Capstone Design Program
Engineering, Design, & Society

COLORADO SCHOOL OF MINES
GOLDEN, COLORADO 80401-1887

Team Uganda Forever
F20-16
Capstone Design Program
Colorado School of Mines
1500 Illinois Street
Golden, CO 80401

May 4, 2021

Global Livingston Institute
5014, 3001 Brighton Blvd #2662
Denver, Colorado 80216

Salutation,

We would like to thank Tom, Raymond, and Jerry for their participation in our Final Design Review. They provided insightful feedback and asked engaging questions that encouraged our learning. We have taken their comments and questions into consideration when updating our report. The final version is attached to this letter. This letter will serve as a follow up to the review which includes a summary of feedback received and engineering recommendations.

Immediately following the Final Design Review the team received feedback from GLI and our PA's. The contacts at GLI thanked the team for our hard work over the past two semesters of working on the project and expressed their hopeful intentions of implementing the hand pump design in the future. The client requested that we send them an instruction manual and maintenance recommendations brochure which are attached to this document. The PA's suggested that the team bulk up the final design report with information regarding the whole design process and iterations from the past two semesters. At the final design presentation the team's report consisted of figures, data, and details of only the final design chosen rather than the project as a whole. The Final Design Report now represents the research, findings, and recommendations of the whole project from start to finish.

Our team was limited these past eight months by the inability to conduct tests and develop a prototype on site. It is our recommendation that future teams who continue work on this project visit the site in order to properly analyze the surroundings and solutions. In person tests will help find flaws in the design that might not have shown up on paper.

The budget chart can be found below in Figure 1 and includes links to parts not found at local stores in Uganda. The items include all of the parts required to make the hand pump; however, the budget sheet does not include costs of the tools required to install the pump. The initial estimate of the cost to build the hand pump system was highly underestimated. The client gave the team a budget of $100 per unit as that was the most they could afford. Currently, the team's bill of materials for the whole project is $642. The reason the cost is so high is mostly due to the lack of transportation of the materials to Lake Bunyonyi. Because the Lake Bunyonyi area is difficult to deliver to, most of the parts must be bought at nearby stores. These stores have limited supplies and the cost of shipping to these rural towns and the cost to transport them to the farms is large.

Part	Description	Unit Cost	Quantity	Total Cost	Link
Hand Pump	Standard hand pump, metal encasing body with lever arm that moves up and down	$500	1	$500	Found locally in Uganda
PVC Piping	Standad PVC tubing	$1.33/ft	60 ft	$79.80	Found locally in Uganda
Coupler		$2	3	$6	Found locally in Uganda
PVC Cement		$4	1	$4	Found locally in Uganda
Ready Mix Concrete	Concrete mix for the concrete slab the hand pump will sit on	$8	3	$24	Found locally in Uganda
Suction Strainer	Large particle suction strainer with large openings to trap large debris. Screws onto the end of the PVC pipe that sits in the lake.	$12.68	1	$12.68	https://www.mcmaster.com/strainers/large-particle-suction-strainers/
Inline Strainer	Medium inline strainer with mesh screen to trap debris that cleared through the large particle suction strainer. Can be removed from the midline PVC tubing for easy cleaning	$15.21	1	$15.21	https://www.mcmaster.com/inline-strainers/medium-pressure-inline-strainers-8/
			TOTAL	$641.69	

Figure 1: Budget Sheet

These past two semesters have been very beneficial to our learning about community development and engineering skills. Tom, Raymond, and Jerry have been very helpful in gathering information and data to support our project development and learning. We would like to thank Global Livingston Institute for their support during this project and opportunity to work with them to enhance our learning. If there are any further questions or comments, please feel free to reach out. We hope to one day visit Lake Bunyonyi and see our design implemented and successfully working.

Sincerely,

Carlos Ramos
Caroline Jeffords
Joe Golter
Megan Dickson
Serena Daluz
Viviana Verde

cc: Alina Handorean
Elizabeth Reddy

Attachments:
Maintenance Manual
Final Design Report

Summary

The Global Livingston Institute was formed to educate students and organizations on community development and encourage new innovative ideas by engaging leaders from the United States and East Africa. Entusi Resort and Retreat Center is one example of GLI's work to encourage conversation.

Located on a peninsula on Lake Bunyonyi in South Uganda, Entusi is a resort where students, leaders, or any other traveler can go to reflect and learn about community topics or current social issues. Entusi contains a model farm where they practice innovative farming techniques so people in the Lake Bunyonyi community can learn new ways to advance their farms and increase production.

This brochure will serve as a briefing for future engineers to continue work on this project as it provides detail instructions and information on a hand pump model which includes required parts, assembly instructions, maintenance information, and operating instructions.

Colorado School of Mines

1500 Illinois St.

Golden, CO 80401

Phone: 303.273.3000

MINES

GLI

GLOBAL LIVINGSTON INSTITUTE

LISTEN. THINK. ACT.

Uganda Forever

COLORADO SCHOOL OF MINES

PARTS REQUIRED/ MATERIALS/ TOOLS REQUIRED FOR SET UP

The following is a list of all the parts required to assemble the Hand Pump irrigation system:

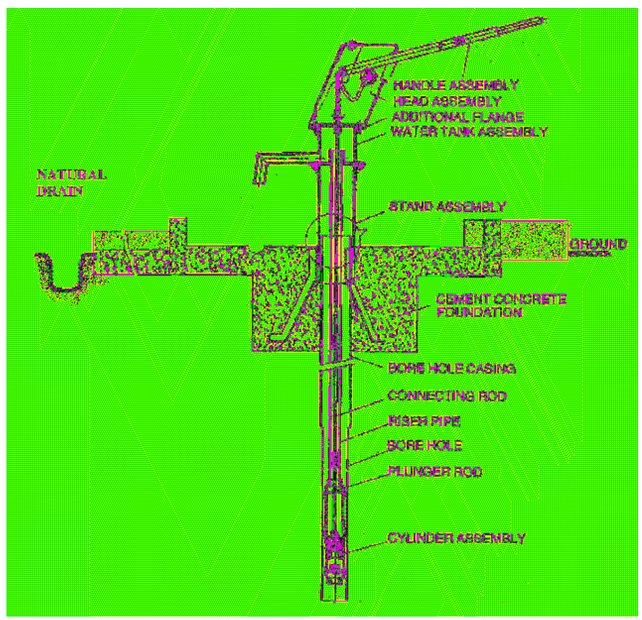
- Locally sourced Uganda Modified Hand Pump (images provided in the FDR)
- 60 ft of 1.25 in. PVC piping
- 3 1.25 in. PVC couplers
- 1 piece PVC cement
- 4 15 kg. Bag of Ready-Mix concrete
- Equal parts water to mix with the concrete.
- Mesh filter for the end of the pipe
- In-line PVC pipe fine mesh filter

The following is a list of all the tools required for assembling the Hand Pump irrigation system:

- Shovel for dirt excavation
- Portable concrete mixer or other preferred method of mixing concrete

Instructions on setup/ Assemble

1. A 1 ft width x 1.5 ft long trench must be excavated from where the hand pump will be located to the bottom of the lake.
2. Connect PVC pipes with couplers along the length of the trench and 10 ft past the edge of the lake.
3. Place the filter at the end of the PVC pipe.
4. Place a removable coupler 5 ft from the end of the pipe and a mesh filter in between that coupler.
5. Place a 3 ft x 3 ft x 1 in wood form.
6. Place the hand pump inside of the wood form and pour with concrete. (make sure to leave the bottom of the hand pump exposed)
7. Once the concrete slab has hardened, the hand pump shall be connected to the PVC pipe that was left sticking out at the top of the concrete slab along with the assemble parts that are provided with the hand pump.
8. Connect the PVC line to the bottom piece of PVC sticking out of the concrete slab.
9. Fill the trench with dirt and compact carefully.
10. Start pumping.



Maintenance

To maintenance the hand pump, there are three separate subsystems that need to be checked annually to ensure that everything is operating properly.

Force Rod Assembly

- Ensure that the motion is smooth when engaging the force rod.

If motion is not smooth, apply lubricant to joint.

- Check that the valve seal is complete so suction is not lost (there should be water flow within a few pumps of the force rod)

If valve is not sealing correctly, clean out slot and replace O-ring.

- Ensure that no debris have built up inside of the pump upon visual inspection.

Water Pump

- Check how much water the pump is delivering if any at all.

If levels are low or non-existent, first replace O-ring.

Post O-ring replacement, if water levels are low or non-existent, check along water suction line for a leak.

- Leak will be identified through wetted soil and erosion.

If a leak is identified that section of PVC will need to be unearthed and replaced.

Filtration System

- Check endcap filter to ensure that it is clear and intact.

If filter is covered in debris, clean debris off
If filter is damaged, replace with a new mesh.

- Check extracted water for small debris.

If there is debris, unearth the section of PVC with the small particle filter and check the filter for any damage.

If there is no filter damage, check the sections of PVC that are between the small particle filter and the pump for leaks.

If a leak is identified, unearth that section of the PVC and replace.

Entusi Model Farm Final Design Report

Submitted to:

5014, 3001 Brighton Blvd #2662
Denver, Colorado 80216

ATTN: Global Livingston Institute

Submitted by:

Group F20-16
Team Uganda Forever
Engineering, Design, & Society
Colorado School of Mines
Golden, Colorado 80401

Capstone Design@Mines

Final Design Report

Team Members:
Serena Daluz (sdaluz@mymail.mines.edu)
Megan Dickson (megandickson@mymail.mines.edu)
Joseph Golter (josephgolter@mymail.mines.edu)
Caroline Jeffords (cmjeffords@mymail.mines.edu)
Carlos Ramos (ramos@mymail.mines.edu)
Viviana Verde (vverde@mymail.mines.edu)
Faculty Advisor: Elizabeth Reddy (reddy@mines.edu)
Faculty Advisor: Alina Handorean (ahandorean@mines.edu)
Consultant: Dr. Kristoph Kinzli (kkinzli@mines.edu)

May 4, 2021

Acknowledgments

With the rise of the pandemic and travel restrictions, it was vital that the team was provided pictures, statistics, and surveys from the land. Our team would like to thank Tom Karrel, Raymond Bokua, Jerry Amanya for thoroughly providing all of the needed information and connecting us with local engineers. We would also like to thank Kristoph Kinzli for his help with our technical calculations. Finally, our team would like to thank Elizabeth Reddy and Alina Handorean for their continuous support and guidance throughout this project.

Table of Contents

List of Figures	5
Executive Summary	7
1. Introduction	9
2. Project Review	10
3. Application of Design Methodology	11
3.1 Lift Concept	11
3.2 Bicycle Concept	13
3.3 Clay Pot Irrigation	14
3.4 Hand Pump Concept	16
3.5 Decision Methodology	19
4. Engineering Analysis	21
5. Final Deliverables	27
6. Project Management	28
7. Lessons Learned	29
8. References	30
9. Appendices	31
Appendix A: Technical Drawings	31
Appendix B: Project Management	32
Appendix C: Failure Analysis	35
Appendix D: Envision Checklist	36

List of Figures

Figure 1. Lake Bunyonyi	9
Figure 2. Average rainfall at Lake Bunyonyi in the past year	10
Figure 3. Lift Concept Drawing	11
Figure 4. Rotating wheel and pulley set 1	12
Figure 5. Pulley set 2 and wooden support post	12
Figure 6. Hook Mechanism	12
Figure 7. Wire “Rope” Analysis	13
Figure 8. Bicycle Pump Concept Sketch	14
Figure 9. Ollas prior to being inserted into the soil	15
Figure 10. Clay Pot Irrigation Concept and Benefits	16
Figure 11: Hand Pump Concept Drawing	17
Figure 12: Hand Pump Upclose Drawing	18
Figure 13: Decision Matrix	18
Figure 14: Hand Pump Used in Most Uganda Communities	19
Figure 15: Decision Matrix	19
Figure 16: Risk Analysis Chart	25
Figure 17: Failure Analysis Chart	26
Figure 18: Failure Provisions Chart	27
Figure 19: CAD Drawing of Hand Pump	28
Figure 20: Overview of Solution Setup	31
Figure 21: WBS	32
Figure 22: Bill of Materials	33
Figure 23: Team Schedule Semester 1 and 2	34
Figure 24: Failure Analysis Chart	35

Figure 25: Failure Provisions Chart 35
Figure 26: Envision Checklist Results for Lift Concept 36

Entusi Model Farm Final Design Report

Prepared by Serena Daluz, Megan Dickson, Joseph Golter, Caroline Jeffords, Carlos Ramos, and Viviana Verde
F20-16
Team Uganda Forever
College of Engineering and Computational Sciences
Colorado School of Mines

Executive Summary

The Global Livingston Institute (GLI) was formed to educate students and organizations on community development and encourage new innovative ideas by engaging leaders from the United States and East Africa. Entusi Resort and Retreat Center is one example of GLI's work to encourage conversation. Located on a peninsula on Lake Bunyonyi in South Uganda, Entusi is a resort where students, leaders, or any other traveler can go to reflect and learn about community topics or current social issues. Entusi contains a model farm where they practice innovative farming techniques so people in the Lake Bunyonyi community can learn new ways to advance their farms and increase production.

Farmers around Lake Bunyonyi rely on rainfall to water their crops. When the rainfall is not sufficient or it is dry season, the farmers must hand deliver water from Lake Bunyonyi to their crops. The process of getting water from the lake, filling in a bucket, and walking it back to their farms is long, difficult, and inefficient. Our task for this project is to provide a solution that will transport water from the lake to the farmers with ease.

Initially, we presented three water transportation methods and one water irrigation method to the clients based on research and client needs. The four design concepts were the lift, hand pump, bicycle pump, and clay pot irrigation. After thoroughly investigating each concept by analyzing and producing design specifications, drawings, and limitations, our team composed a decision matrix to help narrow down the options. After presenting our initial findings, the clients agreed the hand pump was most suitable for this project.

After meeting with the other team working on this project, we decided it was best to individualize our tasks so our work did not overlap. Our team then narrowed down the assignment to developing a water transportation system that will deliver water to farmers within 10-20 meters of Lake Bunyonyi while the other team worked on farms located further from the lake.

This hand pump will be manually operated which will filter and raise the water to a certain elevation and distance to the desired farms. This design report will serve as a briefing for future engineers to continue work on this project. The main topics discussed below are a project review, the approach to solving this problem, engineering analyses, design drawings, project management tactics, and lessons learned.

Entusi Model Farm Final Design Report

Serena Daluz, Megan Dickson, Joseph Golter, Caroline Jeffords, Carlos Ramos, and Viviana Verde
F20-16
Team Uganda Forever
College of Engineering and Computational Sciences
Colorado School of Mines

1. Introduction

Lake Bunyonyi, translated to “place of many little birds” [2], is located on the southwestern side of Uganda. It is about 1,950 meters above sea level, 15.5 miles long, and 1.35 miles wide. The depth of the lake ranges from 45 meters to 900 meters. The water is surrounded by hills that range all the way up to 2,478 meters high, shown in Figure 1. This ecosystem is exposed to environmental problems such as land degradation and soil erosion.

Figure 1: Lake Bunyonyi [1]

Lake Bunyonyi’s climate is tropical and generally rainy with two dry seasons. Figure 2 below illustrates the average rainfall amount in millimeters and the rainy time periods. Looking at the graph, the dry seasons last from December to February and June to August. Heavy rains are experienced between March and May and again from September to November. The annual rainfall is between 1,000 mm and 1,500 mm. These rains can be so heavy that they lead to flooding and render some roads in rural areas as unusable.

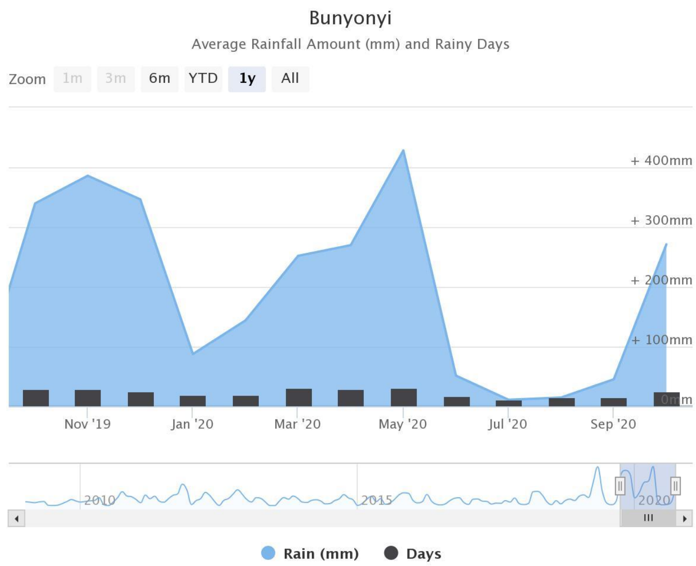


Figure 2: Average rainfall at Lake Bunyonyi in the past year [3]

The farmers in the Lake Bunyonyi community produce a variety of crops including sorghum, bananas, Irish potatoes, beans, peas, maize, peppers, barley, wheat, cabbage, and tomatoes. Uganda's soil is some of the most fertile soil in Africa, making it perfect for growing crops. Because of this, agriculture covers about 50% of occupations in the area [4]. With the limited access to rainfall year round, it is difficult for farmers to efficiently water their crops. Without rain, the locals are forced to trek all the way to the lake, fill buckets, and hand deliver water back to their farms which restricts crop yields and limits the amount of revenue generated. The task assigned to our team was to simplify the process of transporting water from Lake Bunyonyi to farms and communities surrounding the lake.

2. Project Review

From our two initial client meetings with Tom Karrel, Raymond Bokua, and Jerry Amanya, we were able to get a basic understanding of the problem. The task was understood as developing a design for a system that will distribute Lake Bunyonyi water to local farmers. The primary client needs were an easily maintained and replicated system constructed from local materials while minimizing costs.

Three water transportation design options were initially presented to the clients: the lift, hand pump, and bicycle pump. We also added in the clay pot irrigation system to be used with any of the transportation methods. Before deciding which concept would be best suited for this project, both Uganda teams met with the client to regroup. In order to prevent overlap in our two team's work, we decided it was best to develop different scenarios for each team. As stated above, farms range in various distances from the lake. Our team would focus on those farms within 10-20 meters from the lake whereas the other team would develop a concept for transporting water further from the lake. After the redefinition of the problem, our GLI contacts decided the hand pump met more of their criteria than the lift and bicycle pump.

Calculations and risk assessments were then conducted to understand the design constraints of the hand pump including force requirements, dirt removal estimates, and overall costs. These new design details were presented to the clients and advisors. Feedback on filter installation was received and added to the specifications of the design.

Overall, the team and project's progress was held back by the inability to visit Uganda and conduct analyses and tests first hand. Our contacts in Uganda helped us to the best of their ability to find the necessary information for this project, however it is recommended that future engineers on this project visit the site to better understand and provide solutions for this community.

3. Application of Design Methodology

Our team took into consideration multiple design methodology approaches to ensure that the best solution was given to our client. Before our team could start sketching up ideas for a design, we had to better our understanding of irrigation systems, especially in Uganda. Our team first researched different irrigation techniques and processes that could be applied to our project. Based on the systems that are currently used in Uganda and the unique designs of our own group, we were able to construct four design options: the lift, the hand pump, the clay pots irrigation, and the bicycle pump.

3.1 Lift Concept

Our idea was inspired by the design of a ski lift and the use of pulleys to operate the system. The design is composed of a 1000 ft steel cable which can support up to 7000 lb. The cable will have water buckets attached to the steel cable at a specific distance and the cable will be powered by a manual wheel composed of a series of pulleys to ease work. Just like a ski lift, our system will have a series of poles that support most of the system; to facilitate construction we would be using existing trees for this. We intend to design the lift path to reach each farm or at least get close to the farms. Currently we have two designs in mind: one that involves people filling up buckets of water at the bottom of the lake and hanging them on the wire to distribute to the farms. The other design consists of permanently attaching the buckets to the steel cable and having them fill up simultaneously as the system operates.

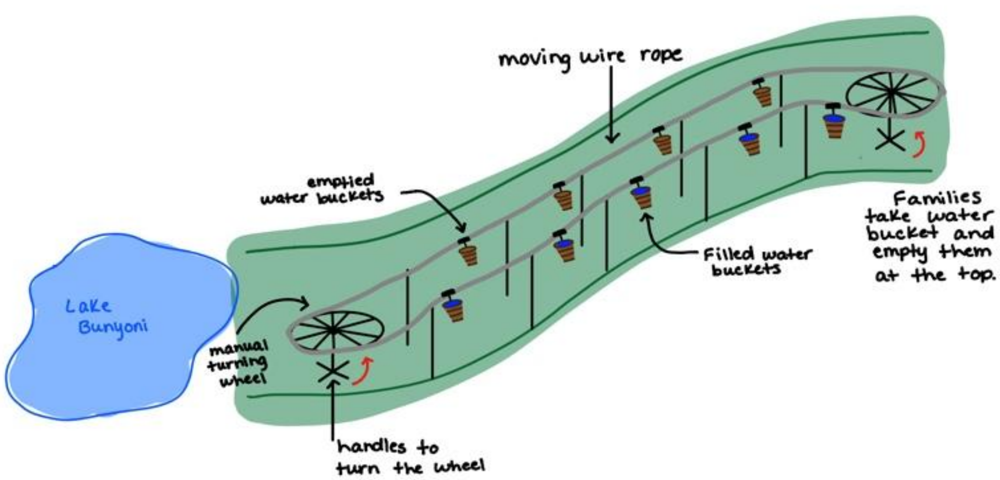


Figure 3: Lift Concept Drawing

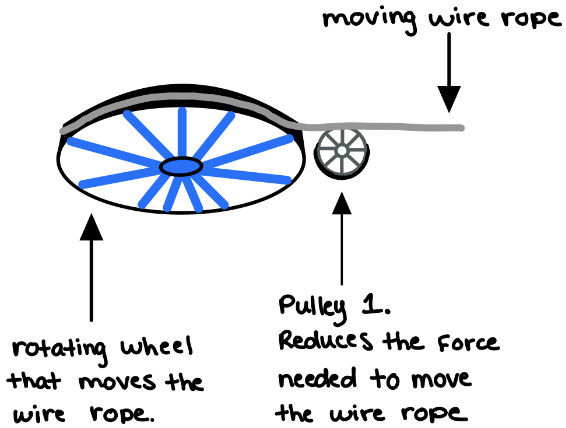


Figure 4: Rotating wheel and pulley set 1

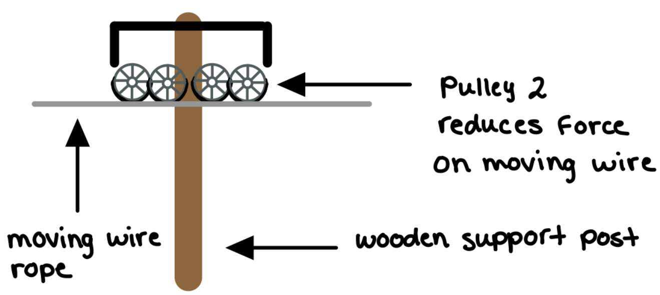


Figure 5: Pulley set 2 and wooden support post

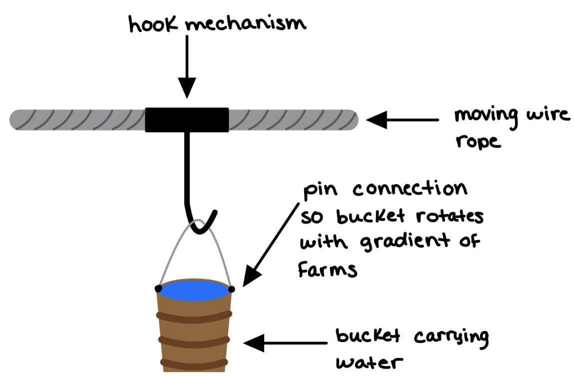


Figure 6: Hook mechanism

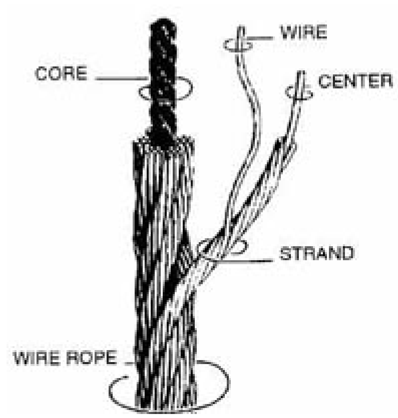


Figure 7: Wire "Rope" Analysis [5]

Pros:

- Easily maintained
- Low cost
- Low environmental impact
- Simple user interface
- Uses local resources
- Delivers water to multiple farms
- Can deliver to long distance ranges regardless of incline

Cons:

- Still requires users to go to Lake Bunyonyi
- Some man power is still required
- Initial set up will take time and effort

3.2 Bicycle Concept

The second concept is the bicycle pump. The bicycle pump is similar to the hand pump design, however, instead of being powered by a manual suction pump, this design is powered by a bicycle. A bicycle will be fixed to the ground using the support frame, seen in Figure 8. The water pump will have to be slightly tampered with to ensure that the bike tires can interface with the manual motor of the pump. There will be direct contact from the back tire of the bike to the manual motor of the pump that will continue to pump the water as long as there is someone riding the bicycle. The pump will have an inlet and outlet. The inlet to the pump will be hooked up to a PVC pipe that will run underground and connect it to Lake Bunyonyi. Once the water is brought up to the level of the pump through the repeated pedaling on the bicycle, the water will exit the pump through the outlet. As figure 8 shows, the outlet will be a much smaller section of PVC piping. At the exit point there will be a tap that will control the outward flow of the water into a bucket. This is a lower cost, lower maintenance system that fits the desires from the stakeholders. Other than the manual work needed to pedal the bicycle, the only other major work will take place in the initial implementation of the system.

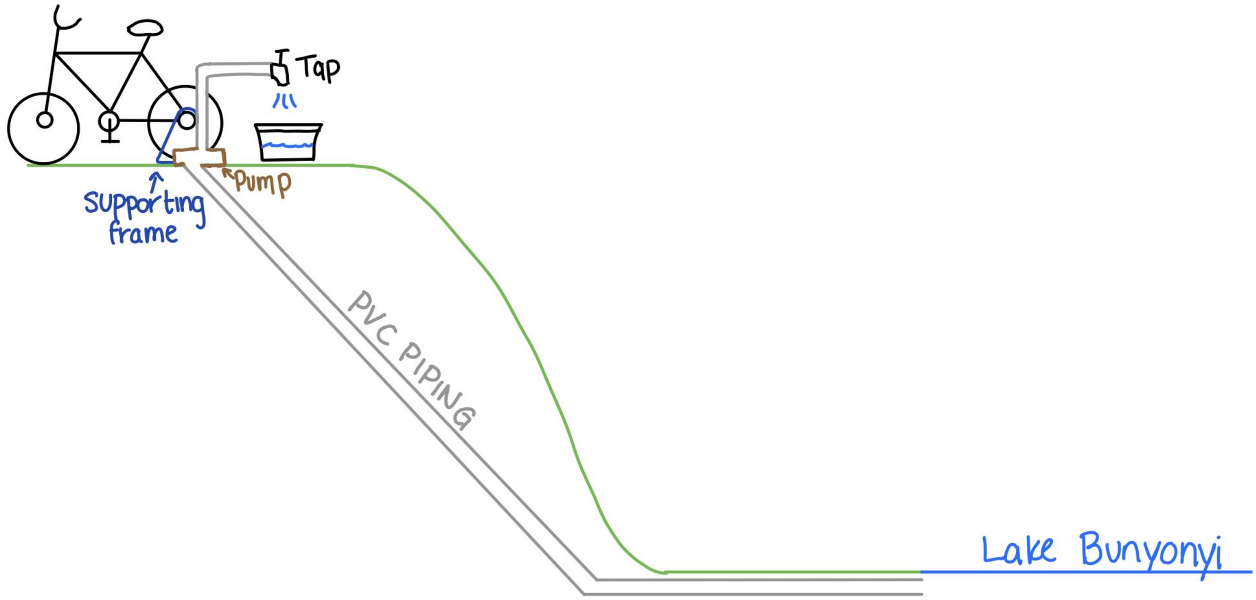


Figure 8: Bicycle Pump Concept Sketch

Pros:

- Low maintenance
- No need for electricity
- The farmers will not need to commute to the lake
- Low cost
- Simple user interface
- Uses local resources

Cons:

- Requires manpower
- Initial set up will take time
- Cannot be expanded for multiple farms
- Environmental habitats will be affected

3.3 Clay Pot Irrigation

It is important to recognize the lift design did not provide a solution for watering the crops and although the hand pump design discussed drip irrigation, this could be replaced with an alternative solution. In conjunction with either the lift concept or the hand pump for water collection without the reliance on rainfall, we are recommending the use of clay pot irrigation on the crops because it is sustainable, simple, and cost effective.

The way clay pot irrigation functions is that an unglazed pot, typically called an olla, is placed in the soil and filled with water. The water will then seep through the clay pot to moisten the dirt around it, providing only the water that the plants need. This functions because the pores in the walls of the olla are not large enough to allow water to flow freely, and need a suction force in order for the water to flow through. This suction force is created by moisture tension in the soil and the roots, so the drier the soil the greater the suction will be. The olla does need to be covered in order to ensure that water does not evaporate, especially in drier and hotter climates.

Figure 9: Ollas prior to being inserted into the soil

Pros:

- Can be made locally
- Reduces water use up to 70%
- Efficient
- Cost Effective
- Easily Maintained

Cons:

- Requires previous water collection
- Requires many pots being inserted into the ground
- Somewhat fragile

Clay pot irrigation method reduces water usage greatly, while still being very efficient in delivering water to the crops with the proper spacing. Also, the pots can be sourced locally through companies such as Purifaaya, which does focus primarily on water filtration. The pots themselves are much more cost effective to create as they are made of simple ceramic, and do not require any energy to run whatsoever--cutting down significantly on costs per individual farmer. The pots are very easy to maintain, and only require to be filled when they are empty and replaced in the occasion that they break. Some other benefits with clay pot irrigation is that it is particularly effective for deep rooted plants such as tomatoes, bananas, and peppers and can be easily adapted for plants with shallow root systems. For planting cycles, it maintains moisture in the soil and root systems year round which yields stronger crops and roots. Ollas prevent weed growth and some insect populations from forming as well, because the surface soil is not as saturated as the deeper soil.

The pots do require previous water collection in order to be effective in Lake Bunyonyi, which is why this design was adapted to be paired with our other designs focusing primarily on water collection. Also, it will require some adaptation to large scale so each farmer does not have an excessive amount of pots taking up space in the farming plot. This adaptation to large scale can be done by optimizing the pot size, surface area, and porosity; and also by developing a tubing method that would allow the pots to fill automatically from a storage tank. These design adaptations will largely be focused on in our next design faze if this irrigation method is decided to expand upon.

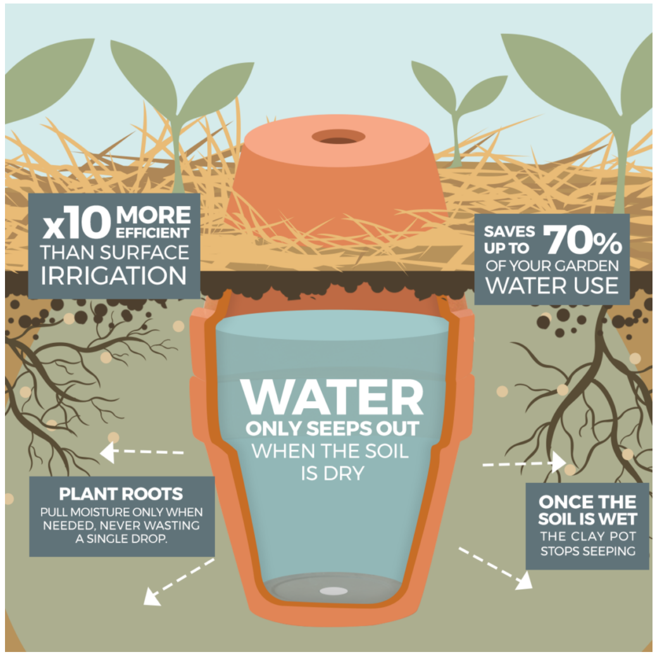


Figure 10: Clay Pot Irrigation Concept and Benefits [6]

3.4 Hand Pump Concept

The basic idea of this concept consists of a hand pump coupled with a drip irrigation system. The hand pump's purpose is to get the water from the lake and raise it a certain elevation and distance to a tank located near the farm or community of farms. After considering stakeholder engagement, we decided that low costs were a major design consideration for the whole system, so a manual hand pump suits this well. Once the water is pumped up to the tank, gravity will do the rest of the work and no further manpower should be necessary. The tank will be raised to an elevation above the farm. There will be a valve on the tank for when the farmers want to turn the irrigation system off. Once the water leaves the tank, a series of PVC pipes will take the water to the desired location of the crops. There will be holes in the pipes at these locations, and the water will leak out of the pipes and onto the soil around the crops. This is a lower cost, lower maintenance system that fits the desires from the stakeholders. Other than the manual work needed to use the pump, the only other major work will take place in the initial implementation of the system. Figure 11 below shows the basic design of the system and Figure 12 shows the inner workings of the hand pump itself.

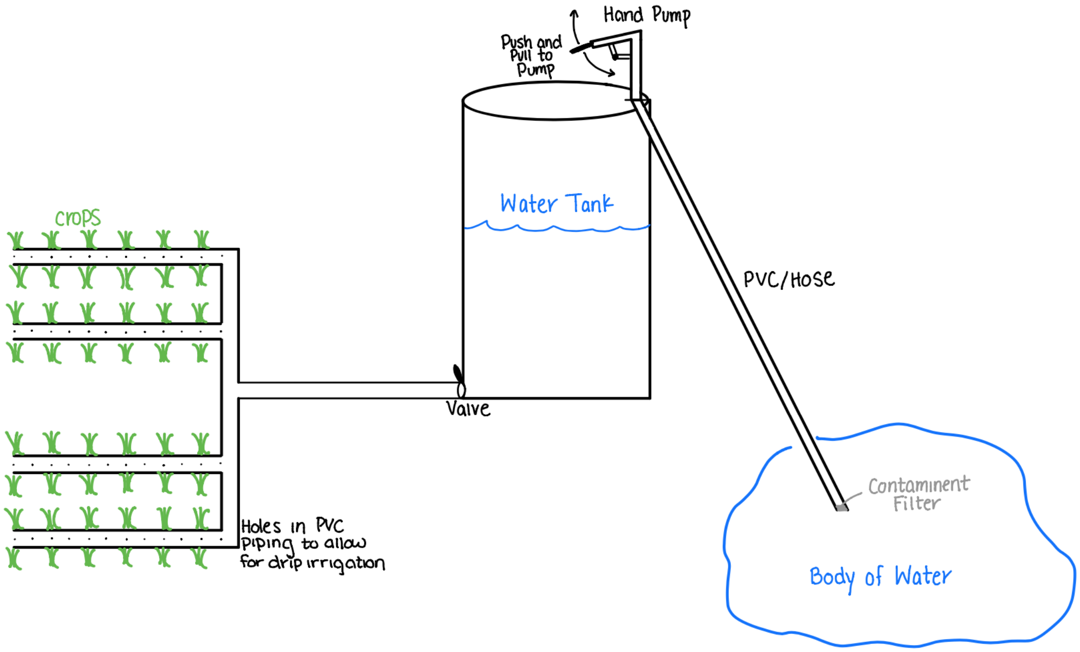


Figure 11: Hand Pump Concept Drawing

Pros:

- Little manpower required
- Low cost
- Low maintenance
- No need for electricity
- The farmers will not need to commute to the lake

Cons:

- Initial setup of system can be taxing for farmers
- Possibility of habitat damage

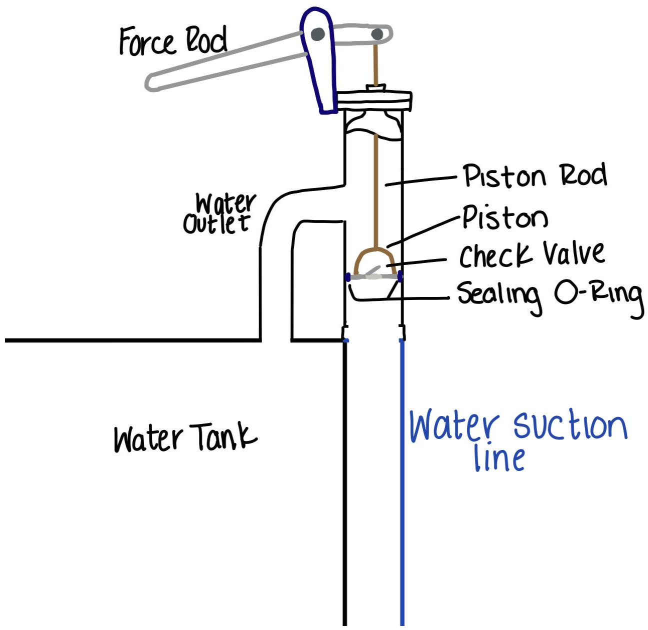


Figure 12: Hand Pump Upclose Drawing

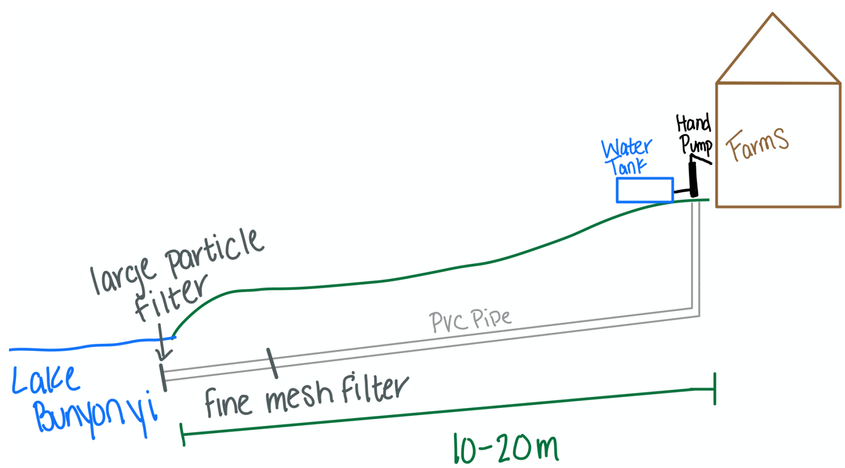


Figure 13: Updated Hand Pump Overview

Figure 14: Hand Pump Used in Most Uganda Communities

This hand pump has a 50 millimeter diameter open top and connecting rod diameter of 12 millimeters. The recommended water setting depth is 20-45 meters.

3.5 Decision Methodology

A design matrix was created to determine the best solution given our constraints and problem statement. The categories were weighted based on the importance given to us from the client.

Concepts										
Selection Criteria	**Weight**	Lift Concept		Hand Pump Concept		Bicycle Pump		Clay Pot		
		Rating	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	
Cost	30%	2	0.6	2	0.6	2	0.6	2	0.6	
Ease of Manufacture	15%	2	0.3	4	0.6	2	0.3	4	0.6	
Maintenance	10%	4	0.4	4	0.4	4	0.4	2	0.2	
Environmental Impacts	10%	3	0.3	3	0.3	4	0.4	2	0.2	
Efficiency	10%	4	0.4	3	0.3	3	0.3	3	0.3	
Rain Water Reliance	10%	5	0.5	5	0.5	5	0.5	5	0.5	
Ease of Use	15%	4	0.6	3	0.45	3	0.45	3	0.45	
	Total Score	3.1		3.15		2.95		2.85		
	Rank	2		1		3		4		
	Continue?	no		yes		no		no		

Figure 15: Decision Matrix

Looking at the decision matrix above, a rating scale of 1-5 was used (1 being bad and 5 great), and the hand pump concept outscored the other designs. The hand pump meets all aspects of the design criteria fulfilling the request of the client.

While working with Global Livingston Institute it was understood from the beginning that there would be expectations that the final product would have to encompass. One of the starting design specifications was that there was a tight budget that the final product would have to stay within because eventually the irrigation systems will be intended to be purchased and run by individual farmers on their own farms. The budget was set between 60 and 80 US dollars per irrigation system. This budget was set in place by our contacts at Global Livingston Institute and the people of the Entusi community. The idea of this project is to make sure the new irrigation system is accessible to all the farmers. A small budget ensures that every farm would be able to recreate the chosen system. In addition to the cost requirements, each irrigation unit needs to maintain a sufficient water supply to each farm along Lake Bunyonyi so the farmers will not need to rely on rain collection.

While maintaining this budget the client specified that the irrigation system would be used to minimize the number of trips the farmers were taking down to Lake Bunyonyi. It is highly encouraged by the client to ensure that the irrigation system is built using resources that are commonly found in the area. With materials that are locally found in the Uganda area maintenance becomes easier for the farmers. Since electricity is privately owned it was also suggested that the best way to implement a pump into the design would be to make it solar powered or manually powered. It is important that the pump is designed in such a way that costs stay low and the pump can be made from locally sourced resources.

A concise list of the preliminary design constraints and criteria can be found below:

Design Criteria:

- Easily replicable for individual farm use
- Easily maintained
- Does not rely on rainwater collection for steady water supply
- Provides enough water for the crops

Design Constraints:

- Price for implementation of individual units is $60 - $80
- Plot sizes of farms are 30 x 20 meters
- Steep gradient
- Incline of 10 meters from base of Lake Bunyonyi up to the farms

On a practical level, the main things that had to be considered by our group were the physical constraints (30 feet of elevation gain from the lake to the irrigation system for our Uganda team), costs, and the feasibility of the system, which are all reflected in the decision matrix. A functioning non-electric 30 ft. water pump was difficult to find at a low price. For this reason, our group decided to hone our focus on completely manual and all mechanical pumps. This kept the cost relatively low and the maintenance levels low, especially since we could not be out in Uganda physically to install the pump. Ease of materials was an important consideration since shipping costs from the U.S. to Uganda began to stack up the further we looked into them. For these reasons our group and the client chose to move forward with the hand pump concept.

4. Engineering Analysis

Due to the physical limitations throughout the course of the year, we couldn't physically test a prototype for our project. Despite these circumstances, our team was able to provide proper engineering analysis to successfully execute our project. First and foremost, we decided to execute the hand pump due to its simplistic design and ease of installation. Although the lift system and the bicycle pump were good solutions to the irrigation problem, they involved complicated installation procedures as well as a complex design. Our goal was not to create the most advanced engineered solution for the community at Lake Bunyonyi but rather a project that was simple and could provide easily accessible water to the farms. Our engineering analysis was solely based upon the hand pump design and the calculations were signed off by Dr. Kristoph Kinzli.

The most important analysis we had to perform was to find the power that would be necessary to lift the water to our 25-foot maximum vertical constraint. We took Bernoulli's equation to perform this analysis and assumed several aspects of the pump. These included incompressible fluid, frictionless steady flow, total conservation of energy along the pipe, negligible head loss, and given values for pressure and velocity based on similar problems.

Equation 1: Bernoulli's Equation

$$P_1 + (\frac{1}{2} * p * v_1^2) + (p * g * h_1) = P_2 + (\frac{1}{2} * p * v_2^2) + (p * g * h_2)$$

Calculations Analysis

$$Pump\ Power = P_2 + (\frac{1}{2} * p * v_2^2) + (p * g * h_2)$$

$$Pump\ Power = 150,000\ \frac{N}{m^2} + \frac{1}{2}(1,000\ \frac{kg}{m^3}) * (4\ \frac{m}{s})^2 + (1,000\ \frac{kg}{m^3}) * (9.81\ \frac{m}{s^2}) * (20\ m)$$

$$Pump\ Power = 348.2\ \frac{N}{m^2} = 348.2\ Pa$$

$$Power = Q * Pump\ Power$$

$$Power = 0.5\ \frac{m^3}{s} * 348.2\ Pa$$

Power = 191.5 Watts

Power (in HP) = 191.5 Watts / 745.6

Total Power = 0.256 hp

The power needed from the pump is 0.256 hp, given our assumptions, and from the results of these calculations, we were able to find a hand pump that would meet this criterion.

For operations of the pump, the 25 ft maximum height will be the worst-case scenario for pumping water, and the closer a farm is located to the lake, the less pump power will be needed. These calculations helped us identify the best pump available for the community in Uganda after taking into consideration other elements such as cost and availability.

After our hand pump calculations, the second analysis we had to make was the dirt removal based on the maximum vertical height and a rough average horizontal distance that most villages are to the lake. A height of 25 ft was set as our maximum vertical displacement with a maximum horizontal displacement of 40 ft yielding a maximum of 47.2 ft of buried pipe for the furthest farm or the "worst-case" scenario. As for the depth of the PVC piping, we suggest burying the pipa at 1.5 ft to avoid corrosion. The amount of dirt to be removed was calculated using the following formula.

$$Length \times Width \times Height$$

With a length of 47.2 ft, a width of 1 ft, and a height of 1.5, we calculated the total dirt to be 70.8 cubic ft. This amount of dirt can be removed using a shovel which discards the use of heavy machinery. We also had to take into account adding a filter to the end of the pipe and within the pipeline. The end of the pipe will have a mesh filter that will keep debris out of the pipe such as leaves, insects, mus, and other types of debris that might be at the lake. The filter within the pipes will then stop anything that went through the first filter; at around 10 feet of pipe from the lake up, there will be a detachable coupler that will be placed for maintenance purposes. It will allow for the filter to be easily cleaned out and the pipe will be attached back again.

We concentrated our engineering analysis on the hand pump rather than the other design proposals such as the lift concept and the bicycle pump. The reason behind this was due to our meetings throughout the semester with the client in which we decided what design proposal was going to work best for the community. The other two proposed solutions were neglected and the engineering analysis was done only for the chosen design.

Testing Plan

Due to COVID 19 restrictions and limitations, we were unable to build a physical prototype this year. For the prototype that will be created in Uganda, we are providing instructions for the testing of three major components: the force rod and valve assembly, the power of the pump and its influence on the water suction line, and the filter that will be at the end of the pipeline in order to mitigate blocking. The detailed testing plan is listed below.

Force Rod Assembly

Torque Test

The torque required to push the force rod down and open the valve will be tested to ensure that it will be useful for many types of people with varying strength and ability while still remaining secure.

1. Assemble force rod assembly
2. Apply 10 N of force at a distance of 5 cm, studying if the assembly is engaged.
    a. If assembly does not engage, increase the distance by 5 cm until assembly engages.

3. Repeat 2 and 2a with higher levels of force increasing by 5 N until a maximum force is reached at 60 N.
    a. Watch for any deformation, fracture, and/or failure with each force increase.
4. Adapt length of force rod so there will be ease of use for community members who cannot apply as much force.

Valve Seal

If the valve does not seal properly, the suction on the water will be wasted and the seal will need to be replaced. The valve must be able to seal at all levels of force applied to the force rod and seal securely.

1. Inspect all surfaces to ensure that they are clean, properly finished, and free of defects so the O-ring will be able to seal properly.
2. Install O-ring and valve.
3. Blow with compressed air on both sides in order to ensure there is not a "false" seal caused by particles stuck in the seat of the valve.
4. Place the "intake" side of the valve pointing up, so the assembly system is vertical.
5. Pour water into the "intake" side of the valve and observe the "output" side to ensure that it is dry.
6. Dump water out of the system and place the "intake" side facing downward once more. Push the force rod and allow it to return to its original position.
7. Repeat steps 4 and 5.

Water Pump

The water pump needs to be tested to be sure that the pump is not blocked at any point and the water has good quality. This testing is ideal for when the pump is already hooked up and running.

1. Evaluate the external conditions of the pump and be sure that everything is installed securely and there are no loose parts.
2. Operate the pump, take note if it is too easy or difficult to pump.
3. Evaluate the condition of the water that comes out, if sediment check the filter.

Filter

Placement Test

The placement of the filters at the end of the pipe to ensure that no debris or wildlife get stuck inside the pipeline is essential to the function of the hand pump system. In order to best place the filter, we will be testing how secure the filter will be on the end of the pipeline.

1. Install the filters on the edge of the pipe and 5-10 meters inside the pipe.
2. Place 10 N of force on the face of the filter to ensure that it can withstand the force.
3. Run water through the filter and the pipe to make sure it does not loosen and fall out.

Filtration Test

The filter must be viable to keep out particles that could cause clogs and buildup, and also aquatic flora and fauna that may get pulled into the pipeline. To ensure that the filter is working properly, we will be testing its ability to filter out particulate matter.

1. Install the filter on the end of a PVC pipe, do not attach the other side of the pipe to the rest of the line, place it in an empty bucket.
2. Incorporate particulate matter of 2 mm into water and pour over the filter and through the pipe.
3. Observe the remaining water in the bucket to see if any particulate matter made it through the mesh.
4. Repeat steps 2 and 3 with particulate matter of 1.5 mm to 0.5 mm in steps of 0.5 mm.

Risk Mitigation

When analyzing the risks that would come along with completion of our project we wanted to make sure that we looked at all the possible risks from different angles. We broke down the risk analysis chart into three main categories consisting of: maintenance risk, budget risk, and design risk.

The analysis tool that was applied was a combination of the Project Risk Assessment Matrix and the Environmental Hazard Analysis. We chose to combine both methods because our project not only consists of a constructional, site project but it also impacts the environment that it will be constructed on. It was helpful to use these tools in order to understand how our project, however small, can have an impact on the environment and the community in Uganda. The tools helped to think about all the issues that could occur when trying to construct the system and also months down the road when it is being used constantly. In our risk analysis we were able to identify possible risks in order to then brainstorm solutions. It is important that we determine solutions well before the irrigation system is in place so that we can hopefully mitigate those risks. We were able to create solutions for all the potential risks.

For the Environmental Hazard Analysis of this project, we focused more on how our project will be disrupting the aquatic ecosystem rather than any chemicals leaking from the project into the ecosystem. From what we could identify, the physical building and implementation of the hand pump will have the most ecological impact on Lake Bunyonyi. The environmental impact would be primarily from the underground pumps as well as the foundation that the tank would be placed on.

					Risk Management			
Lp.	The Main of Risks	Owner of Risk	Reason/Cause	Effect	Probability	Level of Risk	Risk Response Strategy	Cost of Strategy
Maintenance Risk								
1	Blockage/rupture of underground pipe	Owner	Overuse, no filter for debris	Water no longer gets pumped to the tank or decrease in efficiency of pump	60-75%	High	Monthly maintenance checks and bi-annual pump cleanouts	No Additional Cost
2	Algae growth in tank	Owner	Water sitting in the tank with little movement and too much heat	Algae will begin to grow on the sides of the tank and on surface of water	50-55%	Medium	Weekly mixing of water in tank, with bi-annual tank cleanouts	No Additional Cost
3	Inadequate labeling and operating instructions	Design Team	There isn't enough information for the locals to build the system	System will be built incorrectly	20-30%	High	Provide enough information in a panphlet so the locals and properly be instructed on what to do	No Additional Cost
4	Overcomplicated operating instructions	Design Team	Using terminology that is unfamiliar to the locals that are constructing and using system	The system won't be used or constructed in a timely manner or wont be able to be used at all	20-30%	High	Use local terminology to ensure that the locals are able to us and construct the system	No Additional Cost
5	Force rod breaks	Owner	Overuse, too much force on handle	The pump won't be able to properly function	20-25%	High	Provide backup materials in case the rod breaks, monthly maintenance checks	~10USD
Budget Risk								
6	Incorrectly budgegting materials	Design Team	Underestimating the cost of materials in Uganda	Not able to get all the materials needed to implement the system	10-15%	Medium	Use locally made resources to lower costs	No Additional Cost
Design Risk								
7	Improper balance of tank; loose soil	Design Team	Foundation not secure and stable	Tank could slide and be placed angled	40-50%	Medium	Properly place tank on a level foundation	No Additional Cost
8	Too much pressure from pump	Design Team	Creating too much pressure from pumping the handle too much	too much pressure between pipes which can cause it to rupture	10-15%	Low	Determine what the proper number of pumps it takes to fill up the tank at the top of the hill and don't exceed that number	No Additional Cost
9	Insufficient amout of pressure from pump	Design Team	The tank is placed too high up the hill	Not enough pressure will be generated to get the water up the hill	30-40%	Medium	Ensure that the tank is placed at a proper height so enough pressure is generated for water to get up the hill	No Additional Cost

Figure 16: Risk Analysis Chart

The analysis allowed us to notice that there are ways that we could not only improve our design but allow for easier construction and hand off of our solution. The above chart was created to determine the possible risks that could occur during each stage of our implementation of the hand pump solution. The fifth and sixth columns recognize what the probability of each risk occurring is. The probability was calculated through assumptions made between the group and how often we assume each issue would occur. Based on the probabilities we were able to determine the level of severity each risk should be held at. The most common and most severe risks were highlighted in red while the risks that are less likely to occur are highlighted in green. We discovered that it is important that when we give the community of Entusi our solution, we make sure that the instructions on how to construct the irrigation system are well thought out and considerate of their culture. We are going to make a pamphlet that provides all the information to construct the irrigation system and also maintain the irrigation system. We want this irrigation system to last for a long time with little repair needed. In order to accomplish that goal we need to provide a maintenance manual. Overall, no major issues arose from the analysis, only a deeper understanding of the level of detail needed in order to ensure the irrigation system is built properly and in a sustainable way.

Failure Modes

As we evaluated the risks of the irrigation system, there were many considerations taken for the modes of failure that were discovered during the process. Below the Failure Analysis Chart shows possible modes of failure for each component of the system and the effects these failures have on the system as a whole.

Component	Function	Failure Mode and Cause	Operational Mode (when failure happens)	Local Effects	Next Higher Level	End Effects
Force Rod	Uses user-applied torque and creates tension to the piston rod	Rod shears or bends, but would require a lot of force	Normal use/excessive use	Dependent on where the shear happens, still operable with more difficulty.	Shear after the pin, the piston rod will not engage	Shear after the pin, the valve system will not work
Piston Rod	Applies tension to the check valve	Pin between force rod and piston rod shears, would take a lot of force or many years of use	Normal use/excessive use	Piston Rod will no longer translate vertically	Check valve will not lift	The valve system will not work
Piston Rod	Applies tension to the check valve	Connection with the check valve shears, would take a lot of force or many years of use	Normal use/excessive use	Check valve will not be lifted	No water will come through the pump	The system will not work
Check Valve	Seals and unseals the water flow in the pump	Check valve gets stuck in one position due to debris buildup	Improper installation/normal use/excessive use	Check valve will not be lifted	No water will come through the pump	The system will not work
O-Ring	Provides a water-tight seal between Check Valve and the body of the hand pump	Ineffective seal caused by improper installation or degredation of the elastomer	Improper installation/environmental effects	The seal will leak	Water will not remained suctioned in the water suction line	The system will not work
Water Suction Line	Carries water from Lake Bunyonyi to the hand pump	Leaking along the pipeline due to disturbance or improper installation	Improper installation/environmental effects	Water will leak from the pipeline	Water suction line will lose its suction	The system will not work
Filter	Filters out debris and keeps flora and fauna out of the water suction line	Disturbance of the filter so it is no longer positioned on the end of the pipe or punctured	Environmental effects	Debris and wildlife can get into the pipeline	The pipeline will be clogged	The system will not work

Figure 17: Failure Analysis Chart

With the Failure Analysis Chart, we then ranked the failure modes in severity from 1-4: least to most severe as seen in Figure 3. The methods that were marked as most severe required the most effort to replace and repair, versus the methods that were marked the least severe at a 1 could easily be mitigated by annual maintenance. It is advised that yearly maintenance is performed on the hand pump to ensure that all parts are working efficiently and are not being worn by use. Also, the water should be tested for safety in order to ensure that the water being used by the community is safe to use.

Component	Failure Detection Method	Compensating Provisions	Severity Class	Notes
Force Rod	The force rod would be visibly broken/bent	Ensure that a tough material is used for the handle	4	
Piston Rod	Would see that the piston rod would not be attached to the force rod	Ensure that some extra pins are on hand for an easy replacement	2	
Piston Rod	Piston and force rod would move without resistance	Do annual maintenance to ensure that the pin connecting the valve and rod is in good condition	2	
Check Valve	The force rod would not move when force is applied	Yearly maintenance should be done to ensure that the valves are clean, lubricated, and not worn down. The filter installed also will help with debris	1	
O-Ring	Water will not come out of pump when force rod is pressed	Test O-ring material in environment prior to installation. Do yearly maintenance to ensure that the O-ring is not degrading	2	
Water Suction Line	Water will not come out of pump when force rod is pressed and/or areas along the pipeline will be waterlogged	Ensure that pipe couplings are securely fitted and placed properly, place the pipeline deep enough so animals will not interfere with it	4	If failure does occur, will require dirt removal for repair
Filter	Debris will be visible in the water or less water will come out of the spout	Ensure that the mesh is made of a strong material and the filter is securely placed.	3	If failure does occur and pipe becomes clogged, will require dirt removal for repair

Figure 18: Failure Provisions Chart

In order to provide proper maintenance of the hand pump, it is recommended that a local engineer inspect the pump annually so the pump does not fall to disrepair. Also, necessary cleaning of the filter, instructions will be provided so the owner can perform these activities on their own. For cleaning of the water suction line if there is clogging or buildup, it is recommended that the local engineer assist in order to ensure that the site is safe for all involved.

5. Final Deliverables

As a team we discussed what all should be included in the deliverables. We decided that a prototype is not needed to effectively portray our design. The solution can be implemented based on the drawings, provided reports and an instruction brochure that will be provided. The brochure will describe how to implement and maintain the hand pump solution. Table 1 and image 1 show how much each of the materials needed will cost as well as a technical drawing of the hand pump. More drawings are attached in appendix B.

Figure 19: CAD drawing of hand pump [1]

6. Project Management

In order to keep the project organized and the team on track, a work breakdown structure (WBS), schedule, and budgeting charts were created. These resources have been reassessed, redefined, and updated throughout the course of this project. The WBS can be found in the appendices. This structure was amended several times throughout the design process due to changes made to the implementation of the project. Because the team was not able to physically produce and test the hand pump prototype the WBS and schedule needed to be adjusted. As seen in the WBS and schedule found in the appendices prototyping and testing were updated and changed to produce instructions on building, testing plans, and maintenance recommendations. The adjusted budget chart can be found above in Table 1. The items include all of the items required to make the hand pump; however, the budget sheet does not include costs of the tools required to install the pump. The initial estimate of the cost to build the hand pump system was highly underestimated. The client gave the team a budget of $100 per unit as that was the most they could afford. Currently, the team's bill of materials for the whole project is $619. The reason this value is so high is mostly due to the lack of transportation of the materials to Lake Bunyonyi. Because the Lake Bunyonyi area is difficult to deliver to, most of the parts must be bought at nearby stores. These stores have limited supplies and the cost of shipping to these rural towns and the cost to transport them to the farms is large. Most of the parts can be found in a nearby town but they do not come without high cost. The total bill of materials can be found in the appendices along with links to parts not found in the nearby town.

7. Lessons Learned

The definition of what a "good design" meant in terms of this course has certainly changed during the year for our team as we identified more precisely what could be done for the client and what was needed. Coming into Senior Design, every team has an impression that they will be designing something that has never been seen before as has been glorified during years past. Also, with the added difficulty of trying to execute a group project during COVID, we have had to be creative and adaptive to what actually goes into a "good design." The largest hurdle was what the definition of success would look like for this project, especially with the added difficulty that we would not be able to travel to Uganda to evaluate the community that our irrigation system would be implemented in. With our limitations in mind, our goals shifted to a more holistic approach that would allow the community and its engineers to install a device that would actually be useful and effective. Of course, this new list of goals required our team to find a new method of evaluating our project through the lens of Humanitarian Engineering to understand how to fully satisfy the clients.

With any design process, it is natural that mistakes get made while trying to establish what the final product will be. The iterations we were focused on creating in the first half of this project focused on showing our creativity and technical skills. At times during the project, our designs were more complicated than we had anticipated. Of course, this was remedied by communicating more thoroughly with our clients and having some community involvement with the designs we presented at our Intermediate Design Review. On the second time around, we would love to bring in community members' opinions and ideas earlier so we could have more time to work on design iterations for a concept that would be the most useful for them.

For future teams working on this project, we hope that this information that we have studied and accumulated will be the perfect jumping off point for them to implement our design for the Entusi Model Farm and improve upon it as they do.

8. References

[1] J. F, “Hand Pump Assembly,” *GrabCad Community*. [Online]. Available: https://grabcad.com/library/hand-pump-assembly. [Accessed: 01-Mar-2021].

[2] “Engineering Bernoulli Equation,” *Department of Chemical and Biomolecular Engineering Clarkson University. [Online].* Available: https://web2.clarkson.edu/projects/subramanian/ch330/notes/Engineering%20Bernoulli%20Equation.pdf. [Accessed 8-Feb-2021].

[3] “Proper Burial Depths for Subsurface PVC Pipe,” *PVC Pipe Locators*. [Online]. Available: https://www.pvcpipelocators.com/proper-burial-of-pvc/#:~:text=At%20depths%20of%20more%20than,traffic%20loading%20can%20be%20buried. [Accessed: 11-Feb-2021].

[4] “Uganda Modified Hand Pump.” [Online]. Available: https://www.exportersindia.com/ajay-industrial-corporation-ltd-company4684714/uganda-modified-hand-pump-4589490.htm. [Accessed: 01-Mar-2021].

[5] B. Mehdi, M. Herrnegger, J. Dekens, S. Crerar, and K. Schulz, “Assessment of the Current and Future Available Water Resources Under Different Climate Scenarios in the Lake Bunyonyi Catchment, Uganda,” *NAP Global Network*, Feb-2019. [Online]. Available: https://napglobalnetwork.org/wp-content/uploads/2019/10/napgn-en-2019-assessment-of-the-current-and-future-available-water-resources-under-different-climate-scenarios-in-the-lake-bunyonyi-catchment-uganda.pdf. [Accessed: 01-Mar-2021].

Calculations Revised and Approved by Dr. Kristoph-Dietrich Kinzli.

9. Appendices

Appendix A: Technical Drawings

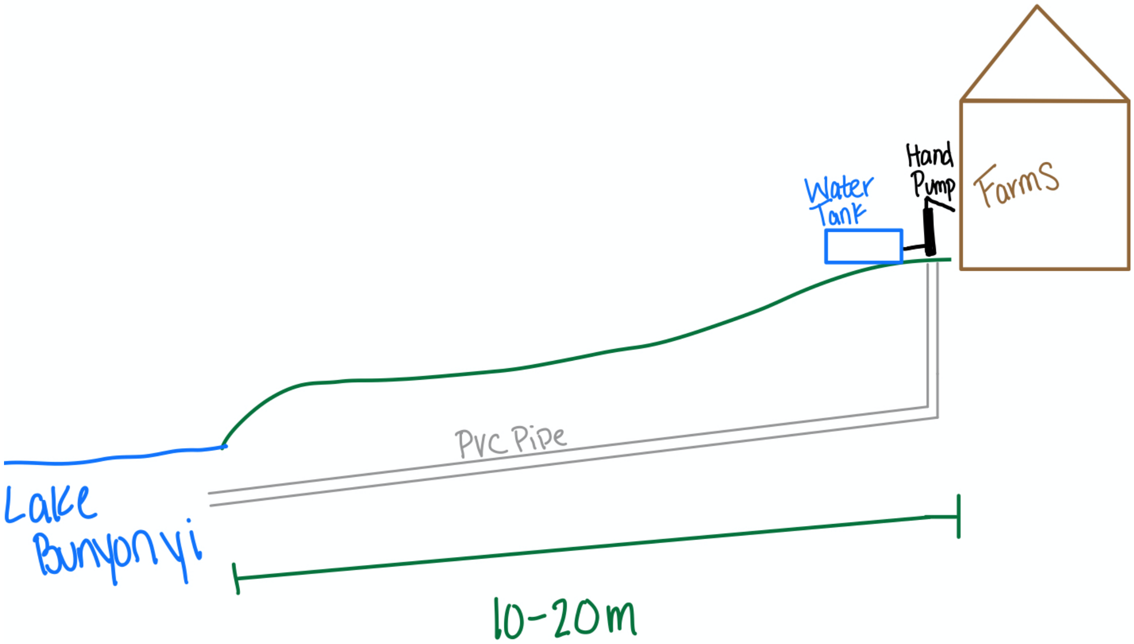


Figure 20: Overview of Solution Setup

Appendix B: Project Management

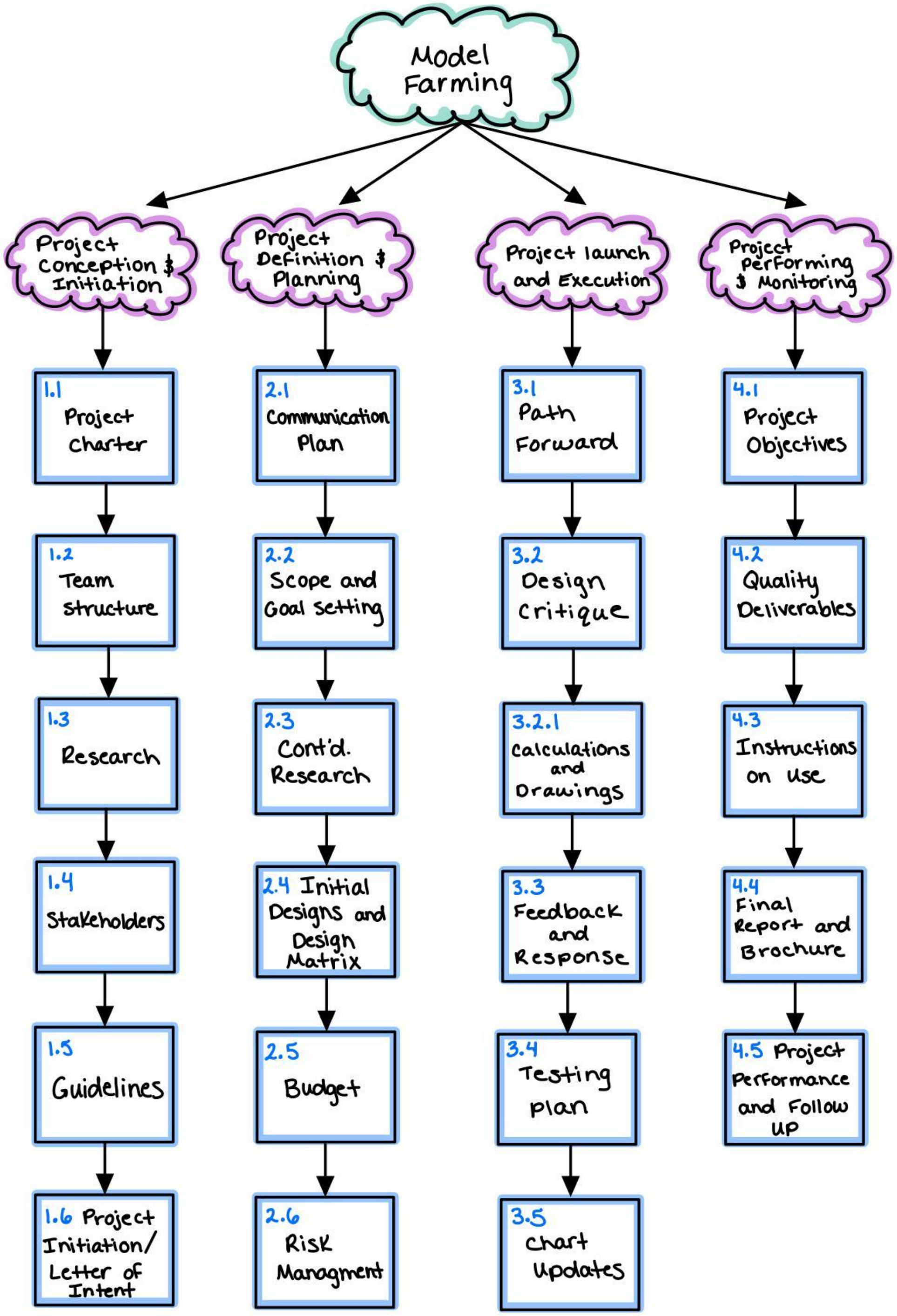


Figure 21 : WBS

Part	Description	Unit Cost	Quantity	Total Cost	Link
Hand Pump	Standard hand pump, metal encasing body with lever arm that moves up and down	$500	1	$500	Found locally in Uganda
PVC Piping	Standad PVC tubing	$1.33/ft	60 ft	$79.80	Found locally in Uganda
Coupler		$2	3	$6	Found locally in Uganda
PVC Cement		$4	1	$4	Found locally in Uganda
Ready Mix Concrete	Concrete mix for the concrete slab the hand pump will sit on	$8	3	$24	Found locally in Uganda
Suction Strainer	Large particle suction strainer with large openings to trap large debris. Screws onto the end of the PVC pipe that sits in the lake.	$12.68	1	$12.68	https://www.mcmaster.com/strainers/large-particle-suction-strainers/
Inline Strainer	Medium inline strainer with mesh screen to trap debris that cleared through the large particle suction strainer. Can be removed from the midline PVC tubing for easy cleaning	$15.21	1	$15.21	https://www.mcmaster.com/inline-strainers/medium-pressure-inline-strainers-8/
			TOTAL	$641.69	

Figure 22: *Bill of Materials*

GANTT CHART

PROJECT TITLE	Entusi Model Farming	COMPANY NAME	Team Uganda Forever
PROJECT MANAGER	Caroline Jeffords	DATE	09-24-2020

WBS NUMBER	TASK TITLE	TASK OWNER	DUE DATE	PCT OF TASK COMPLETE
1	Project Conception and Initiation			
1.1	Project Charter	JG, CR	9/29/20	100%
1.2	Team Structure	CJ	9/24/20	100%
1.3	Research	ALL	9/30/20	100%
1.4	Stakeholders	VV	9/29/20	100%
1.5	Guidelines	ALL	9/29/20	100%
1.6	Project Initiation/Letter of Intent	ALL	9/29/20	100%
2	Project Definition and Planning			
2.1	Communication Plan	ALL	10/14/20	100%
2.2	Scope & Goal Setting	CJ, SD	10/14/20	100%
2.3	Continued Research	ALL	10/14/20	100%
2.4	Initial Designs and Design Matrix	ALL	11/1/20	100%
2.5	Budget	CR, JG	11/8/20	100%
2.6	Risk Management	VV, MD	11/15/20	100%
3	Project Launch & Execution			
3	Project Goal Setting	ALL	1/14/21	100%
3	Re-engagement Letter	ALL	1/14/21	100%
3	Team Video	ALL	1/19/21	100%
3	IDR	ALL	2/25/21	100%
3	Project Synopsis	ALL	2/20/21	100%
3.1	Path Forward	CJ	2/21/21	100%
3.2	Design Critique	MD	2/22/21	100%
3.2.1	Calculations and Drawings	JG, CR	2/23/21	100%
3.3	Feedback and Response	SD	2/24/21	100%
3.4	Testing Plan	VV	2/25/21	100%
3.5	Update Chart	SD	2/25/21	100%
4	Project Performance/Monitoring			
4	FDR - Initital	ALL	4/19/21	100%
4	FDR - Review	ALL	4/20/21	0%
4	Team Website	ALL	4/26/21	25%
4	Final Design Report	ALL	5/4/21	0%
4	Next Steps Letter Post FDR	ALL	5/4/21	0%
4	Project Goal Attainment	ALL	5/7/21	0%
4.1	Project Objectives	CJ,SD	5/4/21	0%
4.2	Quality Deliverables	VV,MD	5/4/21	0%
4.3	Instructions	CR, JG	5/4/21	0%
4.4	Final Report/ Brochure	ALL	5/4/21	0%
4.5	Project Performance/ Follow Up	ALL	5/7/21	0%

PHASE ONE

WBS NUMBER	WEEK 1-3					WEEK 4-6					WEEK 7-9				
	M	T	W	R	F	M	T	W	R	F	M	T	W	R	F
1															
1.1		X		X			X		X			X		X	
1.2		X		X			X		X			X		X	
1.3		X		X			X		X			X		X	
1.4		X		X			X		X			X		X	
1.5		X		X			X		X			X		X	
1.6		X		X			X		X			X		X	

PHASE TWO

WBS NUMBER	WEEK 10-12					WEEK 13-15					WEEK 16				
	M	T	W	R	F	M	T	W	R	F	M	T	W	R	F
2															
2.1		X		X			X		X			X		X	
2.2		X		X			X		X			X		X	
2.3		X		X			X		X			X		X	
2.4		X		X			X		X			X		X	
2.5		X		X			X		X			X		X	
2.6		X		X			X		X			X		X	

PHASE THREE

WBS NUMBER / TASK TITLE	WEEK 1-3					WEEK 4-6					WEEK 7-9				
	M	T	W	R	F	M	T	W	R	F	M	T	W	R	F
3 Project Launch & Execution															
3 Project Goal Setting		X		X			X		X			X		X	
3 Re-engagement Letter		X		X			X		X			X		X	
3 Team Video		X		X			X		X			X		X	
3 IDR		X		X			X		X			X		X	
3 Project Synopsis		X		X			X		X			X		X	
3.1 Path Forward		X		X			X		X			X		X	
3.2 Design Critique		X		X			X		X			X		X	
3.2.1 Calculations and Drawings		X		X			X		X			X		X	
3.3 Feedback and Response		X		X			X		X			X		X	
3.4 Testing Plan		X		X			X		X			X		X	
3.5 Update Chart		X		X			X		X			X		X	

PHASE FOUR

WBS NUMBER / TASK TITLE	WEEK 10-12					WEEK 13-15					WEEK 16				
	M	T	W	R	F	M	T	W	R	F	M	T	W	R	F
4 Project Performance/Monitoring															
4 FDR - Initital		X		X											
4 FDR - Review		X		X											
4 Team Website		X		X											
4 Final Design Report															
4 Next Steps Letter Post FDR															
4 Project Goal Attainment															
4.1 Project Objectives															
4.2 Quality Deliverables															
4.3 Instructions															
4.4 Final Report/ Brochure															
4.5 Project Performance/ Follow Up															

Figure 23: *Team Schedule Semester 1 and 2*

Appendix C: Failure Analysis

Component	Function	Failure Mode and Cause	Operational Mode (when failure happens)	Local Effects	Next Higher Level	End Effects
Force Rod	Uses user-applied torque and creates tension to the piston rod	Rod shears or bends, but would require a lot of force	Normal use/excessive use	Dependent on where the shear happens, still operable with more difficulty.	Shear after the pin, the piston rod will not engage	Shear after the pin, the valve system will not work
Piston Rod	Applies tension to the check valve	Pin between force rod and piston rod shears, would take a lot of force or many years of use	Normal use/excessive use	Piston Rod will no longer translate vertically	Check valve will not lift	The valve system will not work
Piston Rod	Applies tension to the check valve	Connection with the check valve shears, would take a lot of force or many years of use	Normal use/excessive use	Check valve will not be lifted	No water will come through the pump	The system will not work
Check Valve	Seals and unseals the water flow in the pump	Check valve gets stuck in one position due to debris buildup	Improper installation/normal use/excessive use	Check valve will not be lifted	No water will come through the pump	The system will not work
O-Ring	Provides a water-tight seal between Check Valve and the body of the hand pump	Ineffective seal caused by improper installation or degredation of the elastomer	Improper installation/environmental effects	The seal will leak	Water will not remained suctioned in the water suction line	The system will not work
Water Suction Line	Carries water from Lake Bunyonyi to the hand pump	Leaking along the pipeline due to disturbance or improper installation	Improper installation/environmental effects	Water will leak from the pipeline	Water suction line will lose its suction	The system will not work
Filter	Filters out debris and keeps flora and fauna out of the water suction line	Disturbance of the filter so it is no longer positioned on the end of the pipe or punctured	Environmental effects	Debris and wildlife can get into the pipeline	The pipeline will be clogged	The system will not work

Figure 24: Failure Analysis Chart

Component	Failure Detection Method	Compensating Provisions	Severity Class	Notes
Force Rod	The force rod would be visibly broken/bent	Ensure that a tough material is used for the handle	4	
Piston Rod	Would see that the piston rod would not be attached to the force rod	Ensure that some extra pins are on hand for an easy replacement	2	
Piston Rod	Piston and force rod would move without resistance	Do annual maintenance to ensure that the pin connecting the valve and rod is in good condition	2	
Check Valve	The force rod would not move when force is applied	Yearly maintenance should be done to ensure that the valves are clean, lubricated, and not worn down. The filter installed also will help with debris	1	
O-Ring	Water will not come out of pump when force rod is pressed	Test O-ring material in environment prior to installation. Do yearly maintenance to ensure that the O-ring is not degrading	2	
Water Suction Line	Water will not come out of pump when force rod is pressed and/or areas along the pipeline will be waterlogged	Ensure that pipe couplings are securely fitted and placed properly, place the pipeline deep enough so animals will not interfere with it	4	If failure does occur, will require dirt removal for repair
Filter	Debris will be visible in the water or less water will come out of the spout	Ensure that the mesh is made of a strong material and the filter is securely placed.	3	If failure does occur and pipe becomes clogged, will require dirt removal for repair

Figure 25: Failure Provisions Chart

Appendix D: Envision Checklist

#	Category	Subcategory	Credit	Y	N	NA	Score
1	QUALITY OF LIFE	PURPOSE	QL1.1 Improve community quality of life	3	0	0	3 of 3
2			QL1.2 Stimulate sustainable growth and development	2	0	1	2 of 2
3			QL1.3 Develop local skills and capabilities	2	0	1	2 of 2
4		COMMUNITY	QL2.1 Enhance public health and safety	1	0	0	1 of 1
5			QL2.2 Minimize noise and vibration	1	0	0	1 of 1
6			QL2.3 Minimize light pollution	0	0	1	0 of 0
7			QL2.4 Improve community mobility and access	0	0	3	0 of 0
8			QL2.5 Encourage alternative modes of transportation	1	0	1	1 of 1
9			QL2.6 Improve site accessibility, safety and wayfinding	3	0	0	3 of 3
10		WELLBEING	QL3.1 Preserve historic and cultural resources	2	0	0	2 of 2
11			QL3.2 Preserve views and local character	1	1	0	1 of 2
12			QL3.3 Enhance public space	0	0	2	0 of 0
			TOTAL	16	1	9	16 of 17
13	LEADERSHIP	COLLABORATION	LD1.1 Provide effective leadership and commitment	3	0	0	3 of 3
14			LD1.2 Establish a sustainability management system	1	0	0	1 of 1
15			LD1.3 Foster collaboration and teamwork	3	0	0	3 of 3
16			LD1.4 Provide for stakeholder involvement	3	0	0	3 of 3
17		MANAGEMENT	LD2.1 Pursue by-product synergy opportunities	0	0	1	0 of 0
18			LD2.2 Improve infrastructure integration	3	0	0	3 of 3
19		PLANNING	LD3.1 Plan for long-term monitoring and maintenance	2	0	0	2 of 2
20			LD3.2 Address conflicting regulations and policies	1	1	0	1 of 2
21			LD3.3 Extend useful life	1	0	0	1 of 1
			TOTAL	17	1	1	17 of 18
22	RESOURCE ALLOCATION	MATERIALS	RA1.1 Reduce Net Embodied Energy	2	0	0	2 of 2
23			RA1.2 Support sustainable procurement practices	3	0	0	3 of 3
24			RA1.3 Use recycled materials	2	0	0	2 of 2
25			RA1.4 Use regional materials	2	0	0	2 of 2
26			RA1.5 Divert waste from landfills	3	0	0	3 of 3
27			RA1.6 Reduce excavated materials taken off site	2	0	1	2 of 2
28			RA1.7 Provide for deconstruction and recycling	3	0	0	3 of 3
29		ENERGY	RA2.1 Reduce energy consumption	3	0	0	3 of 3
30			RA2.2 Use renewable energy	1	1	0	1 of 2
31			RA2.3 Commission and monitor energy systems	0	0	3	0 of 0
32		WATER	RA3.1 Protect fresh water availability	4	0	3	4 of 4
33			RA3.2 Reduce potable water consumption	4	0	0	4 of 4
34			RA3.3 Monitor water systems	4	0	0	4 of 4
			TOTAL	33	1	7	33 of 34
35	NATURAL WORLD	SITING	NW1.1 Preserve prime habitat	3	2	0	3 of 5
36			NW1.2 Protect wetlands and surface water	1	2	0	1 of 3
37			NW1.3 Preserve prime farmland	1	0	0	1 of 1
38			NW1.4 Avoid adverse geology	3	0	0	3 of 3
39			NW1.5 Preserve floodplain functions	0	0	6	0 of 0
40			NW1.6 Avoid unsuitable development on steep slopes	2	0	0	2 of 2
41			NW1.7 Preserve greenfields	2	0	0	2 of 2
42		LAND & WATER	NW2.1 Manage stormwater	2	0	0	2 of 2
43			NW2.2 Reduce pesticide and fertilizer impacts	0	0	5	0 of 0
44			NW2.3 Prevent surface and groundwater contamination	4	0	-1	4 of 4
45		BIODIVERSITY	NW3.1 Preserve species biodiversity	3	1	0	3 of 4
46			NW3.2 Control invasive species	0	0	3	0 of 0
47			NW3.3 Restore disturbed soils	2	0	0	2 of 2
48			NW3.4 Maintain wetland and surface water functions	5	0	0	5 of 5
			TOTAL	28	5	13	28 of 33
49	CLIMATE	EMISSION	CR1.1 Reduce greenhouse gas emissions	2	0	0	2 of 2
50			CR1.2 Reduce air pollutant emissions	0	0	2	0 of 0
51		RESILIENCE	CR2.1 Assess climate threat	1	0	0	1 of 1
52			CR2.2 Avoid traps and vulnerabilities	2	0	0	2 of 2
53			CR2.3 Prepare for long-term adaptability	0	0	1	0 of 0
54			CR2.4 Prepare for short-term hazards	2	0	0	2 of 2
55			CR2.5 Manage heat islands effects	0	0	1	0 of 0
			TOTAL	7	0	4	7 of 7

Figure 26: *Envision Checklist Results for Lift Concept*