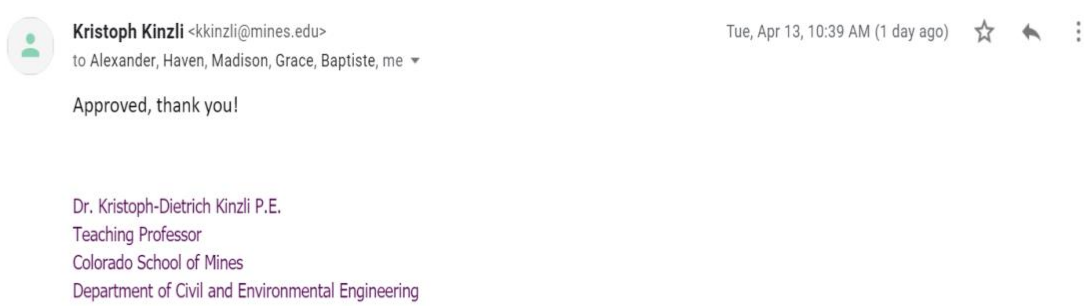
$$\phi M_N = 665.45\ ft \cdot lb \quad > \quad M_U = \left(4.178 \cdot 10^3\right) \frac{m}{s^2} \cdot ft \cdot lb$$

therefore passes code requierments

Figure 11: Tank Foundation Calculation

The above calculation shows that the slab design is adequate for the given loading conditions. The final slab design is 3” in height with #3 Grade 60 rebar at 15 in. on center each way (O.C.E.W). Please see the Appendix L for further details and construction considerations. Given the loading conditions, the team is recommending 3,000 psi compressive strength concrete to be used in this non-structural application.

Technical Advisor: Dr. Kristoph Kinzli P.E.
Technical Advisor Signature:


Kristoph Kinzli <kkinzli@mines.edu>
to Alexander, Haven, Madison, Grace, Baptiste, me

Tue, Apr 13, 10:39 AM (1 day ago)

Approved, thank you!

Dr. Kristoph-Dietrich Kinzli P.E.
Teaching Professor
Colorado School of Mines
Department of Civil and Environmental Engineering

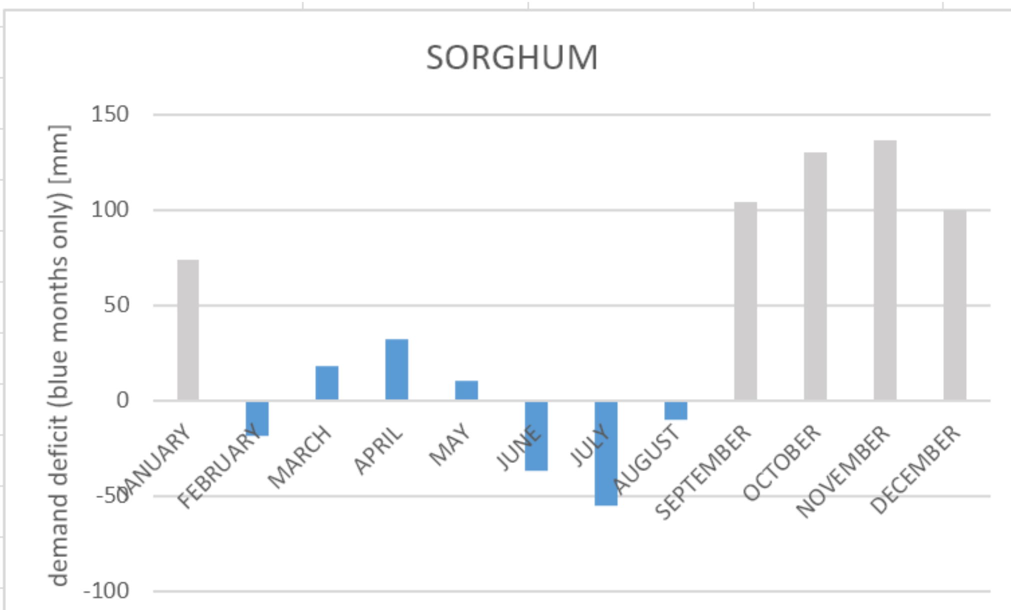
4/13/2021

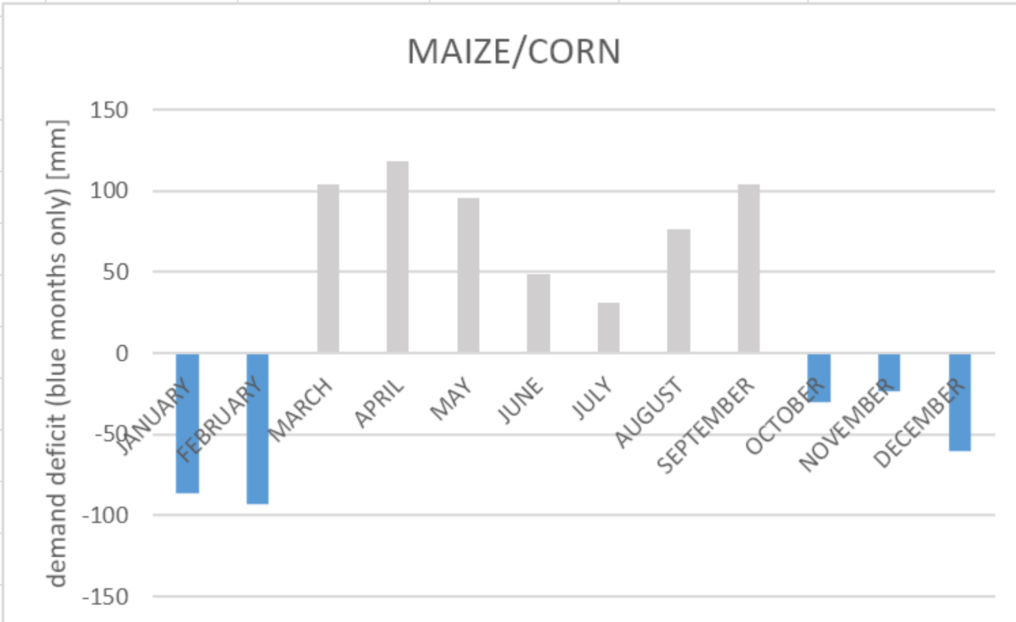
It should be noted that these are initial calculations and may be modified based on the client's wants and needs. All calculations are performed by students and may contain errors. A professional engineer should be consulted to validate the calculations before implementation.

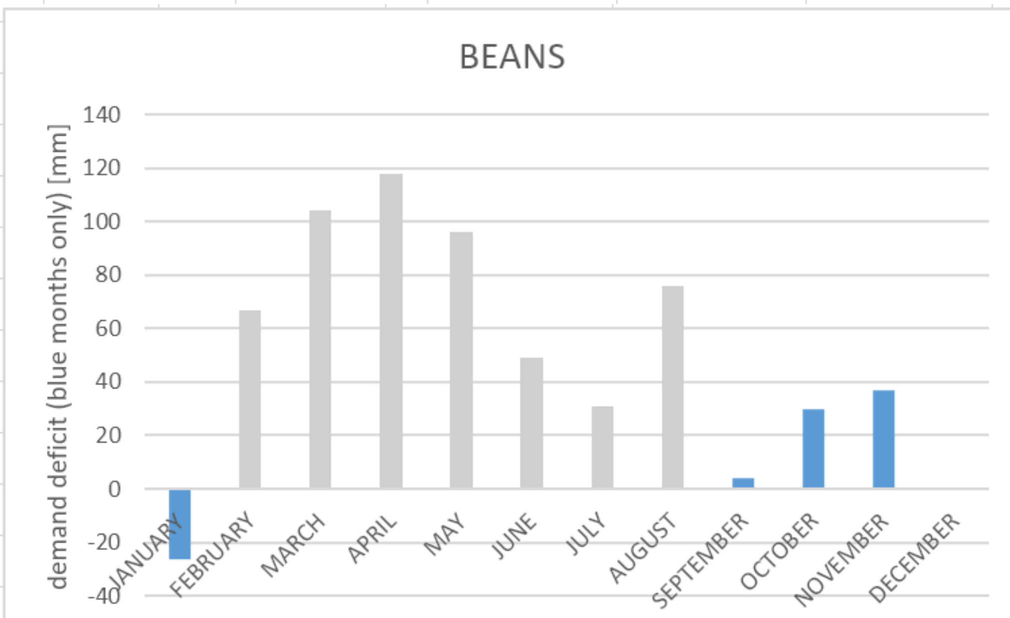
Water Supply Analysis

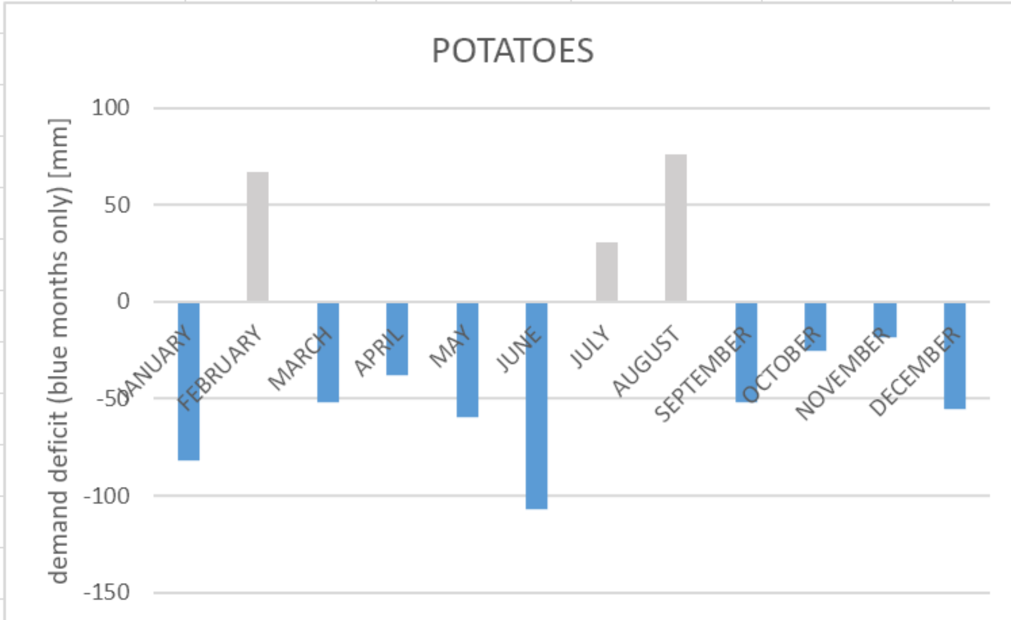
Both proposed systems will perform well in terms of collecting rainwater over time. However, in order to assess the extent to which our design will alleviate issues with drought, we performed a supply and demand analysis. This analysis compared the difference in supplied rainfall and the water demands of five different crop types. The rainfall data for the nearby town Kabale was obtained from weather-and-climate.com [1], while information on local growing seasons and water demand was provided by Raymond Bokua.

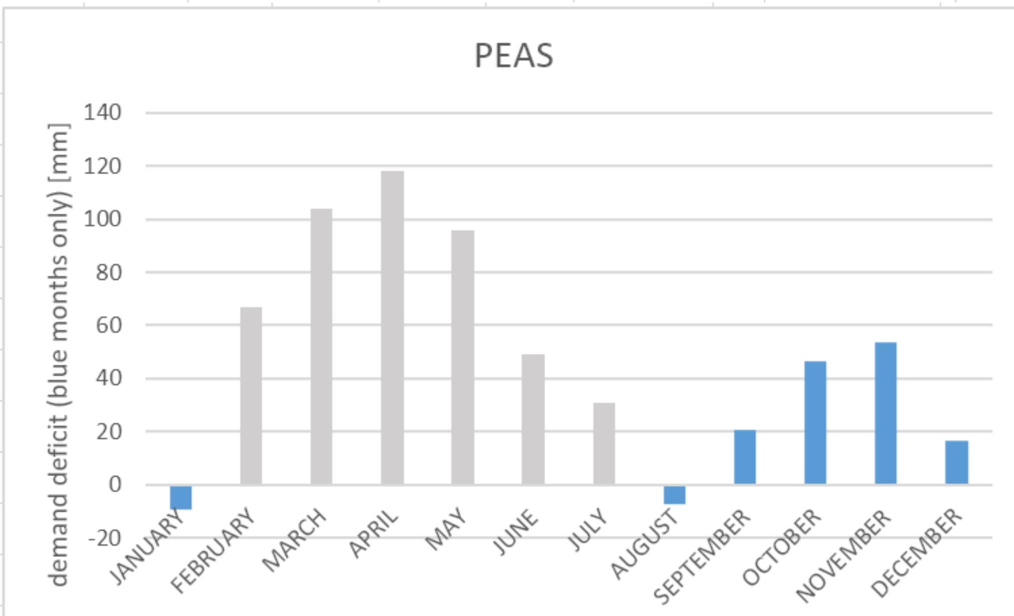
The analysis was performed in Excel using simple equations. The results are shown below in graphs for each crop type. The graphs show the difference in water supplied in the form of rainwater and the water needed to grow the crop. A negative value shows that there is not enough rainwater supplied in that month to grow the crop. A positive value shows that there is a surplus of water in that month. The period of growth for each crop is shown in blue. The crop is not grown in grey months.




MAIZE/CORN
demand deficit (blue months only) [mm]
150
100
50
0
-50
-100
-150
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER


BEANS
demand deficit (blue months only) [mm]
140
120
100
80
60
40
20
0
-20
-40
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER





Figures 12-16: Demand Deficit for different crop types

Several assumptions were made that impact the accuracy of these results. The first assumption was the crop demand would be equal across each growing month. This is not an accurate assumption. Therefore, our graphs only reflect an average of the water needed across the growing season. More water demand data would be required to refine the accuracy of the demand predictions.

The other assumption made is that the rainfall is predictable. This assumption is also inaccurate given that part of our project is to address changing weather patterns. Without more frequently collected data, it is difficult to know how weather patterns are changing. However, according to Raymond Bokua, we know that rainfall events are happening less often with greater intensity.

Thus, is it likely that that months at the beginning and end of the rainy seasons are experiencing a downward trend in mm of rainfall. It is likely that more water would need to be collected in months such as January, February, June, and July.

Despite the accuracy of the graphs not being very high, the results do lead to several conclusions. By introducing the area of a field into the results, the volume of water needed to grow each crop can be calculated. The resulting volume can be used to predict how much of a water deficit or surplus exists during each month of a crop's growing season. For example, given a field size of 15 by 100 meters, sorghum would need 28,071 more liters of water in February and Maize would need 139,500 more liters of water in February. The full tables showing the volumetric analysis of water deficit per month for each crop are included in Appendix K.

Naturally, neither of our design options will be able to supply this much water in order to fully irrigate any commonly grown crops in dryer months. The 1000L tank is the limiting factor in our designs since the problem ultimately boils down to cost. The size of tank needed to fully irrigate any commonly grown crop is too large to fit within a budget of 100 USD. A 1000L tank is already expensive and barely within budget. Several 10,000 L tanks would be a more ideal solution, but much too expensive for most farmers.

Ultimately, it is not possible for our design to completely address water security issues stemming from changing weather patterns. However, the additional water provided by a 1000L tank could be used to grow smaller crops such as vegetables and fruit. This could incentivize diversification as well as changes in diet if more types of food are grown and consumed by families in the area.

Sustainable Design Analysis

An additional analysis of our designs is based on the Bridger and Luloff criteria for Sustainable Community Development [13]. The criteria are broken down into several categories shown below and then further broken down into more specific criteria. Our solution is assigned a score in each category from 1-5. A score of 5 indicates that this solution meets the criteria fully without reservation, while a score of 1 means the solution does not meet the criteria at all. A single, wholistic analysis is provided for both design options.

Table 2: Sustainable Community Development Scores (1- Low, 5 – High)

Criteria Name	Specific Criteria	Score
Local Economic Diversity	Capacity building and diverse job creation	3
	Revenue re-invested locally	2
	Creation of new products and markets	3
Self-determination	Autonomy in decision-making	3
	Reduce dependency from external capital, materials, expertise	1
	Autonomy in problem definition and solution	4
Reduce Energy	Incorporate renewables, reduce fossil fuels	2
	Improve efficiency, curb consumption	3
	Include storage capabilities	4
	Design for cradle-gave (replace, repair, durability)	2

Reduce/ Recycle Materials	Reduce toxic materials while increasing non-toxic, organic materials	2
	Easy recycling and responsible disposal	2
Social Justice	Respect and enhance human rights	5
	Enhance opportunities equally	4
	Increase resources equally	4
	Reduce risks/ help equally	4

Overall, our design preforms best in the Social Justice category and worst in the Reduce/Recycle Materials category. The designs score about average (score of 3) or below average in most categories. There are several reasons behind this scoring.

First, some community members already use a form of rainwater catchment for irrigation purposes. Our design does not improve upon or investigate the pre-existing rainwater catchment systems in the community. Thus, our design does not improve upon or reduce the cost of the existing solutions. Instead, the funnel system we have proposed a new, untested design that is likely more expensive that existing rainwater catchment systems. A form of the roof catchment system is already used by several members in the community, but our design does not attempt to improve on this design. These facets of our design result in lower score in Self-determination and Reduce/Recycle Materials. Furthermore, our design continues to rely on unrenewable materials produced outside of the community such as plastic tanks and PVC pipe. These materials also have short, expected life spans with little to no options for reuse or recycling. In some cases, there may also be materials that will need to be transported to the community from other parts of the country. Transportation constitutes an additional environmental cost. Finally, our design promises little in terms of increased economic diversity as the solution and materials already exist on the market in some form or another.

The strengths of this design lie primarily in its ability to serve community members who do not live close to the lakeside. By providing two design options, we also ensure that there are options for people who cannot use their roof to catch rainwater. The focus on equality has resulted in higher scores in the Social Justice category.

Our design process generally did not consider many of the criteria for sustainable community development as a result of an overly technical focus in project deliverables (testing, calculations, CAD drawings). Additionally, due to a shortened design timeline compared to the deliverable timeline, there was less time to explore the bigger impact our design may have on the community. Our first iteration involving a retention pond was discarded in an attempt to consider the long-term impact of our design, leaving even less time to refine our next iteration. By offering two design solutions we also hope to address some of the short comings of our design by increasing community member's autonomy through choice. Ultimately, future work on this project should focus on ways to address the short life span of the materials, as well as utilizing more local knowledge and improving upon existing systems. If these concerns are addressed, the project will be more likely to be adopted and sustainable in the long term.

Final Deliverables

To best illustrate the team's design, the following final deliverables are included in this report:

- Technical drawings of the entire solution illustrating its implementation on an example house
- Technical details of different components that will be used in the design and how they will be implemented
- A technical detail of the concrete pad used for supporting the water tank
- A bill of materials outlining the expected cost of the project.

The team believes these deliverables will allow for the client to fully implement this design. Due to the nature of the design, a physical prototype was not created as a scale model of this system would not be effective in portraying the full design. The only potential needed component not delivered would be an operations and maintenance manual (see the Project Management section for more details). Shown below in figure 17 and 18 of the most important technical drawings as well as the bill of materials. For more detailed drawings and cost analysis, please see Appendix L and B respectively.

Technical Drawings

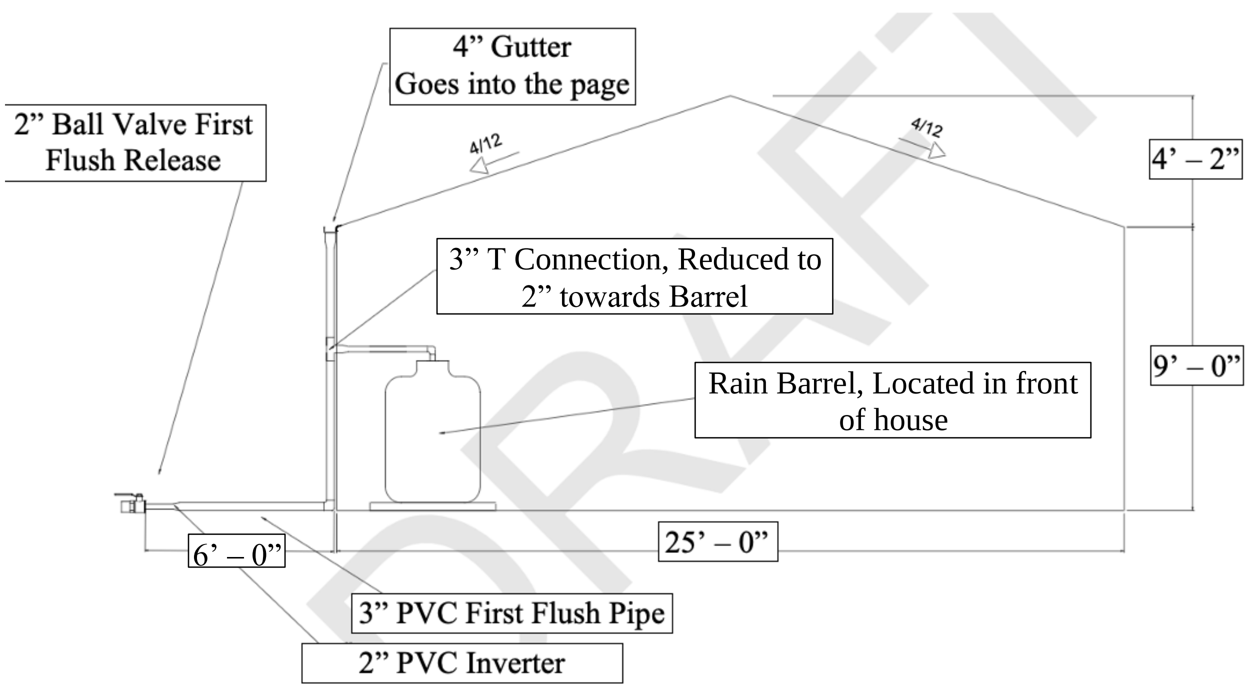


Figure 17: 25' Elevation view of entire system

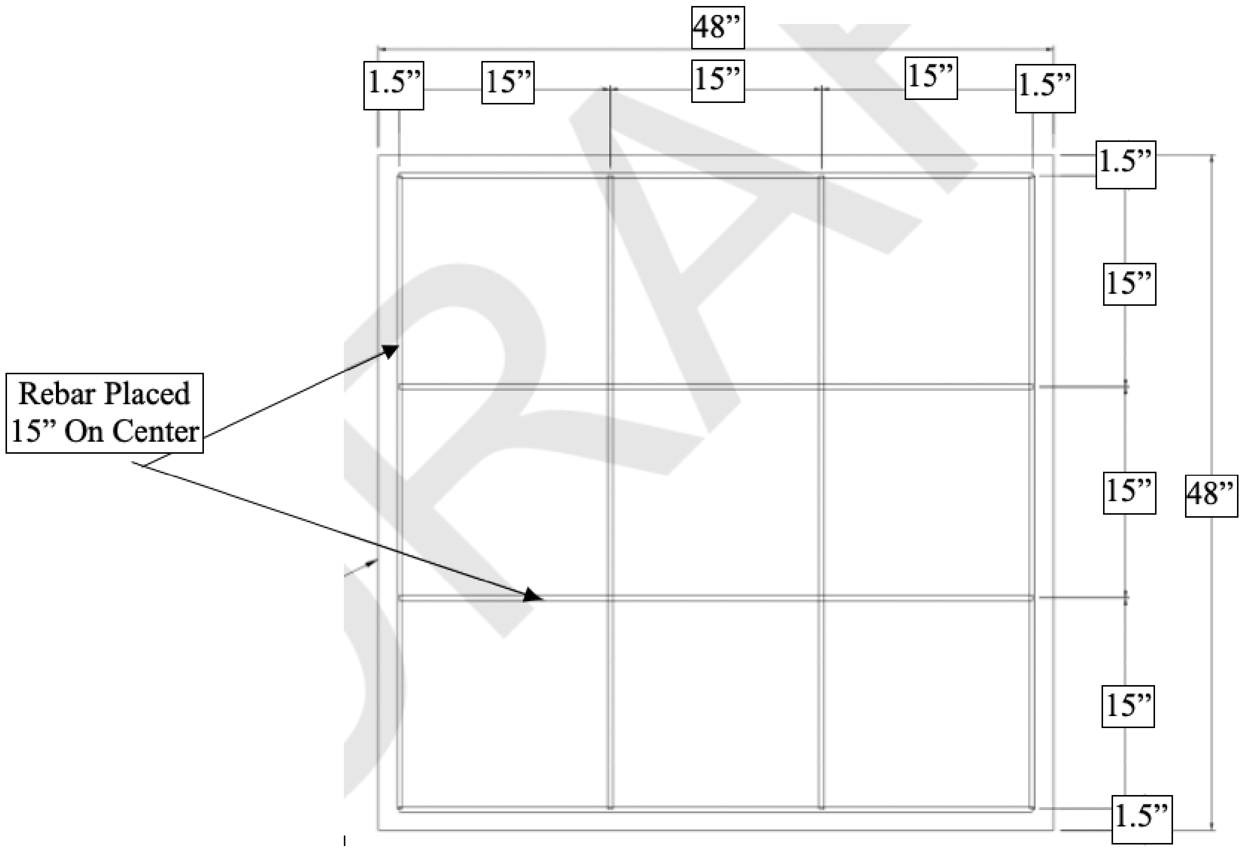


Figure 18: Plan view of concrete pad used for supporting tank. See appendix L for more details.

Table 3 on the next page is a cost breakdown of the design solution with values in green being confirmed at local prices and prices in yellow being U.S. estimates. The team expects the overall price of the project to decrease as parts are likely cheaper in the local community.

Cost Analysis

Table 3: Cost Analysis: 1000L Tank on concrete foundation: Roof Runoff

Item	Description	Units	Cost/Unit (USD)	Quantity	Cost (USD)	Cost (UGX)
Gentex 1000L Tank [2]	Main water collection vessel	EACH	$51.86	1	$51.86	UGX 192,074.074
4" Gutter	30 ft Needed	Sold in 18 ft sections for $8	$8.00	2	$16.00	UGX 59,259.259
3'" (DN 75) Schedule 40 PVC Pipe	11 ft Needed for First Flush	Sold in 20 ft increments for $7	$7.00	1	$7.00	UGX 25,925.93
4" to 3" PVC Reducer	For connecting 4" gutter to 3" pipe	EACH	$5.47	1	5.47	UGX 20,259.26
3" to 2" PVC Reducer	For connecting 3" pipe to 2" pipe	EACH	$4.11	2	$8.22	UGX 30,444.44
3" PVC Elbow	90º 3" PVC Elbow	EACH	$2.84	1	$2.84	UGX 10,518.52
2" PVC Elbow	90º 2" PVC Elbow	EACH	$2.84	2	$5.68	UGX 21,037.04
2" PVC Ball Valve	Used at End of First Flush	EACH	$7.39	1	$7.39	UGX 27,370.37
1" PVC Check Valve	Used for Overflow Pipe	EACH	$7.82	1	$7.82	UGX 28,962.96
1" PVC Ball Valve	Used for Discharge Pipe	EACH	$4.98	1	$4.98	UGX 18,444.44
Pipe Fastener Brackets	Used to fasten PVC to Roof	x10	$2.54	1	$2.54	UGX 9,407.41
3" PVC tee	Used to direct flow of water toward tank	EACH	$4.50	1	$4.50	UGX 16,666.67
Wire Mesh	For filtering contaminants (10'x2' > 45 pieces)	EACH	$4.63	2	$9.26	UGX 34,296.30
Cement	For tank foundation	cu-ft	$6.53	4	$26.12	UGX 96,740.74
#3 Grade 60 Rebar	Reinforcement for Concrete pad, total of 22.5'	$/lb	$0.75	16.94	$12.70	UGX 47,050.26
Lumber	For cement form	EACH	$5.92	5	$29.60	UGX 109,629.6
Shovels*	Tool	EACH	$10.00	1	$10.00	UGX 37,037.04
Nails *	Support Fasteners (4" 28 pieces in bag)	BAGS	$4.00	2	$8.00	UGX 29,629.63
Hammer *	Tool	EACH	$10.00	1	$10.00	UGX 37,037.04
Hand Saw *	Tool	EACH	$10.00	1	$10.00	UGX 37,037.04

Total Cost with extra *	**$239.98**	**UGX 888,828.04**
Total Cost without extra	**$201.98**	**UGX 748,087.30**

Project Management

The team was able to complete almost all of the work it set out to do and produced a design that is overall effective at creating a solution for the Entusi community. Looking back at the work breakdown schedule (WBS), the team was able to: do sufficient research on the community culture and environment as well as relevant irrigation systems, a community survey, an engineered rainwater catchment system with calculations and analysis to support the design, as well as a final report with drawings and supporting budget. One item the team sought out to complete and did not was an operations and maintenance manual that would be in support of the drawings and calculation for the team's design. The team recommends that GLI or a future engineering team creates an operations and maintenance manual as it would greatly benefit community members who chose to implement this design. Please see in Appendix I and J for an updated WBS and schedule respectively.

The initial budget for this project was around $100 USD per family, and the total budget the team's final design is projected to cost about $202 USD. While the proposed design goes over the initial budget, the team felt this was the most affordable design to implement in the community while also providing something that would be effective and useful. See Appendix B for a breakdown of the project budget that includes the cost analysis for our previous designs as well as the Final Deliverables section.

Lessons Learned

Alex’s Lessons Learned

Our team learned that there are multiple factors beyond our control that will make the design process more challenging, and the “best” design may require some tradeoffs. For our team, we did not have much of the typical engineering related data that we needed to complete our project due to multiple factors including: our inability to travel to the site and collect data, a lack of information such as professional surveys and soils reports, and difficulties related to speaking with engineering professionals who lived in the community. These challenges together forced our team to make assumptions in our design that limited our overall ability to create the “best” design possible. However, this situation is reflective of many real-world scenarios for professional engineers, and it taught us to work around the information we were given and use our engineering judgement when faced with uncertainty. This taught our team resilience and adaptability to challenging solutions with limited information available.

Madison’s Lessons Learned

Overall, I have found this project to be very frustrating. I plan to work in international development after graduation and have had experience working on development projects in the past. My main take away from this particular experience is that development projects do not work well within the framework of a two-semester design class. The constraints of a "design" project are too inflexible to allow for complex, systemic issues, which have gone unsolved for decades, to be addressed in any meaningful way. From personal experience, I know how community engagement and input can make or break an engineering project. Although our team worked hard to consider and incorporate feedback from community members, we were still unable to propose a truly collaborative and useful solution for the community. Overall, I learned that long term, continual collaboration is completely necessary when attempting to address issues in a context which you are unfamiliar with. Without long term collaboration it is impossible to conduct sustainable knowledge transfer.

Baptiste’s Lessons Learned

Over the past 8 years, I have worked on multiple engineering problems where solutions were imminent and involved communities in developing countries. Never would I have thought that talking to local members of the community would have such a great impact on my decision making. I want to say thank you to the personnel at GLI and members of the Lake Bunyonyi community for taking the time to talk to this team, answering all of your questions and giving us feedback our all of our solutions proposed throughout the entirety of this project. Not travelling to Uganda did pose problems at the start of the project and was a huge constraint on this project, however, as a team we found ways to overcome this challenge and have the ability to understand the area to best design a solution. With previous projects, I did not have that connection and now I see the value in local contacts and having a dialogue with as many people as possible.

Grace’s Lessons Learned

Through this project, the greatest lesson I have learned is the importance of stakeholder concerns and feedback. Working within tight design constraints required tradeoffs and close contact with GLI members and local community members. It was incredibly interesting and even rewarding to work with GLI and community members halfway across the world, and they really helped our team be more educated during the design process. I also enjoyed researching and learning about some of the different irrigation techniques that farmers around the world use. I learned about how these irrigation and water storage systems worked as well as why they were utilized over another system.

Anthony's Lessons Learned

Throughout the duration of this project, I naturally gravitated towards the technical aspects of the design. I became fascinated with various forms of pumps, their intricacies, and applications. However, the more I learned about the context of this project, the more that I began to discover that the effectiveness of the design solution will depend less on the technical aspects and more on understanding how the design will mesh with the community. Understanding local materials, resources available, construction practices and local expertise, ease of construction and maintenance became the emphasis in the second semester of the project for me and taught me that the best design solution is the one that is not the most technical, but the most balanced and practical.

Works Cited

[1] M. Rains, "Entusi Model Farm Photo," 2020.

[2] Weather & Climate , "Average Monthly Snow And Rainfall in Kabale in Millimeter," 3 Feburary 2021. [Online]. Available: https://weather-and-climate.com/average-monthly-precipitation-Rainfall,Kabale,Uganda.

[3] Gentex Enterprises , "Blow Mould Water Tank," [Online]. Available: https://gentexenterprises.com/watertank-product/. [Accessed 5 Februrary 2021].

[4] E. C. J. R. c. E. S. D. C. (ESDAC), "Ugandan Soils," Ugandan Government , 1967. [Online]. Available: https://esdac.jrc.ec.europa.eu/content/uganda-soils. [Accessed 8 Februrary 2021].

[5] G. Info, "Unit Weight of Soil," [Online]. Available: http://geotechnicalinfo.com/soil_unit_weight.html. [Accessed 5 February 2021].

[6] A. I. o. Japan, "Design Recommendations for Storage Tanks and their Suppors with Emphasis on Seismic Design," p. 179, 2010.

[7] Britannica, "Cavitation; Physics," The Editors of Encyclopaedia Britannica , [Online]. Available: https://www.britannica.com/science/cavitation. [Accessed 5 Februrary 2021].

[8] ResearchGate, "Air Lock in Pipe Systems," March 2017. [Online]. Available: https://www.researchgate.net/figure/Schematic-of-an-entire-air-lock-in-a-small-diameter-pipe-system-Z-u-upstream-water_fig1_314703315. [Accessed 8 Februrary 2021].

[9] Krah.net, "Water Hammer and how PVC pipes react," 29 September 2017. [Online]. Available: https://www.krah.net/de/news/latest-news/312-water-hammer-and-how-pe-pipes-react. [Accessed 8 Februrary 2021].

[10] PipeEng , "Water Hammer Calculation," 28 January 2019. [Online]. Available: https://pipeeng.com/water_hammer.html. [Accessed 5 Februrary 2021].

[11] Engineering Toolbox , "PVC Pipes- Pressure Rating," [Online]. Available: https://www.engineeringtoolbox.com/pvc-cpvc-pipes-pressures-d_796.html#:~:text=%20%20%20%20Nominal%20Pipe%20Size%20(inches),%20%20378%20%2011%20more%20rows. [Accessed 8 Februrary 2021].

[12] T. R. o. U. M. o. W. a. Environment, "Water Supply Design Manual Second Edition," Ministry of Water and Environment , Kampala, Uganda , 2013.

[13] DICA, "Ground Bearing Capacity Table," Cranes and Derreks, Fourth edition, Author Jay Shapiro , [Online]. Available: https://dicausa.com/soil-bearing-capacity/. [Accessed 14 4 2021].

[14] L. B and T. C. D, "Reframing Engineering Capstone Design Pedagogy for Design with Communities," 121st ASEE Annual Conference and Exposition, Indianapolis, 2014.

[15] C. Diaz, E. Jones, J. Kohl, E. Lundeen, A. Ni and B. Treanor, "Entusi Model Farm: Intermediate Design Report," Golden, CO, 2020.

Appendices

Appendix A: Complete Risk Analysis

Table A.1: Siphon System (PVC Focus)

Risk	Category (Environmental, Social, Technical, Human Safety, Financial)	Likelihood (Low, Medium, High)	Consequences (Minimal, Medium, Critical)	Risk Level (Green, Yellow, Red)	Action (AMAT) (Accept or Decline based on Research)	Strategy (what we are doing to mitigate it?)
PVC Deterioration due to sunlight	Human Safety, Financial	High	The PVC could crack, causing damage to the pipe, flooding, and possible injury. Damage to the pipe will result in higher costs (Minimum)	Medium	Accept	There are multiple options to mitigate this risk, including burying the pvc pipe or painting with a UV- Resistant or white paint.
Excess Discharge	Technical	Medium	Would result in possible flooding near and around the discharge. (Critical)	Medium	Accept	The design will call for a series of redundant ball valves to allow siphon to be turned off
Water-hammer effect	Technnical, Financial	Medium	PVC components may separate which could cause pipes bursting or imploding, resulting in high costs to replace the system. (Critical)	Medium	Accept	Reinforce bends in the pipe with thrust blocks, or if not cost prohibitive, install pressure regulating valves. Also locating the cutoff valves at the top of the siphon to unsure the
Air lock effect/Capillation	Technical	Medium	Excess amounts of bumps and vertical vends in pipes will result in dissolved gas bubbles settling towards the top of the pipe. This has the potential to stop the flow of water.	Medium	Accept	Reduce the amount of bends in pipes by cutting/filling the hillside to best achieve a 45 degree angle of discharge.
Pipe becomes damaged after passing over terrace drop-offs	Technical, Financial	Medium	The PVC pipe may crack and leak over time. If subject to extreme loads, Pipe may burst Resulting in high costs to replace. (Medium)	Medium	Accept	Cut/Fill the existing grade to matchthe 45 degree angle of the discharge line. Another remedy would be to provide a supporting structure for the pipe over drop-offs

Table A.2: Rain-water Catchment (Buried) + Runoff + Siphon

Risk	Category (Environmental, Social, Technical, Human Safety, Financial)	Likelihood (Low, Medium, High)	Consequences (Minimal, Medium, Critical)	Risk Level (Green, Yellow, Red)	Action (AMAT) (Accept or Decline based on Research)	Strategy (what we are doing to mitigate it?)
Tank deterioration due to sulfate attack	Technical	Low	Deterioration of the tank may cause cracking and leakage. (Medium)	Medium	Accept	A plastic lining could be installed around the tank to mitigate deterioration of the plastic.
Damage to tank by earth pressures and seismic loads	Technical	Medium	The tank could crack and collapse on itself. (Critical)	High	Decline	The tank should be buried, and a supporting structure around the tank could be built.
Pump filter clogging	Technical	High	The water inflow will be reduced and result in water losses.	Low	Accept	The community will be advised to clean intake filters regularly.
Sediment/Trash build up	Environmental	High	There will be water loss and possible contamination from trash.	Low	Accept	The community will be advised to clean intake area regularly.
Water Contamination	Environmental	High	Contaminated water may cause sickness if consumed or damage to crops	Medium	Accept	Chlorine of other chemical filtration techniques can be used to make the water potable
Retention Time	Environmental	Medium	Algae may grow with stagnant water inside the tank.	Medium	Accept	The community will be advised to clean tanks regularly. Bury the tank.
Tank Overflow	Technical, Human Safety	Medium	Due to the high volumes of rainwater and runoff, internal pressures may cause the tank to break or overflow	Medium	Accept	Design an overflow valve and supporting land around tank to accept overflow water.

Table A.3: Rainwater Catchment (Above Ground) + No Runoff + Treadle Pump

Risk	Category (Environmental, Social, Technical, Human Safety, Financial)	Likelihood (Low, Medium, High)	Consequences (Minimal, Medium, Critical)	Risk Level (Green, Yellow, Red)	Action (AMAT) (Accept or Decline based on Research)	Strategy (what we are doing to mitigate it?)
Algae Growth	Environmental	High	Algae may grow with stagnant water inside the tank and contaminate water. (Minimal)	Medium	Accept	Use chlorine to clean water or clean out tank regularly.
Mosquitos	Human Safety	Medium	Mosquitos are drawn to water and bring diseases. (Critical)	Medium	Accept	Cover tank with cap
Stability of ground under tank	Technical	Medium	Tank might tip over or move. (Medium)	Medium	Accept	Flat out land, Design short layer of foundation using gravel and bricks
Sun damage	Environmental	High	The tank could crack or mitigate. (Medium)	Medium	Accept	Use UV resistant tanks
Sediment builds up at bottom of tank	Environmental	Medium	Algea growing or water quality	Low	Decline	Empty tank after every dry season
Tank tipping over	Technical	Low	If tank fills up, the weight of the water may tilt the tank causing it so to spill out.	Low	Decline	Keep a record of water level after every rainstorm
System not catching runoff	Technical	High	System is relying only on rainwater to fill up the tank	Low	Decline	If runoff in area is high, switch to having a buried tank.

Risk Quantification Tool

In order to evaluate the risks associated with each design quantitatively and consistently, the team is utilizing a chart comparing impact and probability to determine risk. Shown in table A.4 below, the combination of a certain defined impact and associated risk determines a risk.

Table A.4: Risk Quantification Matrix [14]

	Impact				
	Trivial	**Minor**	**Moderate**	**Major**	**Extreme**
Probability	*Minimal injury, little to no environmental impact*	*Minor injury/ environment al impact*	*Moderate-Severe injury, substantial environmental impact*	*Small number of casualties, irreparable environment al damage*	*Large number of casualties, total environmental destruction*
Rare	Low	Low	Low	Medium	Medium
Unlikely	Low	Low	Medium	Medium	Medium
Moderate	Low	Medium	Medium	Medium	High
Likely	Medium	Medium	Medium	High	High
Very Likely	Medium	Medium	High	High	High

Appendix B: Cost of Materials, Extended

In this appendix, areas highlighted in green denote confirmed local Ugandan pricing/availability. Areas highlighted in yellow denote prices for supplies at U.S. hardware stores or equivalent, and the team will be further looking into the actual prices of these items in Uganda. Prices for all items highlighted in yellow will be determined for the final design as the team does further research on each item's availability. Table B.1 represents the standard design with a small tank and 8 meters of piping; this is also what is reflected in "Cost of materials" section of the report.

Table B.1: Cost Analysis (Small Tank, Standard Piping)

Item	Description	Units	Cost/Unit (USD)	Quantity	Cost (USD)	Cost (UGX)
Gentex 1000-liter Tank	Main water collection vessel	EACH	$51.86	1	$51.86	UGX 192,074.074
1" PVC Pipe (DN25)	8 meter length needed	6m Section	$5.00	2	$10.00	UGX 37,037.04
1" PVC Elbows (DN25)	45 degree elbows	EACH	$1.12	3	$3.36	UGX 12,444.44
1" PVC Ball Valves (DN 25)	Used for Siphon Shut off	EACH	$1.64	3	$4.92	UGX 18,222.22
Wire Mesh	For filtering contaminants out of funnel (10'x2' > 45 pieces)	EACH	$4.63	1	$4.63	UGX 17,148.15
PVC Cement (liters)	For grouting PVC pipes	EACH	$8.48	1	$8.48	UGX 31,407.41
10' x 10' Plastic Tarp	Rain collection	EACH	$10.00	1	$10.00	UGX 37,037.04
Crushed Gravel	10-cu ft Pea Gravel for 4" foundation underneath tank	cu-yd	$60.98	0.35	$21.34	UGX 79,048.15
2"x4"x8' Lumber	Wood for supporting structure	EACH	$5.92	5	$29.60	UGX 109,629.63
Shovels*	Tool	EACH	$10.00	1	$10.00	UGX 37,037.04
Nails *	Support Faseners (4" 28 pieces in bag)	BAGS	$4.00	2	$8.00	UGX 29,629.63
Hammer *	Tool	EACH	$10.00	1	$10.00	UGX 37,037.04
Hand Saw *	Tool	EACH	$10.00	1	$10.00	UGX 37,037.04
Total Cost with extra *					**$182.19**	**UGX 674,788.89**
Total Cost without extra					**$144.19**	**UGX 534,048.15**

Table B.2: Cost Analysis (Larger Tank, Standard Piping)

Item	Description	Units	Cost/Unit (USD)	Quantity	Cost (USD)	Cost (UGX)
Gentex 2000L Tank	Main water collection vessel	EACH	$98.29	1	$98.29	UGX 364,037.037
1" PVC Pipe (DN25)	8 meter length needed	6m Section	$5.00	2	$10.00	UGX 37,037.04
1" PVC Elbows (DN25)	45 degree elbows	EACH	$1.12	3	$3.36	UGX 12,444.44
1" PVC Ball Valves (DN 25)	Used for Siphon Shut off	EACH	$1.64	3	$4.92	UGX 18,222.22
Wire Mesh	For filtering contaminants out of funnel (10'x2' > 45 pieces)	EACH	$4.63	1	$4.63	UGX 17,148.15
PVC Cement (liters)	For grouting PVC pipes	EACH	$8.48	1	$8.48	UGX 31,407.41
10' x 10' Plastic Tarp	Rain collection	EACH	$10.00	1	$10.00	UGX 37,037.04
Crushed Gravel	10-cu ft Pea Gravel for 4" foundation underneath tank	cu-ft	$60.98	0.35	$21.34	UGX 79,048.15
2"x4"x8' Lumber	Wood for supporting structure	EACH	$5.92	5	$29.60	UGX 109,629.63
Shovels*	Tool	EACH	$10.00	1	$10.00	UGX 37,037.04
Nails *	Support Faseners (4" 28 pieces in bag)	BAGS	$4.00	2	$8.00	UGX 29,629.63
Hammer *	Tool	EACH	$10.00	1	$10.00	UGX 37,037.04
Hand Saw *	Tool	EACH	$10.00	1	$10.00	UGX 37,037.04
Total Cost with extra *					**$228.62**	**UGX 846,751.85**
Total Cost without extra					**$190.62**	**UGX 706,011.11**

Table B.3: Cost Analysis (Small Tank, More Pipe Needed)

Item	Description	Units	Cost/Unit (USD)	Quantity	Cost (USD)	Cost (UGX)
Gentex 1000L Tank	Main water collection vessel	EACH	$98.29	1	$51.86	UGX 192,074.074
1" PVC Pipe (DN25)	20 meter length needed	6m Section	$5.00	4	$20.00	UGX 74,074.07
1" PVC Elbows (DN25)	45 degree elbows	EACH	$1.12	3	$3.36	UGX 12,444.44
1" PVC Ball Valves (DN 25)	Used for Siphon Shut off	EACH	$1.64	3	$4.92	UGX 18,222.22
Wire Mesh	For filtering contaminants out of funnel (10'x2' > 45 pieces)	EACH	$4.63	1	$4.63	UGX 17,148.15
PVC Cement (liters)	For grouting PVC pipes	EACH	$8.48	1	$8.48	UGX 31,407.41
10' x 10' Plastic Tarp	Rain collection	EACH	$10.00	1	$10.00	UGX 37,037.04
Crushed Gravel	10-cu ft Pea Gravel for 4" foundation underneath tank	cu-ft	$60.98	0.35	$21.34	UGX 79,048.15
2"x4"x8' Lumber	Wood for supporting structure	EACH	$5.92	5	$29.60	UGX 109,629.63
Shovels*	Tool	EACH	$10.00	1	$10.00	UGX 37,037.04
Nails *	Support Faseners (4" 28 pieces in bag)	BAGS	$4.00	2	$8.00	UGX 29,629.63
Hammer *	Tool	EACH	$10.00	1	$10.00	UGX 37,037.04
Hand Saw *	Tool	EACH	$10.00	1	$10.00	UGX 37,037.04
Total Cost with extra *					**$192.19**	**UGX 711,825.93**
Total Cost without extra					**$154.19**	**UGX 571,085.19**

Table B.4: Cost Analysis (Small Tank, Less Pipe Needed)

Item	Description	Units	Cost/Unit (USD)	Quantity	Cost (USD)	Cost (UGX)
Gentex 1000L Tank	Main water collection vessel	EACH	$98.29	1	$51.86	UGX 192,074.074
1" PVC Pipe (DN25)	5 meter length needed	6m Section	$5.00	1	$5.00	UGX 18,518.52
1" PVC Elbows (DN25)	45 degree elbows	EACH	$1.12	3	$3.36	UGX 12,444.44
1" PVC Ball Valves (DN 25)	Used for Siphon Shut off	EACH	$1.64	3	$4.92	UGX 18,222.22
Wire Mesh	For filtering contaminants out of funnel (10'x2' > 45 pieces)	EACH	$4.63	1	$4.63	UGX 17,148.15
PVC Cement (liters)	For grouting PVC pipes	EACH	$8.48	1	$8.48	UGX 31,407.41
10' x 10' Plastic Tarp	Rain collection	EACH	$10.00	1	$10.00	UGX 37,037.04
Crushed Gravel	10-cu ft Pea Gravel for 4" foundation underneath tank	cu-ft	$60.98	0.35	$21.34	UGX 79,048.15
2"x4"x8' Lumber	Wood for supporting structure	EACH	$5.92	5	$29.60	UGX 109,629.63
Shovels*	Tool	EACH	$10.00	1	$10.00	UGX 37,037.04
Nails *	Support Faseners (4" 28 pieces in bag)	BAGS	$4.00	2	$8.00	UGX 29,629.63
Hammer *	Tool	EACH	$10.00	1	$10.00	UGX 37,037.04
Hand Saw *	Tool	EACH	$10.00	1	$10.00	UGX 37,037.04
Total Cost with extra *					**$177.19**	**UGX 656,270.37**
Total Cost without extra					**$139.19**	**UGX 515,529.63**

Appendix C: Funnel Design Length Depending on Tank Size

The table below is used to design the funnel dimensions as a function of the tank capacity. Based on how much storage the tank has and how much rainwater falls, the dimensions of a square funnel can be calculated.

Table C.1: Funnel Design Length as a function of Tank Size

Tank Capacity (L)	Rainy Season Rainfall (March - May) (mm)	Design Length of Square Catchment (m)	Design Length of Square Catchment (ft)
250	370	0.866	2.84
500	370	1.225	4.02
1000	370	1.733	5.69
1500	370	2.122	6.96
2000	370	2.451	8.04
2500	370	2.740	8.99
3000	370	3.002	9.85
4000	370	3.466	11.37
5000	370	3.875	12.71
8000	370	4.901	16.08
10000	370	5.480	17.98

Appendix D: Gentex Tank Pricing and Value

This table provides the different costs for the various Gentex water storage tanks. Also included in the table is the overall value that farmers would receive (Liters/$). Providing this information will aid farmers with different price points in choosing the tank size that fits their needs.

Table D.1: Gentex Tank Pricing

TANK CAPACITY	GENTEX Retail	GENTEX	Price in USD Retail	Value Liters/$
250 LTR WATER TANK	68,000	61,000	18.46	13.54
500 LTR WATER TANK	117,000	105,000	31.77	15.74
1000 LTR WATER TANK	191,000	172,000	51.86	19.28
1500 LTR WATER TANK	303,000	273,000	82.26	18.23
2000 LTR WATER TANK	362,000	326,000	98.28	20.35
2500 LTR WATER TANK	487,000	438,000	132.22	18.91
3000 LTR WATER TANK	545,000	491,000	147.97	20.27
4000 LTR WATER TANK	821,000	739,000	222.90	17.95
5000 LTR WATER TANK	893,000	804,000	242.45	20.62
8000 LTR WATER TANK	1,632,000	1,469,000	443.09	18.06
10000 LTR WATER TANK	2,017,000	1,815,000	547.62	18.26

Appendix E: Adequacy for Tanks to be Buried

This table analyzes whether the various Gentex tanks are safe to bury. If the flexural strength resistance of an empty tank cannot withstand both active and passive earth pressures using a factor of safety of 1.5, then the tank is deemed unfit to be buried. It is important to note that this table uses average data for the sandy loam soil found in the Lake Bunyonyi region, and site-specific soil testing should be conducted before construction.

Table E.1: Adequacy for Tanks to be Buried as a Function of Depth and Strength of Tank

Tank Capacity (L)	Tank Height (m)	Tank Diameter (m)	Typical Flexural Stress Resistance of PCV Water Tanks (kN/m^2)	Tank Flexural Strength Resistance with FS of 1.5 (kN)	Active Earth Pressure Force (kN)	Passive Earth Pressure Force (kN)	Is the Tank Safe to Bury?
250	0.65	0.77	78	26.03	0.66	9.00	Yes
500	0.89	0.94	78	43.50	1.51	20.61	Yes
1000	1.33	1.08	78	74.69	3.88	52.87	Yes
1500	1.45	1.25	78	94.25	5.34	72.74	Yes
2000	1.62	1.35	78	113.72	7.20	98.06	Yes
2500	1.84	1.39	78	133.00	9.56	130.24	Yes
3000	1.91	1.50	78	148.98	11.12	151.45	No
4000	1.99	1.72	78	177.99	13.84	188.51	No
5000	2.17	1.82	78	205.37	17.42	237.19	No
8000	2.43	2.17	78	274.20	26.04	354.63	No
10000	2.78	2.30	78	332.49	36.13	491.95	No

Appendix F: Water Hammer Effect Report

PipeEng

Pipeline Engineering

Water Hammer Calculation *ver 0.0*

https://pipeeng.com/water_hammer.html

Project	*ABC Project*		Developer	*PipeEng*
Date	*2/3/2021, 8:33:46 PM*		Approver	
Revision	*0*		Reviewer	

An abrupt change in the velocity of a flowing liquid in a pipe generates a pressure wave, which is commonly referred as "Water Hammer".This tool was developed using the Joukowsky equation to provide you with a simplified method for calculating the peak transient pressure experienced when a valve is closed against a fluid in motion. Absent a formal surge analysis, this tool can be used to obtain an estimate of the magnitude of a surge pressure.

Input Data

Pipe Diameter, D	inch	1.315
Pipe Wall Thickness, t	inch	0.133
Flowrate, Q	gpm	15.85
Weight of Fluid, W	lb/ft^3	62.4
Liquid Bulk Modulus of Elasticity, k	psi	299938
Pipe Young's Modulus of Elasticity, E	psi	471373
Pipe Poisson Ratio, μ		0.40
Dimensionless Parameter due to System Pipe-Constraint Condition, c		0.91

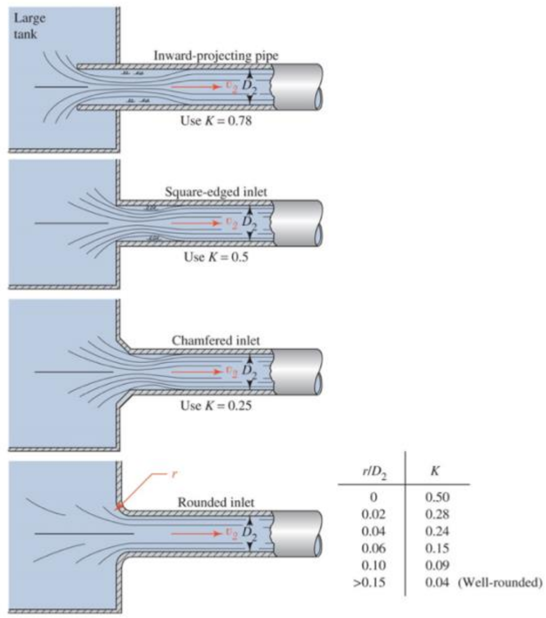
Result

Pipe Inner Diameter, d	inch	1.05
Fluid Velocity, V	ft/s	19.29
Wave Velocity, a	ft/s	2000.1
Surge Pressure, ΔP	psi	158.4

Appendix G: Motts Tables Used in Siphon Calculations

Motts 10.13 Entrance Loss Depending on Inlet Characteristics

Entrance Loss



Roughness

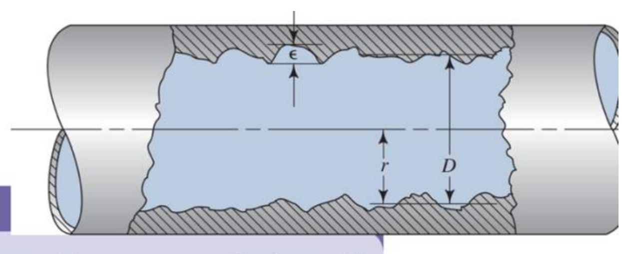


TABLE 8.2 Pipe roughness—design values

Material	Roughness ε (m)	Roughness ε (ft)
Glass	Smooth	Smooth
Plastic	3.0×10^{-7}	1.0×10^{-6}
Drawn tubing; copper, brass, steel	1.5×10^{-6}	5.0×10^{-6}
Steel, commercial or welded	4.6×10^{-5}	1.5×10^{-4}
Galvanized iron	1.5×10^{-4}	5.0×10^{-4}
Ductile iron—coated	1.2×10^{-4}	4.0×10^{-4}
Ductile iron—uncoated	2.4×10^{-4}	8.0×10^{-4}
Concrete, well made	1.2×10^{-4}	4.0×10^{-4}
Riveted steel	1.8×10^{-3}	6.0×10^{-3}

TABLE 10.4 Resistance in valves and fittings expressed as equivalent length in pipe diameters, L_e/D

Type	Equivalent Length in Pipe Diameters L_e/D
Globe valve—fully open	340
Angle valve—fully open	150
Gate valve—fully open	8
—¾ open	35
—½ open	160
—¼ open	900
Check valve—swing type	100
Check valve—ball type	150
Butterfly valve—fully open, 2–8 in	45
—10–14 in	35
—16–24 in	25
Foot valve—poppet disc type	420
Foot valve—hinged disc type	75
90° standard elbow	30
90° long radius elbow	20
90° street elbow	50
45° standard elbow	16
45° street elbow	26
Close return bend	50
Standard tee—with flow through run	20
—with flow through branch	60

Appendix H: First Flush Schedule

The table below shows different first flush lengths as a function of the roof dimensions. The row in blue is the dimensions used for the design of this project, but the other dimensions can be used for different sized houses.

Table H.1: First Flush Length as a Function of Roof Dimensions

Roof Dimensions		Width of one Roof Panel	Area of Catchment	Area of Catchment	First Flush Volume using 0.4 mm depth of rain	Total Length of 3" (DN 75) PVC Pipe Needed	Total Length of 3" (DN 75) PVC Pipe Needed
Width (ft)	**Length (ft)**	**(ft)**	**(sf)**	**(sq. m)**	**(L)**	**(m)**	**(ft)**
25	30	13.17	395.28	36.72	14.69	3.32	10.91
30	30	15.81	474.33	44.07	17.63	3.99	13.09
30	35	15.81	553.39	51.41	20.56	4.65	15.27
20	25	10.54	263.52	24.48	9.79	2.22	7.27
20	20	10.54	210.82	19.59	7.83	1.77	5.82
15	20	7.90	158.11	14.69	5.88	1.33	4.36
15	15	7.90	118.58	11.02	4.41	1.00	3.27

Appendix I: Final Work Breakdown Schedule

PROJECT TITLE	Entusi Model Farm Irrigation System	**TEAM NAME**	Water Benders
COMMUNICATIONS LEAD/SCRUM MASTER	Madison Berry/Alex Wood	**DATE**	Sunday, April 11, 2021

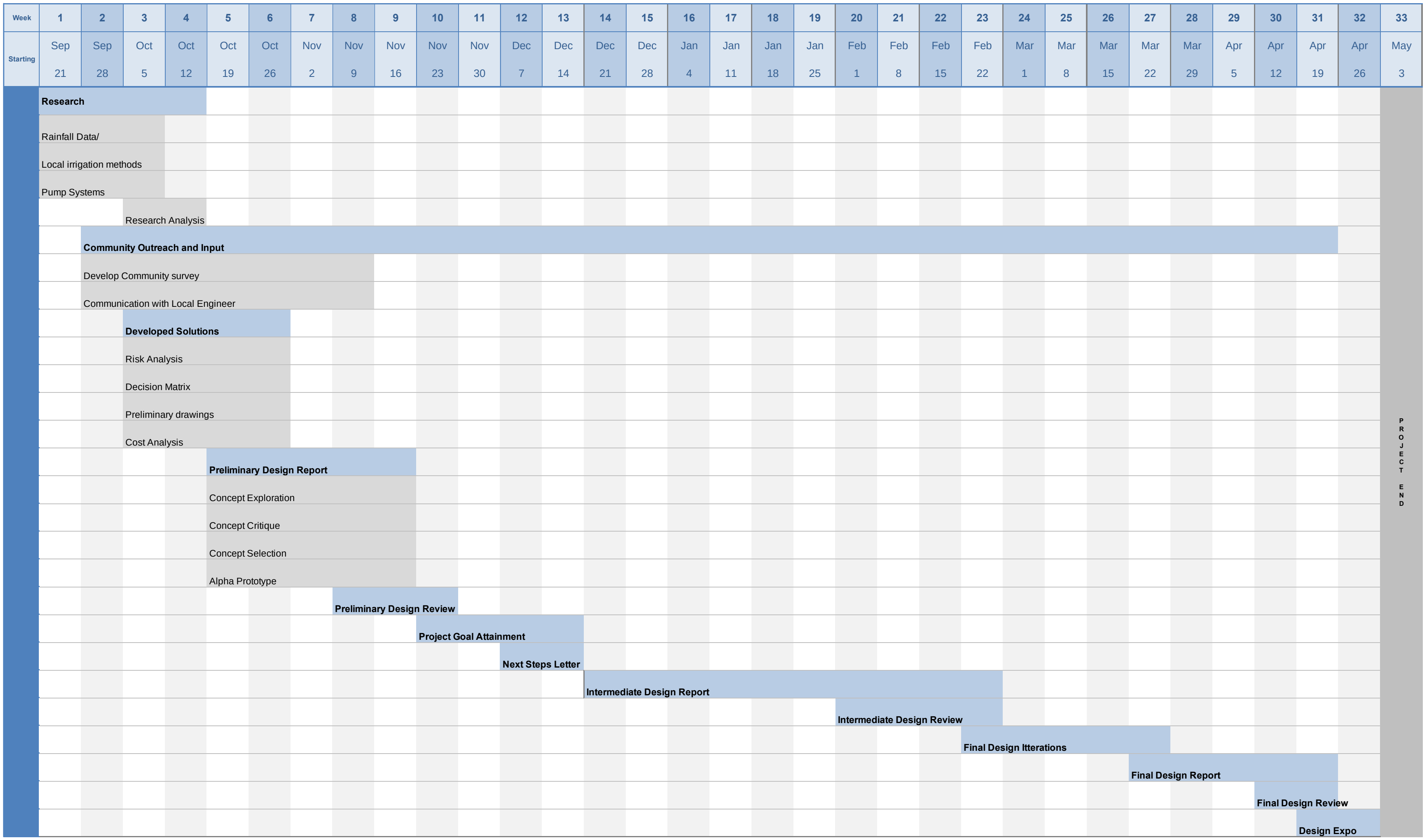
PROJECT	**Model Farm Irigation System**			
PHASE	**Research**	**Community Input and buy-in into the proposed product design**	**Prototype of small-scale irrigation system**	**Final Design Report of Irrigation System**
TASK	**Cultural Context of Uganda**	**Community Engagement**	**System testing**	**Research**
	Irigation Methods and technologies	**Community Surveys/Interviews**	**Risk Analysis**	**Full drawing package of Irrigation System**
	Rain catchment	**Communication with Local Engineer**	**Decision matrix of materials**	**Project Budget**
	Environmental constraints		**Cost-Benefit Analysis**	**Schedule**
	Preexisting farming and irrigation methods		**Communicating with local water engineer**	
	Different pump systems		**Prototype Selection and Ranking Criteria**	

Appendix J: Final Project Schedule

GLI Lake Bunyonyi Irrigation System

Project Schedule

Start Week	Sep 21, 2020



Appendix K: Volumetric Analysis of Water Deficit

The table below shows the different expected water demands for a range of locally grown crops based on the amount of rainfall in the given month. Rainwater deficits are expressed as a negative number while rainwater surpluses are expressed as positive.

Table K.1: Volumetric Analysis of Water Deficit as a function of Expected Rainfall per month

Difference in rainfall needed per crop upper demand (L)	Crop	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
	SORGHUM	111000	-28071	27429	48429	15429	-55071	-82071	-14571	156000	195000	205500	150000
	MAIZE/CORN	-129000	-139500	156000	177000	144000	73500	46500	114000	156000	-45000	-34500	-90000
	BEANS	-39000	100500	156000	177000	144000	73500	46500	114000	6000	45000	55500	0
	POTATOES	-122333	100500	-77333	-56333	-89333	-159833	46500	114000	-77333	-38333	-27833	-83333
	PEAS	-14000	100500	156000	177000	144000	73500	46500	-11000	31000	70000	80500	25000

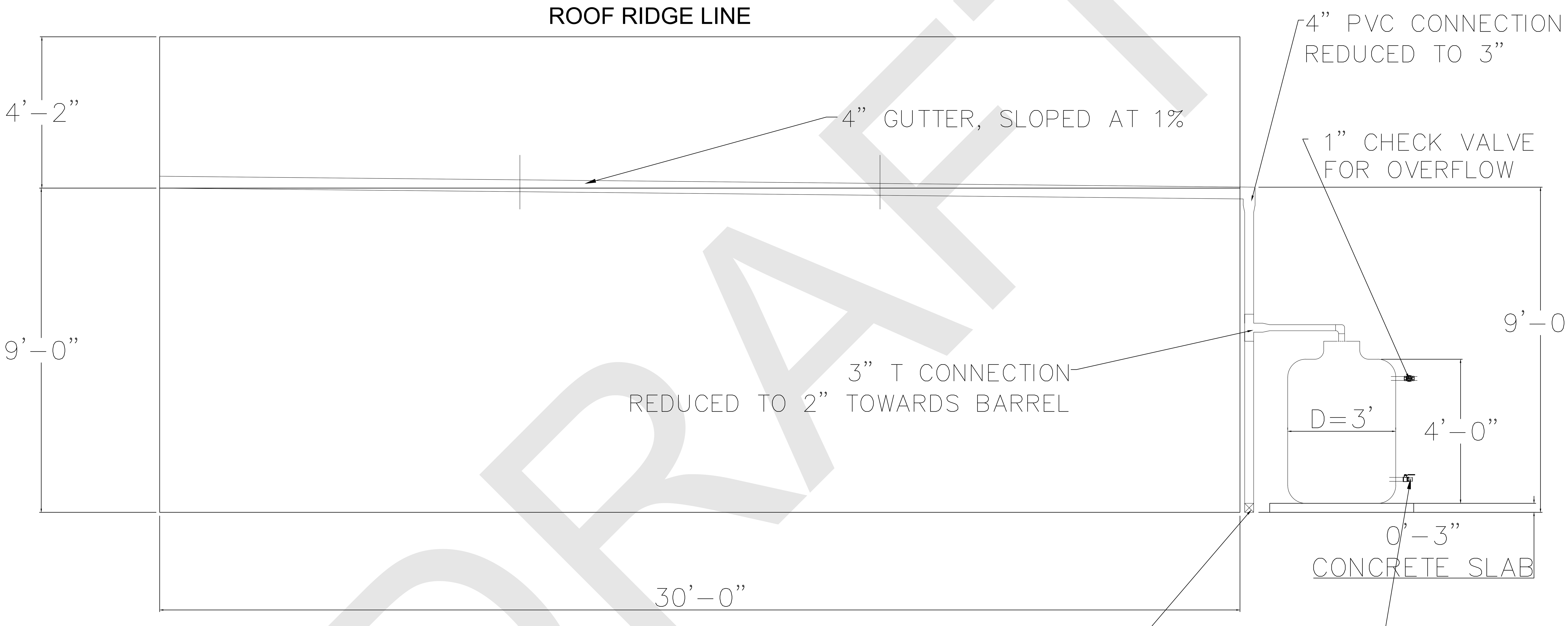
Difference in rainfall needed per crop lower demand (L)	Crop	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
	SORGHUM	111000	4071	59571	80571	47571	-22929	-49929	17571	156000	195000	205500	150000
	MAIZE/CORN	-39000	-49500	156000	177000	144000	73500	46500	114000	156000	45000	55500	0
	BEANS	21000	100500	156000	177000	144000	73500	46500	114000	66000	105000	115500	60000
	POTATOES	-55667	100500	-10667	10333	-22667	-93167	46500	114000	-10667	28333	38833	-16667
	PEAS	23500	100500	156000	177000	144000	73500	46500	26500	68500	107500	118000	62500

LEGEND
crop not grown
sufficient rainwater
insufficient rainwater

Appendix L: Detailed Drawings of Design

Please see the following pages for full-sized drawings of the design.

RAIN WATER COLLECTION SYSTEM: ELEVATION VIEW (30')



GENERAL NOTES

1. ALL REDUCTIONS IN PIPE SIZE WILL REQUIRE A REDUCER.
2. CONCRETE SLAB WILL BE REINFORCED WITH REBAR.
3. THIS WORK IS DONE BY STUDENTS, NOT PROFESSIONALS, WE ARE NOT LIABLE, CSM IS NOT LIABLE, THESE DRAWINGS ARE NOT RELEASED FOR CONSTRUCTION UNLESS SIGNED AND SEALED BY A P.E. AFTER HIS/HER INDEPENDENT REVIEW... THESE DRAWINGS ARE NOT RELEASED FOR CONSTRUCTION.
4. UNDEFINED DIMENSIONS ARE FLEXIBLE IN ORDER TO ALLOW VARIANCES BETWEEN SITES.
5. SEE DETAILS FOR CLOSE UP VIEWS OF THE VALVES AND ROOF CONNECTION.
6. ASSUMED PLAN DIMENSIONS OF HOUSE IS 25'X30'.

COLORADO SCHOOL OF MINES

REVISIONS

DATE	DESCRIPTION	APPROVED
4/8/2021	ISSUED FOR PRELIMINARY REVIEW	AW

GLOBAL LIVINGSTON INSTITUTE

CONTACT: TOM KARREL, DIRECTOR OF ACADEMIC PARTNERNSHIPS
EMAIL: TOM@GLOBALLIVINGSTON.ORG

DRAWN BY: ALEX WOOD

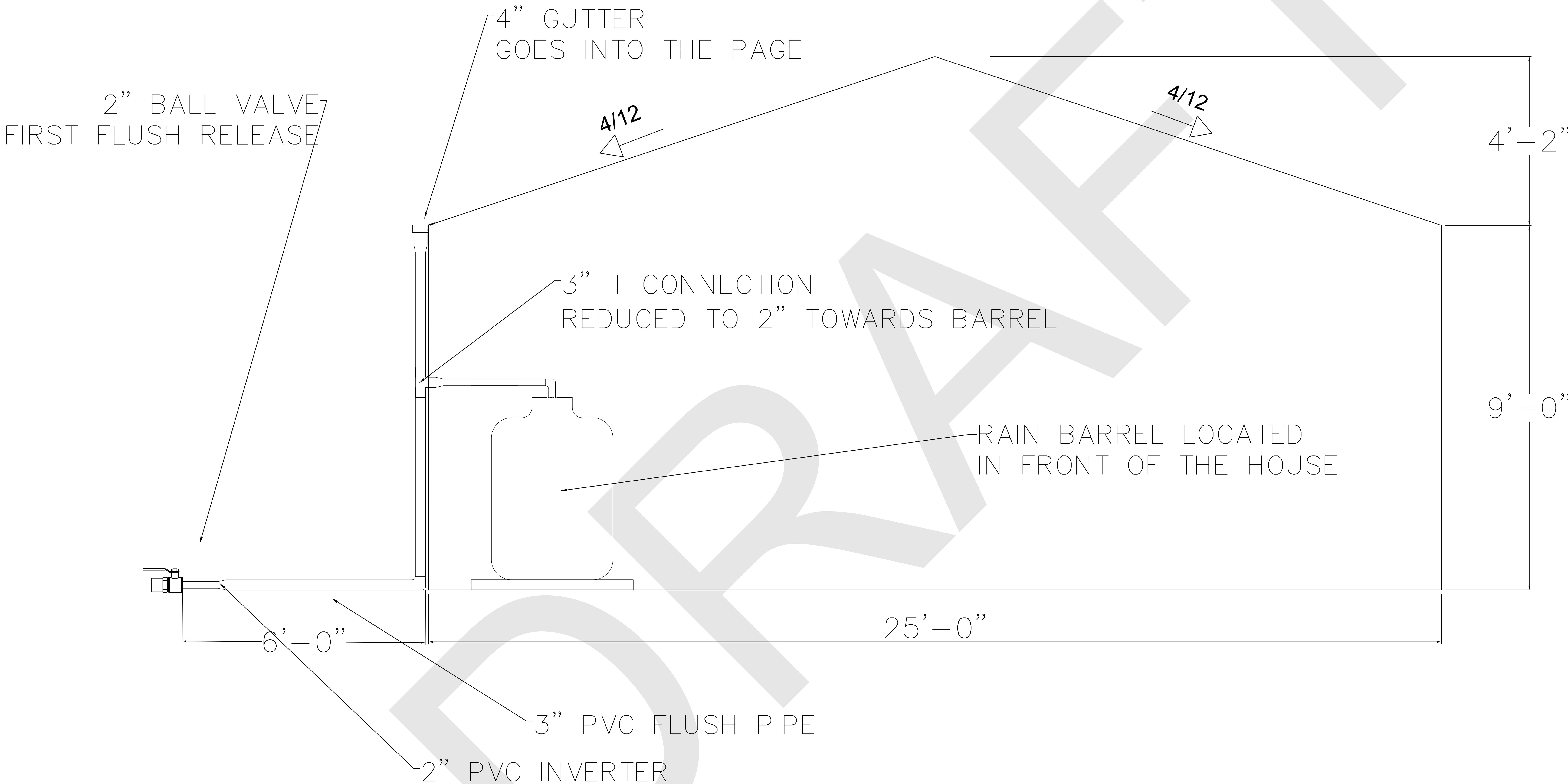
SCALE

PREPARED: APRIL 8TH, 2021

101

30' ELEVATION VIEW

RAIN WATER COLLECTION SYSTEM: ELEVATION VIEW (25')



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COLORADO SCHOOL OF MINES

REVISIONS

DATE	DESCRIPTION	APPROVED
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GLOBAL LIVINGSTON INSTITUTE

CONTACT: TOM KARREL, DIRECTOR OF ACADEMIC PARTNERNSHIPS
EMAIL: TOM@GLOBALLIVINGSTON.ORG

DRAWN BY: ALEX WOOD

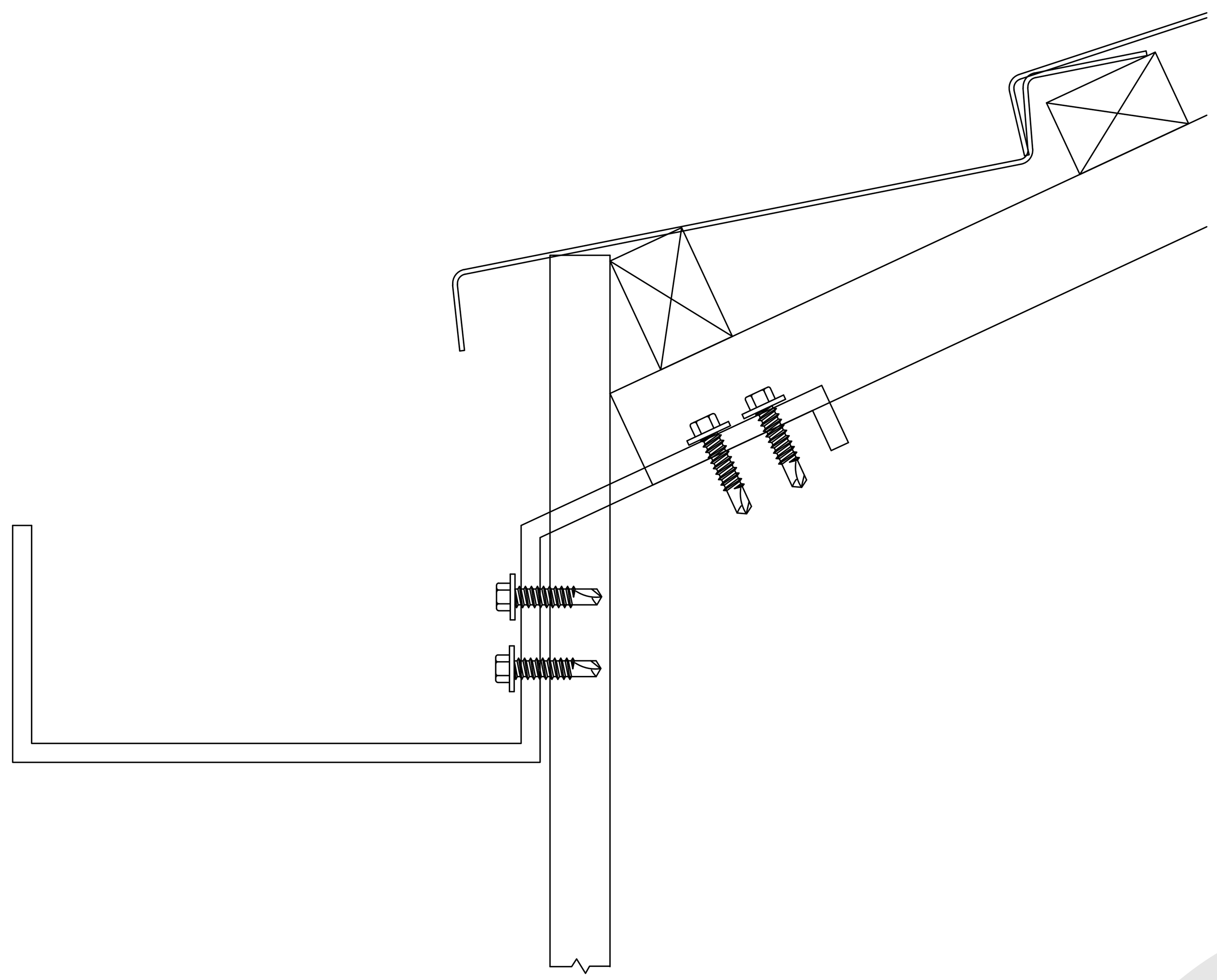
SCALE

PREPARED: APRIL 8TH, 2021

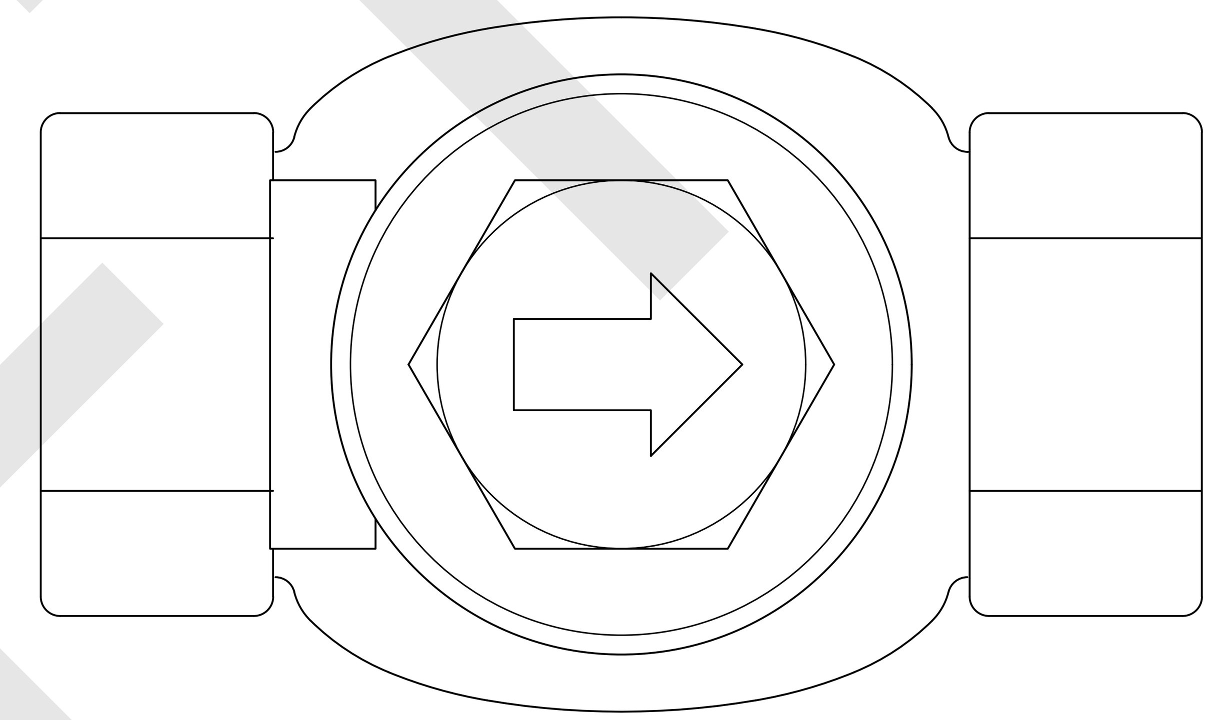
102

25' ELEVATION VIEW

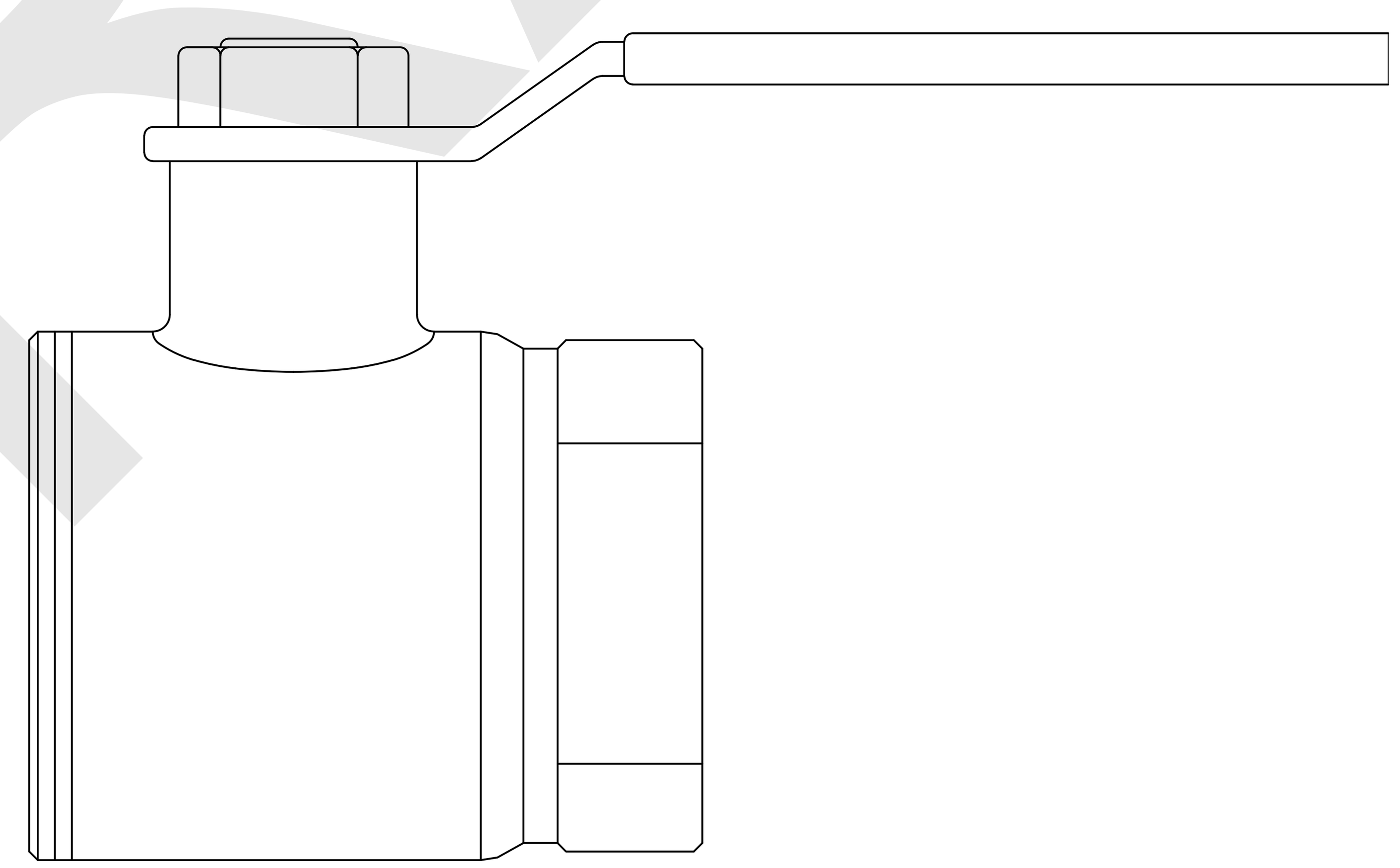
RAIN WATER COLLECTION SYSTEM: DETAILS



NOTES
1. DESIGN CREDIT TO CADBLOCKSFREE.COM
2. CONNECTED USING $\frac{3}{8}$" SCREWS.
3. ATTACHED TO THE SIDE WALL AND TOP OF ROOF.
4. GUTTER MUST BE SLOPED DOWNWARDS AT 1% OR GREATER TO ENSURE WATER FLOWS AND DOES NOT STAGNATE.



NOTES
1. DESIGN CREDIT TO LINECAD.COM
2. USED FOR 1" OVERFLOW POINT



NOTES
1. DESIGN CREDIT TO LINECAD.COM
2. USED FOR BOTH 3" RELEASE POINT FOR FIRST FLUSH AND 1" RELEASE POINT ON TANK

COLORADO SCHOOL OF MINES

REVISIONS

DATE	DESCRIPTION	APPROVED
4.8.2021	ISSUED FOR PRELIMINARY REVIEW	AW

GLOBAL LIVINGSTON INSTITUTE

CONTACT: TOM KARREL, DIRECTOR OF ACADEMIC PARTNERSHIPS
EMAIL: TOM@GLOBALLIVINGSTON.ORG

DRAWN BY: ALEX WOOD

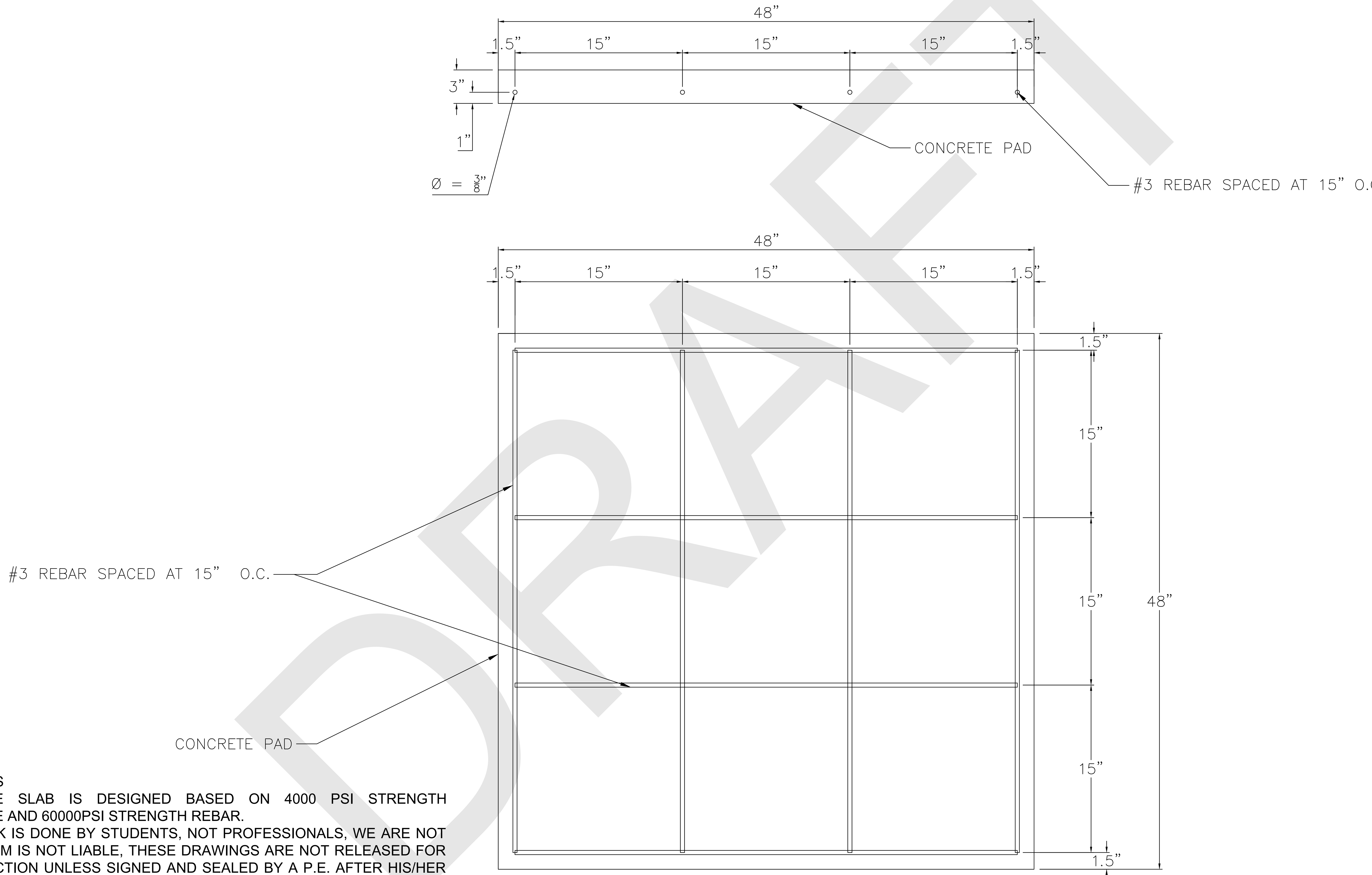
PREPARED: APRIL 8TH, 2021

DRAWING IS NOT TO SCALE

201

DETAILS

RAIN WATER COLLECTION SYSTEM: SLAB DETAIL



GENERAL NOTES

1. CONCRETE SLAB IS DESIGNED BASED ON 4000 PSI STRENGTH CONCRETE AND 60000PSI STRENGTH REBAR.
2. THIS WORK IS DONE BY STUDENTS, NOT PROFESSIONALS, WE ARE NOT LIABLE, CSM IS NOT LIABLE, THESE DRAWINGS ARE NOT RELEASED FOR CONSTRUCTION UNLESS SIGNED AND SEALED BY A P.E. AFTER HIS/HER INDEPENDENT REVIEW... THESE DRAWINGS ARE NOT RELEASED FOR CONSTRUCTION.
3. EACH REBAR OVERLAP SHOULD HAVE A REBAR TIE TO CREATE A REBAR CAGE.
4. ALL DIMENSIONS TAKEN FROM A REBAR ARE MEASURED ON CENTER.
5. THE TOP DRAWING IS A PROFILE VIEW AND THE BOTTOM IS A PLAN VIEW.

COLORADO SCHOOL OF MINES

REVISIONS

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4.8.2021	ISSUED FOR PRELIMINARY REVIEW	AW

GLOBAL LIVINGSTON INSTITUTE

CONTACT: TOM KARREL, DIRECTOR OF ACADEMIC PARTNERNSHIPS
EMAIL: TOM@GLOBALLIVINGSTON.ORG

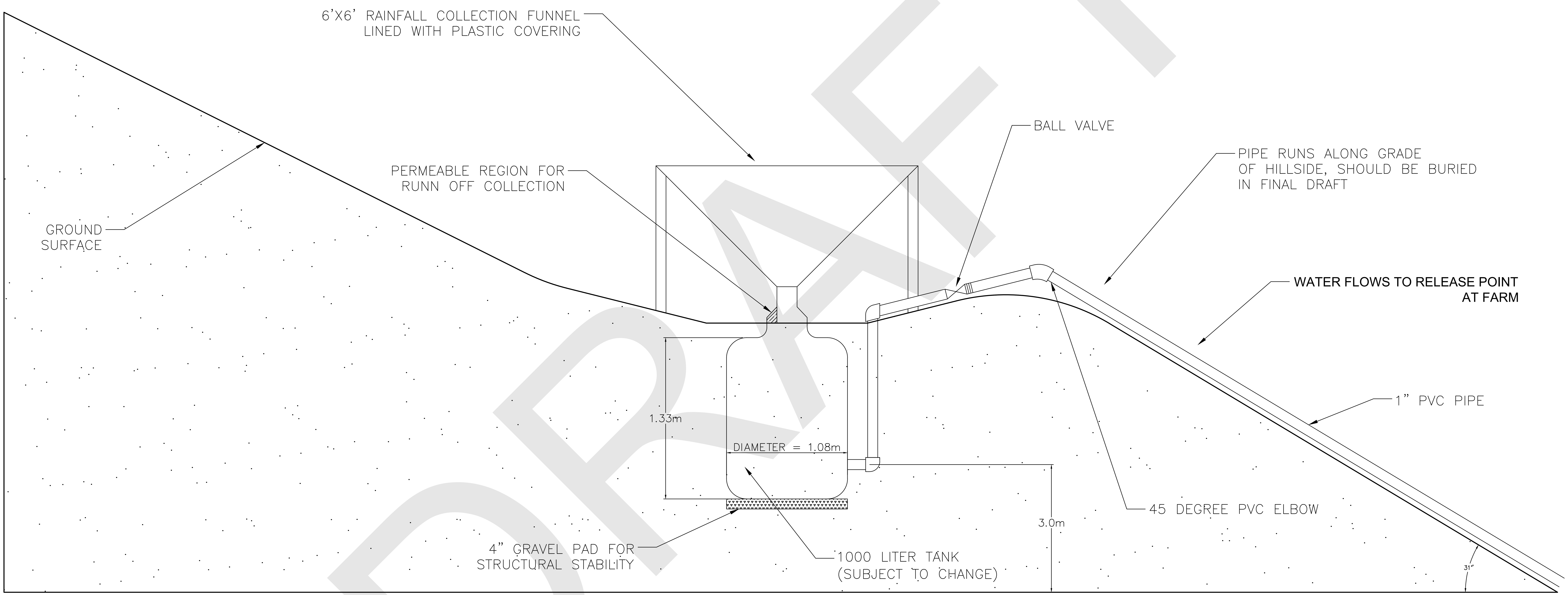
DRAWN BY: MADISON BERRY

PREPARED: APRIL 8TH, 2021

202

SLAB DETAIL

RAIN WATER COLLECTION SYSTEM: ENTIRE MODEL



GENERAL NOTES

1. THE RECOMMENDED TANKS ARE THROUGH GENTEX ENTERPRISES.
2. DESIGNS COMPLETED ARE NOT TO SCALE AND ARE FOR VISUAL ILLUSTRATION PURPOSES ONLY.
3. MULTIPLE ASSUMPTIONS WERE MADE ON THE TOPOGRAPHY OF THE LAND AND THE DEIGN OF THE SUBSYSTEMS TO ILLUSTRATE THE PRACTICALITY OF THE DESIGN.
4. EXPOSED PIPE LEADS TO INCREASE RISK IN DAMAGE FROM PEOPLE OR ANIMALS AS WELL AS DEGRADATION FROM UV RAYS.
5. THIS WORK IS DONE BY STUDENTS, NOT PROFESSIONALS, WE ARE NOT LIABLE, CSM IS NOT LIABLE, THESE DRAWINGS ARE NOT RELEASED FOR CONSTRUCTION UNLESS SIGNED AND SEALED BY A P.E. AFTER HIS/HER INDEPENDENT REVIEW... THESE DRAWINGS ARE NOT RELEASED FOR CONSTRUCTION.

COLORADO SCHOOL OF MINES

REVISIONS

DATE	DESCRIPTION	APPROVED
2.2.2021	ISSUED FOR PRELIMINARY REVIEW	AW

GLOBAL LIVINGSTON INSTITUTE

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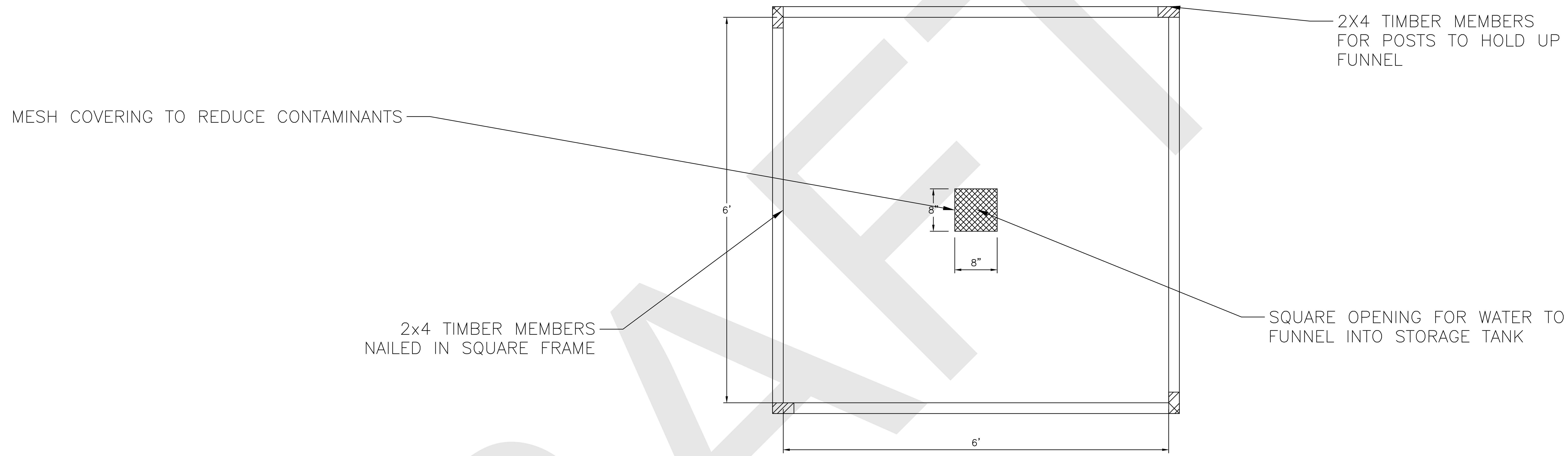
DRAWN BY: ALEX WOOD

PREPARED: JANUARY 31ST, 2021
NOT TO SCALE

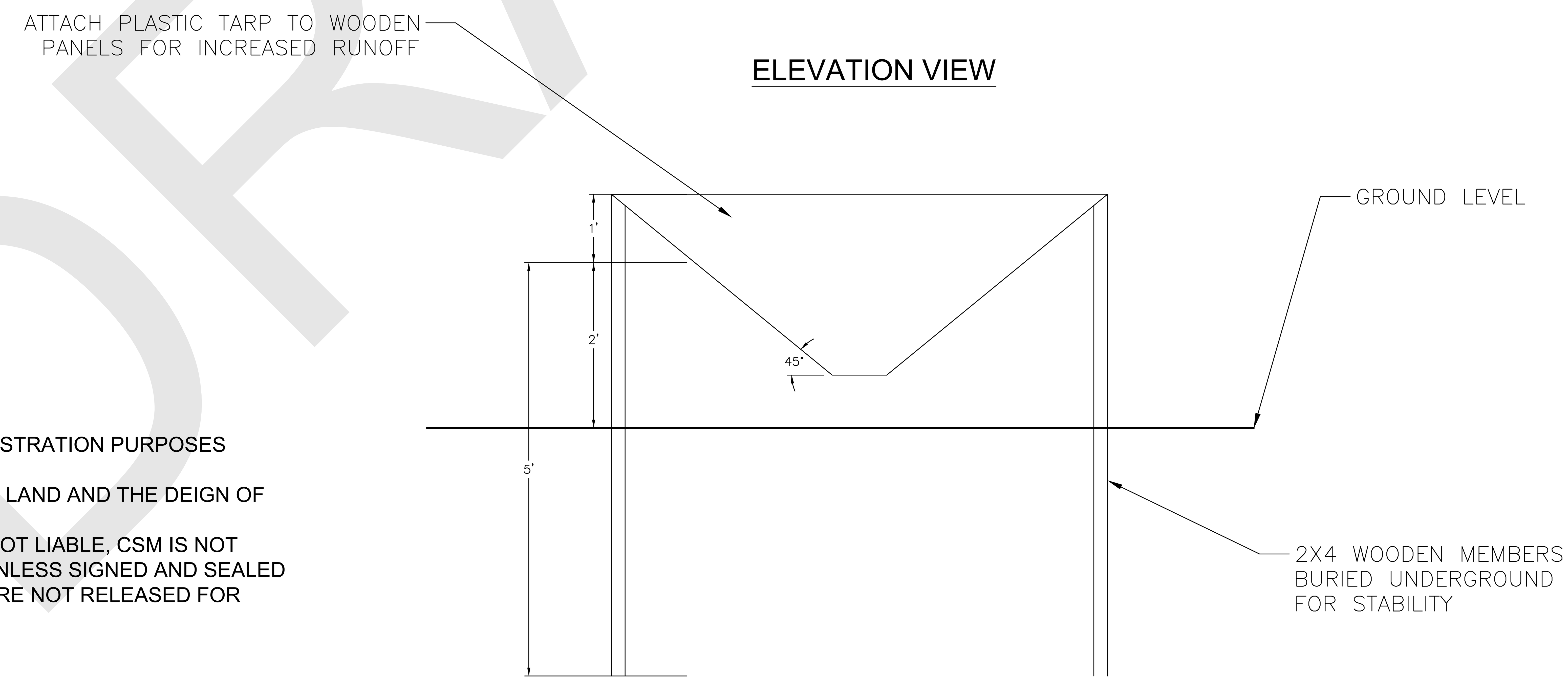
100
ENTIRE SYSTEM

RAIN WATER COLLECTION SYSTEM: FUNNEL DETAIL

PLAN VIEW



ELEVATION VIEW



GENERAL NOTES

1. DESIGNS COMPLETED ARE NOT TO SCALE AND ARE FOR VISUAL ILLUSTRATION PURPOSES ONLY.
2. MULTIPLE ASSUMPTIONS WERE MADE ON THE TOPOGRAPHY OF THE LAND AND THE DEIGN OF THE SUBSYSTEMS TO ILLUSTRATE THE PRACTICALITY OF THE DESIGN.
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COLORADO SCHOOL OF MINES

REVISIONS

DATE	DESCRIPTION	APPROVED
2.2.2021	ISSUED FOR PRELIMINARY REVIEW	AW

GLOBAL LIVINGSTON INSTITUTE

CONTACT: TOM KARREL, DIRECTOR OF ACADEMIC PARTNERNSHIPS
EMAIL: TOM@GLOBALLIVINGSTON.ORG

DRAWN BY: ALEX WOOD

PREPARED: FEBRUARY 1ST, 2021

SCALE: 1" = 1'

0 1 2 Feet

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FUNNEL DETAIL