



Engineers for a Sustainable World
PURDUE UNIVERSITY CHAPTER



Gashora Irrigation Project

Final Report

Global Team for Irrigation in Africa

Purdue University
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Executive Summary

In November 2008, a team of eight students from Purdue University formed a global team with two students from the National University of Rwanda (NUR) to collaborate on a global design project. The students from NUR proposed designing an irrigation system for two farmers in the Gashora Sector of the Bugesera District of Rwanda and the Purdue students accepted. The farm is located in a region that does not receive enough rainfall to grow crops during the dry seasons, even though the temperature is appropriate for crop growth. The goal of this project was to develop an irrigation system that would allow crops to be grown in the dry season.

Four of the Purdue students travelled to Rwanda in January 2009 for an assessment trip. The team visited the farmers and learned more about their farming practices, economic circumstances, and requirements for an irrigation system. The trip established a foundation for its global teaming experience. The accomplished tasks included delegating responsibilities, creating a timeline, developing a task list, and establishing communication techniques to be used throughout the semester. The team also visited local suppliers and participated in several meetings to raise awareness and support of the project. These meetings included audiences with the Vice Rector of NUR, the Dean and Vice Dean of both Agronomy and Applied Sciences, and the Permanent Secretary of the Rwandan Ministry of Agriculture.

After the assessment trip, the teams began the research phase of the project. The irrigation system was decomposed into the following main parts to be researched: water source, extraction, movement, storage, and distribution. The topics were all researched to determine the most feasible design for this irrigation system. As a result of the research, the following conclusions were made. The local lake would be the main water source. The water would be extracted with either a petrol powered pump or a treadle pump. A system of pipes, hoses, and junctions would be used to move water to the crops. Water would not be stored on the field, but would be directly pumped to the crops. The water would be distributed to the roots of the crops by furrows that run horizontally across the field.

Calculations were performed to determine the expected operating cost, capital cost, and profit of the system. The conclusion of the calculations was that none of the viable system options were profitable or sustainable. The team then decided to make a simulation program. The objectives of this program were to provide a method of summarizing research and analysis for future projects, determine the feasibility of irrigation on any hillside field. It also allowed design parameters such as crops/water requirements, field dimensions, and labor situations to be varied to highlight direct areas for improvement.

The program is based in Octave, an open-source MATLAB equivalent, and an interface was created with Rapture. The interface makes it easy for people without programming experience change inputs and run the program. It outputs a recommended system by tabulating a bill of materials and numerous graphs that provide clear and concise summaries of the results. The program has been released as an open-source tool under GPL for other groups to use the simulation for current irrigation projects, improve the code, and continue its development. The next step for the project is to validate and expand the model with more data from Africa.

Introduction

Agriculture has always played an important role in the lives of farmers in Africa as a source of subsistence and income. Rwanda, a small country in the heart of Africa, is no exception. Its thousands of farmers have been struggling to survive amidst the negative impacts of climate change and the aftermath of the 1994 genocide, which have strained the limited production.

One proposed solution to address this problem is to provide irrigation systems for farmers to supplement the natural rainfall during the rainy seasons and provide water to cultivate crops during the dry season. Many efforts have been made to implement various irrigation systems. The Global Team for Irrigation in Africa (GTIA) team, a global engineering team with members from Purdue University and the National University of Rwanda, set out to develop an agricultural irrigation system to aid in reducing poverty in the Gashora Sector of Rwanda using environmentally, socially, and economically sustainable design practices. The team also documented the process in order to provide future teams with their conclusions and recommendations for future work.

Background Information

This project set out to design an irrigation system to assist with farming in the Gashora Sector of the Bugesera District of Rwanda. After the 1994 genocide, the entire agricultural system of the country was impacted. The deaths of thousands of farmers strained the ability of the country to provide for itself. The Gashora Sector has seen droughts in the last few years and has struggled to cultivate crops during the rainy seasons. This has greatly hurt the food production in the area and has forced residents to leave. The project will focus on helping increase yield for one farm through a sustainable irrigation system during the dry season that could be easily employed by other farmers in the area.

The Project

The project was initiated as a joint project between Purdue University and the National University of Rwanda (NUR). The joint project was initiated by five Purdue University students, and NUR students evaluated several potential projects in Rwanda and proposed one project to the global team. Their proposal outlined an irrigation project in the Gashora Sector of Rwanda with two rural farmers who cultivate an area of 4 hectares (10 acres). Therefore, the project initially focused on irrigating maize (corn) and beans during the dry season (very little natural rainfall).

The Global Team

This project was then officially confirmed and the team was formed. The Purdue University student team was comprised of five mechanical engineering

seniors who used this project as their capstone design course. They were assisted by two agricultural economics students and a junior in mechanical engineering who volunteered their time. The NUR student team was composed of two civil engineering students who also volunteered to help with the project.

Technology

Working in a global team leads to many obstacles to overcome, especially when it comes to maintaining communication pathways as well as sharing research and information. During this project, the team implemented several new technologies and resources to try and overcome these obstacles. The first of which is GlobalHUB.org. GlobalHUB is a site that was founded to provide an online workspace for students and groups working in a global engineering environment. This project was one of the first true tests of a global team relying on GlobalHUB, and as such, in addition to using the site to host our research and information, the group was also responsible for reporting on improvements that needed to be made to the site. These improvements provided true user feedback to the website and allowed them to see exactly how this site could be used for global teaming. More detail on these improvements can be found in Appendix A.

The second new technology being tested by this group was a digitizing pen from LiveScribe, known as the Pulse Smartpen. The pen was a digital voice recorder as well as a handwriting recorder. It uses special notebooks and an infrared camera to record notes that are taken, as well as what was said when the notes were taken. These notes can easily be uploaded to a computer, and in turn, uploaded online or e-mailed as needed. As in most design environments, design notebooks were required to be kept for this project. The Pulse Smartpen was evaluated by three teammates as to whether or not it could be used effectively to record the “offline” aspect of this project. These notes could be captured and posted for other teammates to review, regardless of location. Individual reflections can be found in Appendix B.

Assessment Trip

In January 2009, four of the Purdue students and their advisor went to Rwanda for an assessment trip. The goals were to acquaint the students with each other, learn more about the project, and begin to form relationships with key people in Rwanda. While they were there, the students began brainstorming for the project, met with the farmers, visited local suppliers to find what materials are locally available, and met with several administrators at NUR and influential people in the community.

Interaction with Farmers

The most important outcome of the trip was visiting the farm and talking with the farmers. The students were able to ask the farmers questions about their

farming methods, average seasonal yield, current market prices, and expectations. In summary, the field is owned by two local women who work the field and hold other jobs. They currently grow maize and beans with an intercropping technique. The yield is used as subsistence and the surplus, if any, is sold on the market. Since beans have a higher market price, they are the preferred crop for making a profit, but the maize is the staple food crop. The farmers also asked the students questions about the feasibility of expanding the project to include their neighbors if it is successful, whether the project would impact their current growing season, and the long-term economic impact if everyone in the area has an irrigation system. The farmers were very intelligent and very willing to assist with the project in any way possible.

While visiting the farmers, the team was able to analyze the field. The soil was analyzed by one of the Purdue agricultural economics students and determined to be sandy loam soil. The field dimensions were measured with a hand-help GPS to be roughly 170m by 220m. The field was on a hill with a lake near the bottom of the field and the vertical rise from the lake to the field was roughly 25m. In addition to the field, the team took note of the living conditions and available supplies at the farm. They have a small house in which they live, but do not have electricity or running water in their house. They also do not have a car and did not appear to have bicycles. The community looked like a typical African community with very few resources. The only technology that was found at the farm was cell phones. The farmers both have cell phones and one of the farmers' husbands has a job and has occasional access to e-mail at work, but there is no computer in the community near the farm.

Global Team Formation

The team members were able to meet each other and spend time together. As aforementioned, four of the eight Purdue students were able to go, so only those students were introduced face-to-face. The global team was able to begin brainstorming for the project as well as discuss goals and expectations for the semester. Before the Purdue students left Rwanda, the global team created a task list and timeline to guide the project.

Meetings

In order to generate interest and support in the project, the students presented their project to numerous administrators at NUR. They met with a head administrator, the Dean of Agronomy, and the Interim Dean of Applied Science. They were all supportive of the project and promised to help the students obtain the necessary equipment and materials. While the team was talking with the Dean of Agronomy at NUR, he mentioned a GPS mapping organization that is located near the university, so the team met with the head of that organization and ordered several maps of the farm and its surrounding area.

The team also met with the Permanent Secretary of the Ministry of Agriculture. He said that irrigation in the Gashora Sector is a high priority of the Ministry of Agriculture and was excited about the project. He offered more information regarding a similar project in a nearby area.

Constraints

Several constraints were discovered and agreed upon while discussing the project with the various people during the trip. As aforementioned, maize was the main crop that was targeted for the irrigation per discussion with farmers. The maize is used as food and the excess is sold in the markets for money. Due to the remote location of the farms, the materials that were considered have to be available in the local area including Kigali (the capital city of Rwanda). Due to the lack of availability of long-term loans, the system was defined as profitable if the farmers are able to make a profit after the first season of operation. These constraints were generated after the assessment trip and were re-examined after the feasibility analysis to see if any of them could be relaxed to allow for more profitability.

Research Summary

In order to learn more about irrigation and agriculture, an extensive amount of research was compiled. Figure 1 shows a generic schematic of the system.

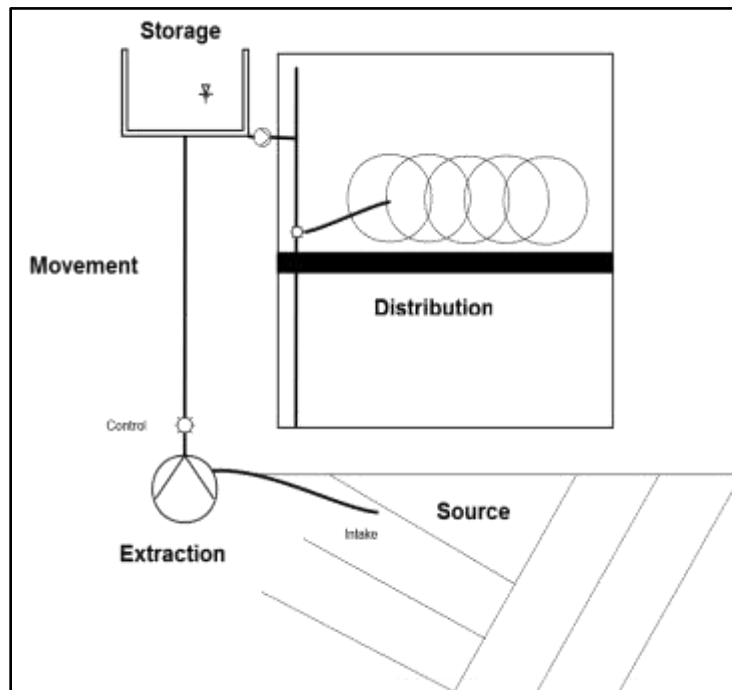


Figure 1 - Irrigation System Schematic

Figure 2 shows how the problem was decomposed into five sub-problems. The water source was the first stage/step, which led to the water extraction, movement, storage, and finally distribution steps.

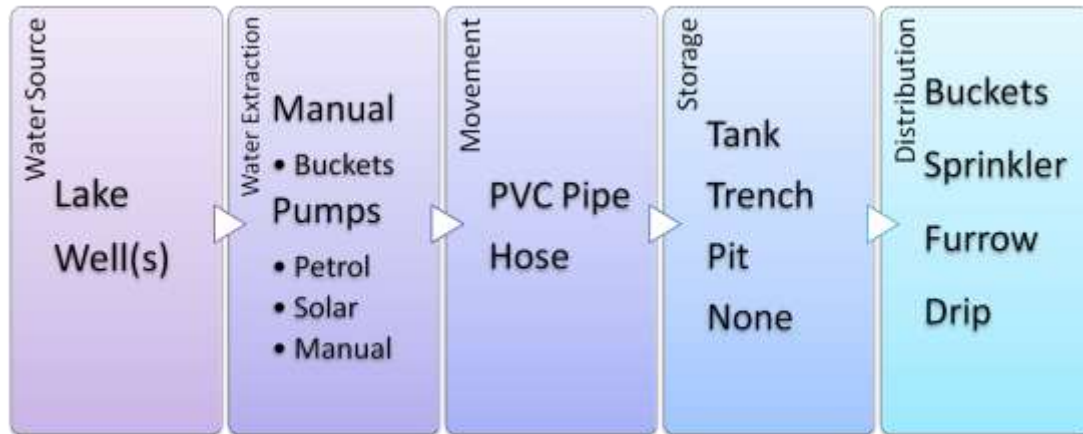


Figure 2 - System Decomposition

Water Source:

As stated previously, there is a large lake at the bottom of the field. While in Rwanda, the team decided to pursue the possibilities of pumping the water directly from the lake as well as drilling a well at the top of the farm. Both options were researched and are described below.

The idea of drilling a well to irrigate the field originated from the assessment trip. The team saw numerous wells drilled throughout the countryside with hand pumps on them used to distribute water. We were told by the farmers that there is a possibility of the well water being salty due to the minerals in the soil. When the team returned from the assessment trip, well drilling was further examined. In order for a well to be dug, a hole must be drilled/bored in the ground, a pipe must be inserted, and the pipe is generally lined to protect from the surrounding soil and minerals. A pump must then be installed to bring water up to the ground surface. The amount of water that can be pumped out a well is affected by the amount of water in the ground, the diameter of pipe used to pump the water, and the suction head and flow rate of the pump.

Several methods of drilling the well were researched. The first method was to bore a hole with a big drilling rig. While this is certainly the most efficient and direct method, well drilling is very costly, especially in Rwanda. The well would require a significant amount of capital to be raised by the farmers and/or donated by an external organization as well as finding and hiring a drilling crew and drilling rig. The next method was called percussion drilling, which is a much more inexpensive method. It uses a large weight (a rock or piece of scrap metal) that is repeatedly raised and dropped into the well hole. Water is added to the hole to soften the soil so the weight is able to displace it more easily. The mud is then extracted and the process repeated. While it is a very laborious process, wells as

deep 4000 ft have been drilled.¹ This method is relatively inexpensive and requires very little equipment, yet requires much more manual labor. One common way of drilling these wells is to have an external organization provide the materials to dig the well and show the local people how to use the equipment. They are then charged with drilling their own well and are able to drill wells for others as well. While more methods exist for drilling wells, none were more cost-effective and readily available in Rwanda than the percussion method, so no other methods were researched in-depth.

Water Extraction:

There are a few options for extracting the water from the lake to get it to the field. First, it should be noted that no system is currently in place; therefore, any method of extraction that can yield a profitable outcome would work. The first method of water extraction that was evaluated was the simple method of hiring workers to carry buckets from the lake to the field. The only cost would be buckets for the workers and their wages.

A solar-powered pump system would require an electric DC pump that would be powered by an array of solar panels. To use this system, many system attributes needed to be considered. First, the cost of the solar array needs to be added to the cost of the electric pump to determine the cost of the system. Also, if the system requires a battery bank to store energy, the batteries would have to be stored in a shelter. Next, the space that is required for the solar array would need to be considered because it might cut into a portion of the field that may otherwise be used to grow food. The costs of electric pumps and the solar-powered systems that would accompany those were researched. The electric pumps deliver a much lower flow rate and a much lower head delivered than most of the petrol pumps that were researched. In addition, they cost significantly more, on the order of \$1000 USD.

Petrol pumps are significantly cheaper and deliver higher flow rates and pressures than electric pumps. Four different petrol pumps were considered. The costs for those pumps ranged from \$600 USD to \$2300 USD (converted to \$ USD from actual prices in Rwanda) depending on the flow rate and required head. The various pumps came with unique performance specifications and suitable pumps were able to be evaluated for various operating scenarios.

There are several varieties of manual pumps that were evaluated. Hand pumps and treadle pumps were researched and considered in great depth. Hand pumps are widely used in Africa to provide safe drinking water to communities, schools, and hospitals. They have a basic operation platform and can be easily operated by children. Hand pumps can deliver very high levels of suction head, but they have low flow rates (about 0.5 liters per second). Since they have been used for many years in Africa, there has been a great deal of research and sustainability analyses done on them. Studies show that “about 90 % of most hand pumps break down within 3 years due to worn out or broken parts.”² This is often due to pumping rods and PVC pipes breaking, bearings and piston seals wearing out, galvanized pipes rusting, and foot valves leaking³. Unfortunately, most communities

do not have the resources or the funding to properly maintain their pumps, pay for them to be repaired and or buy replacement parts. There have been recent projects to design new hand pumps that are capable of being operated for long periods of time with no maintenance. One example is the Afripump®, which has a simple design that claims to only need replacement parts every 15-25 years⁴. All of the components that need replaced are contained in one simple box that can be easily removed and then replaced with a new one.

Treadle pumps are commonly used Asia, Africa, and South America for small-scale irrigation. They deliver water at a small suction head (5 to 8 meters) and a moderate flow rate (1 liter per second). They work much like a Stairmaster®, in which an operator shifts his weight between two different platforms to power the pump. The main disadvantage of this is that pumping for continuous durations of time can be extremely fatiguing, especially in the hot African sun. These pumps can also be more challenging for women to use. They have been proven to be successful on small farms in Africa (typically 1-2 Acres). One particular example is the MoneyMaker®, which is designed and made by the company KickStart. As of December 31, 2008⁵, it has sold more than 115,000 pumps, created over 77,000 enterprises, and helped bring 380,000 people out of poverty. The MoneyMaker excels because it is small and lightweight and can be easily carried and transported. It is also has a low enough price that farmers can afford it or take out small loans that can quickly be repaid with part of a seasons profits. No information is yet to be reported about the sustainability of these pumps.

Storage:

Storage refers to a possible way to store water between the water-extraction and distribution stages of the system. Three storage options are available for use in Rwanda. These options are plastic agricultural tanks, plastic-lined, hand-dug pits, and hand-dug trenches. The plastic tanks available in Rwanda are elevated, enclosed tanks. The largest tanks available are 5000 L and 10,000 L. These tanks cost \$654.55 and \$1261.82 respectively. Many tanks would need to be purchased to hold the amount of water that is required (250,000 L/day).

The next option is hand-dug pits that would be lined with plastic. This option is relatively cheap, and pits can be dug to any volume. However, any area of the field that is used for pits is area that cannot be used for planting. Also an extra pump is required to pump out of the pit to get the water to the field.

The third option is hand-dug trenches that would be dug along the rows of crop and lined with plastic or rocks and tile. As is the case with pits, trenches would also require a second pump or buckets to distribute the water to the crop.

Distribution:

Distribution is the way that the water reaches the crops after it is pumped. This requires a system of pipes, hoses, and junctions. PVC pipe is readily available in

Rwanda, and there is a PVC pipe manufacturing plant in Kigali. PVC is lightweight and strong. The main disadvantages of using PVC pipe are that it can be crushed if it is stepped on and UV rays can damage it with prolonged exposure to the sun. Hoses have an advantage because they are flexible so they can quickly be moved and they will not break if they are stepped on. They too are at risk to UV damage, as well as the heat of the sun. Research showed that they are also expensive in Rwanda.

The four main types of distribution considered were

- Buckets or Watering Cans
- Sprinklers
- Furrows
- Drip

In order for bucket irrigation to be successful, water would need to be pumped to several different storage locations. Long trenches would work well because the distance that would have to be walked between the crops and the water would be minimized. Pits could also be used, but several different ones would be needed. Bucket irrigation would be a tedious and physically challenging task for such a larger field, but if the field were to be reduced to 1 or 2 acres, it could effectively be carried out.

Sprinklers are widely used for irrigation. There are several different types of sprinklers (rotary, oscillating, and stationary) and they can be either fixed or mobile. For this particular system, the sprinklers would most likely be mounted on wheels and slowly pulled across the field. For this to be successful, careful attention must be placed on water pressure, flow rate, and the amount of overlap that the sprinklers have. Pressure is a major concern for this field, because it is located on a hill and 1 meter of elevation change is equal to a 1.4 psi change in pressure. This means that a pressure regulation system would need to be implemented. If the pressure can be regulated, then the flow rate also needs to be relatively constant. If this can be done, then the sprinklers will cover a constant area of the field. This will make it easier to get even coverage across the entire field. Since the sprinklers have a circular area of coverage, they must be overlapped. This can either be done by moving them at slow velocities across the field, or moving them from location to location and ensuring that their diameters overlap each other by about 65% as seen in Figure 3. This will allow for a nearly constant concentration of water as seen in Figure 4.

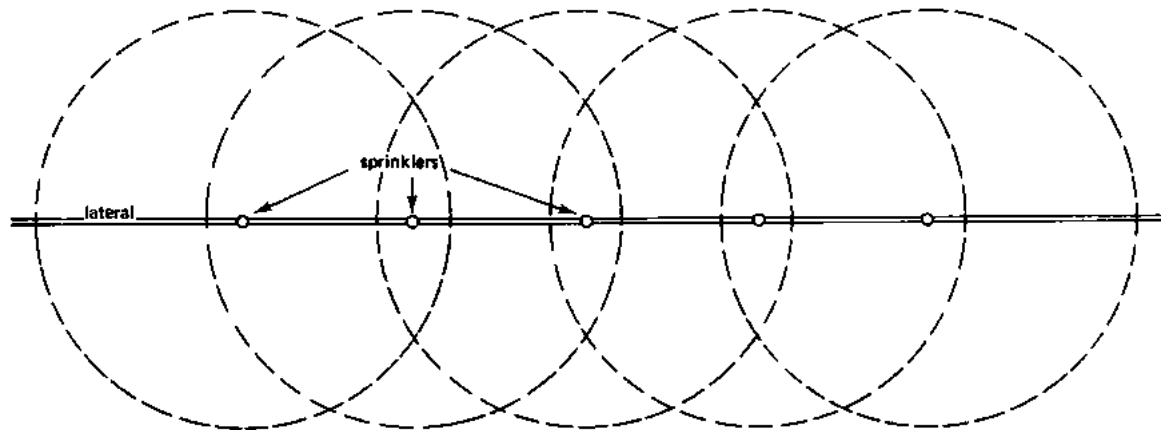


Figure 3 - Proper Sprinkler Spacing⁶

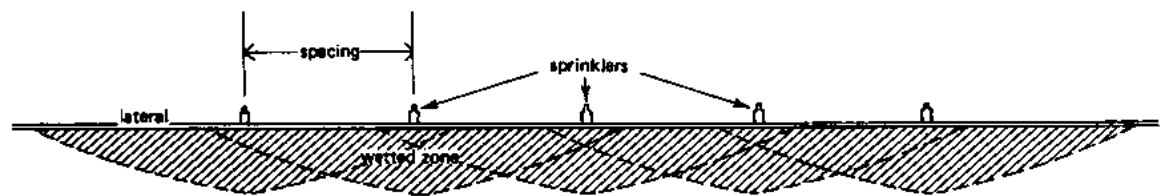


Figure 4 - Nearly Constant Water Concentrations from Sprinklers⁷

Sprinkler irrigation should never be done in the middle of the day because crops can easily be damaged by being irrigated in the middle of the day (from the hot water burning the leaves) and evaporation losses are the highest at this time. It is also important for clean water to be used, in order to prevent the sprinklers from being clogged with particulates.

Furrow irrigation (also known as surface irrigation) is a process in which long furrows are dug along the sides of row crops. The furrows have a slight slope so that they can be filled with water and it will run to the bottom. The crops absorb the water through their roots. The important factors in furrow irrigation are:

- Flow rate
- Slope of the field
- Seed placement
- Soil type
- Furrow depth and shape
- Furrow length

A flow rate of approximately 0.5 liters per second is usually sufficient for furrow irrigation. Anything over 3 liters per second can cause large amounts of erosion⁸. The slope of the field must be around 0.05% to .5%. This is not a large slope, and careful attention needs to be placed on the location of the furrows on the field. They need to follow the land contours in order to keep them on as small of a slope as

possible. There are several methods used to position the seeds along the furrows. In drier conditions, the seeds are placed directly at the bottom of the furrow, as seen in Figure 5. Careful attention must be paid in order to keep the newly planted seeds from washing away or being flooded. When water is readily available, seeds are placed on the sides of the furrows as seen in Figure 6. This is advantageous because one furrow can be used to water two rows, unlike planting at the bottom, which requires one furrow per row. The soil type is important because sandy soils will absorb water at much higher rates than clay soils. This factor, as well as the flow rates and slope will help to determine the appropriate furrow length, depth, and shape.



Figure 5 - Furrow Irrigation with Seeds Placed at the Bottom of Furrows⁹



Figure 6 - Furrow Irrigation with Seeds Placed on the Sides of Furrows¹⁰

The final type of distribution is drip irrigation. This is a process in which water is allowed to slowly drip to the base of crops. It drips out of a pipe or hose through what is known as an emitter. The advantages to this type of irrigation are that the water is precisely placed and only the roots of the crops are watered, which helps conserve water. In a previous study, “Maize irrigation water use for furrow irrigation ranged from 547 to 629 mm per year compared with 371 to 428 mm per year for drip irrigation. Irrigation water use efficiency was always superior for drip irrigation compared with furrow irrigation¹¹.” As with sprinklers, careful attention must be placed on pressure and flow rate. Typical emitters operate at a pressure of about 1 psi. This means that for every one meter of elevation changes, the pressure at the emitters will more than double without proper pressure regulation. There are two main types of drip irrigation used for maize. Typically flow rates of 2 to 8 liters per hour are seen through each emitter¹². In microdrip irrigation, flow rates of 0.5 liters per hour are used. This would allow for a pump with lower flow rates to be used, but it would require much longer durations of irrigation. Drip irrigation requires an immense amount of pipe (the number of rows times the length of the rows in the length of pipe required) and also a clean water source in order to prevent the emitters from being clogged.

Evaluation of Research

Water Source:

The water source research was compiled and evaluated in conjunction with the water extraction research as described below. The water extraction research showed that a hand pump on the top of a well was not feasible due to the flow rate limitations of the hand pump and the petrol pump was not feasible due to the flow rate limitation of the diameter of the pipe used in the well. Also, there was concern about the water table depth and water salinity due to the unknown mineral content of the soil. Finally, a well would cost a prohibitive amount of money to have drilled by a drilling rig and would require a large amount of effort and some money, albeit less than hiring a rig to drill, using the percussion drilling methods. Due to these conclusions, the lake was determined to be the best option for the water source.

Water Extraction:

The first water extraction method that was evaluated was the buckets. This was performed to not only determine its feasibility, but to produce an upper limit of the cost of the irrigation system because it would not make sense to purchase a system that would be more expensive than hiring the local people. Unfortunately, it was quickly determined that this method would require hundreds of people to deliver the required amount of water. The labor costs for that system greatly outweigh the profit that could be made so that option was eliminated. That leaves three different types of pumps that could be used to pull water from the lake; solar, petrol (gas), and manual as discussed below.

The pumps were evaluated to determine how well they will perform on the field. Hand pumps are incapable of delivering a high enough flow rate to be used for this irrigation system. They would [simply](#) require too much labor and too many pumps to meet the daily water requirements. There are a lot of lessons to be learned from them though, and the research that has been found about their sustainability directly pertains to other types of pumps.

Treadle pumps do not have a [high enough](#) head [large enough](#) to allow them to be fully implemented on this field. The total head that they can deliver water is roughly 14 meters, which means they can irrigate about two-thirds of the field. Their flow rate is high enough to allow them to be a feasible solution, but small increases in the flow rate would lead to a large decrease in the overall system cost and number of pumps required. By evaluating different field sizes, they appear to be optimal for fields that are less than 2 acres. If they were to be implemented on a 2-acre field, approximately seven pumps would be required to irrigate up to the 14 meters of head that they can deliver. This causes the capital cost to reach approximately the same price as petrol powered pumps.

The solar pump method was analyzed as well. As mentioned above, the battery system and electronics must be housed in a shelter. This means that a small barn or hut would need to be built because there is currently nowhere to store the batteries or any other component near the farm. Additionally, the cost is

prohibitively high. To install the solar array, thousands dollars would be required in parts, labor, and maintenance. So even though this system would most likely require the lowest operating cost, the capital cost of the system makes this option infeasible.

In addition to the capital cost of the petrol pumps, several factors must be considered. First, the pumps require petrol, which necessitates the transport of petrol to the farm, the storage of petrol at the farm, and consideration of the cost of the daily petrol requirement of the pump. Second, a security guard would need to be hired and on duty 24 hours a day to watch the pump to ensure it is not stolen. Third, a cement slab would have to be installed to provide a place for the pump to be mounted and secured. Finally, the pump would have to either sit out in the elements or be moved inside a shelter during the rainy season. Both of these scenarios affect the feasible pump options.

The conclusion of the water extraction research was that treadle pumps are most feasible for small farms and small petrol pumps are most feasible for larger fields. These conclusions focused strictly on the performance requirements and largely ignored the majority of sustainability analysis, which affected the final conclusions and will be discussed after the research evaluation.

Storage:

Three different storage options were evaluated. These three options were plastic agricultural tanks, plastic-lined, hand-dug pits, and hand-dug trenches. The advantages and disadvantages of these storage options are summarized below.

Plastic Agricultural Tanks

- About: The plastic tanks that were found to be available in Rwanda were elevated, enclosed tanks. The largest tanks available were 10000 L and 5000 L tanks.
- Advantages: Cleaner water storage option, water is pressurized at tank exit
- Disadvantages: Expensive (\$1262 USD for 10000 L tank), requires extra pumping head to pump water into tank, difficult to acquire/transport, will begin to break down after 8 years in sun

Pits

- About: The pits would be hand dug and lined with plastic.
- Advantages: Can be dug to desired size, inexpensive, allows for the possibility of adding fertilizer to the water
- Disadvantages: Clean water would be difficult to ensure, another pump would be required to extract the water from the pit

Trenches

- About: The trenches would be hand dug along the rows of crop. The trenches would be used to store water and would likely be lined with rock or tile.
- Advantages: Minimal transportation from trench to crop, no pressure requirement
- Disadvantages: Very labor intensive, water lost due to seepage, would require numerous outlets from pump

Distribution:

The advantages and disadvantages of sprinkler, furrow, and drip irrigation are summarized below.

Sprinkler

- Advantages: Able to cover large areas, precise placing is less critical, can be easily moved to new positions
- Disadvantages: Accurate pressure regulation is critical, water must be free of particulates, high evaporation losses

Furrow

- Advantages: Low capital cost, easy to implement to entire field, few parts to maintain or replace
- Disadvantages: Slope of field is critical in order to evenly distribute water, high maintenance and upkeep, high risk of erosion, inefficient water use

Drip

- Advantages: Efficient water use, minimal erosion and runoff, minimal evaporation losses
- Disadvantages: Accurate pressure regulation is critical, water must be free of particulates, emitters must be placed at each root which requires large quantities of pipe, difficult to move to new positions

From this summary, it was concluded that furrow irrigation is the most feasible irrigation technique for this field. There are two main reasons for this decision. Furrow irrigation requires a small number of parts and a low capital cost. Additionally, sprinkler and drip irrigation are more suitable for flat farms. Because of the high elevation changes, a proper regulation system would be too expensive and require the operators to have a great deal of knowledge about the system. With furrow irrigation, the system will be easy to operate and maintain. Since there are fewer parts and components, the risk of the system breaking down and being abandoned is much smaller.

Proper implementation of this furrow irrigation system will require that the furrow be less than 100 meters long and the slope be minimized as much as possible. The water will be transported up the hill in two locations (one on the edge

and one in the middle) and allowed to run along furrows that are parallel to the bottom of the field to the middle and the other edge of the field respectively. The seeds will be planted along the sides of the furrows in order to minimize the number of furrows needed.

Performance Analysis

With the several different systems defined and evaluated, it was necessary to expand on these systems and complete a more in-depth performance analysis. This analysis was done in order to provide a higher resolution analysis with varying parameters. The steps taken are summarized below:

- The field size was a variable so that the labor and capital requirements as well as profit could be determine for different sizes of the field.
- Detailed water requirements over time were determined in order to provide the daily volume of water that the crops require.
- The number of laborers required each day was calculated throughout the entire season.
- The maximum number of pumps that would be needed was calculated.
- The required cost of pipes, junctions, and elbows was calculated with respect to the size of the field and the required number of pumps.
- Variables such as crop yield and selling price, flow rates, percent of required water that is delivered, and different prices were then varied to determine their direct effects on the system.
- The cost and profit for these implementations was then considered over several irrigation seasons.

The results of this analysis lead to the conclusion that none of the current systems provides a solution that is profitable and sustainable for the farmers.

Although the analysis did not provide a feasible system, the analysis was able to identify multiple areas where improvements could be made to the system in order to make it feasible to implement. An example of this can be seen in Figure 7. This figure shows the effects of varying the flow rate of treadle pumps. Treadle pumps can only deliver flow rates of 1 liter per second. This is only sufficient to break even on operating cost each season. This performance will never be enough to pay off the capital cost of this system. It can be seen that doubling the flow rate creates a system with much higher profits that could actually be considered feasible.

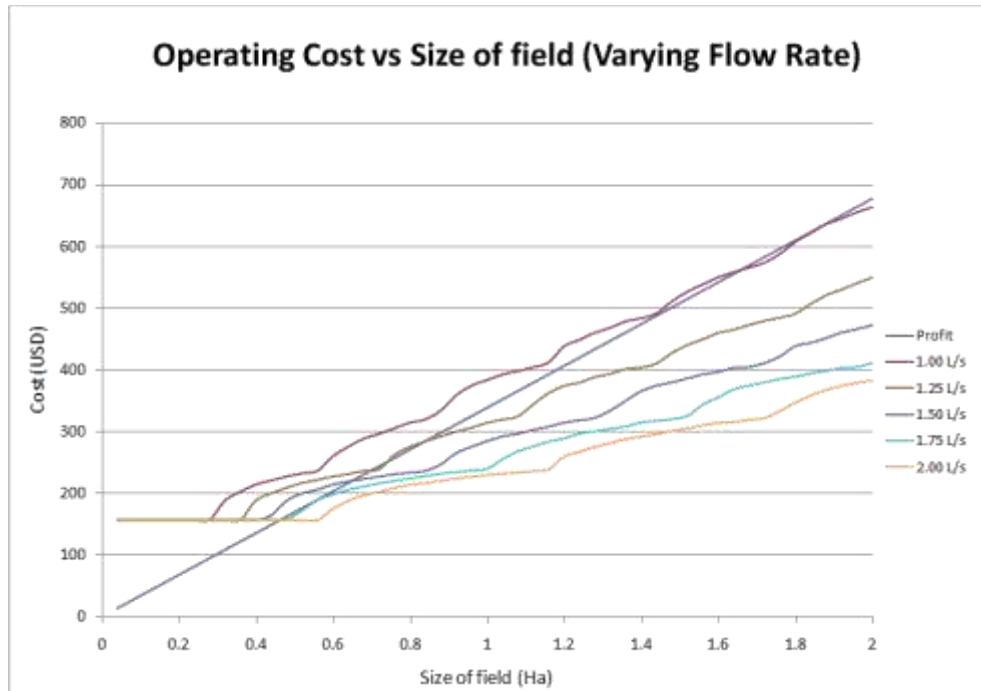


Figure 7 - Treadle Pump Performance Analysis

There are many factors that keep these systems from being profitable. Maize is an inefficient crop that requires large quantities of water with very little yield and does not have a high value in Rwandan markets. In both our assessment trip and conversations with members of the Purdue School of Agriculture, we were asked why we were trying to irrigate maize and told to consider other options such as horticulture crops.

The research showed numerous successful small-scale irrigation projects in Africa, but they were slightly different from our project in the following ways. First, the analyzed system must operate without rainfall. Most maize based irrigation systems are only supplemental, which vastly decreases the irrigation requirement. Second, many successful irrigation systems in Africa are on very small-scale fields. The farmers are able to completely operate their systems alone and do not have to invest in extra labor, which is plentiful and inexpensive, but not feasible to pay on a daily basis.

Sustainability Analysis

During the evaluation of research, the three aspects of sustainability were considered. Due to the iterative nature of sustainability analysis, it was not always performed concurrently with the performance analysis, but the results were assessed jointly before a decision was made.

The environmental sustainability of an irrigation system is a very complicated analysis. The three most important impacts to assess are soil loss due to erosion, nutrient depletion of the soil, and chemical pollution due to runoff from fertilizers. Several factors about this project simplified the analysis greatly.

First, the erosion of the soil is directly related to the method of water distribution. For drip irrigation, the threat of erosion is negligible. For furrow irrigation, the threat is higher, but still not large. If the soil erodes down a furrow, the farmers can move the soil back up the furrow if it is a large issue. For sprinkler irrigation, the damage due to erosion would be comparable to furrow irrigation due to the dispersion of the water and the possibility of puddles forming and causing the water to run down the field. Flood irrigation would have the largest negative impact due to the large volume of water put on the field at one time and the possibility of that water washing away the first layer of soil. Another large factor that affects the erosion potential is the slope of the field. As the slope of the field increases, the risk of erosion damage increases as well. For furrow irrigation, the furrows could intentionally be dug in a direction that would provide only a slight gradient, which would help prevent erosion.

Second, the nutrient depletion of the soil is a large environmental concern. Since the farmers currently do not plant in the summer season, their land is left fallow. If crops are planted during the summer season, the land will be growing crops all year. During the assessment trip, the farmers told the team that the land is fertile and they do not use fertilizer because it is not needed. Based upon this information, the team decided to assume the soil is suited to grow crops during the summer. The farmers would then be encouraged to look into using fertilizer if their yields start decreasing.

Finally, while chemical runoff is a very damaging environmental impact, it was neglected during this project due to the fact that the farmers are not currently using fertilizer and our system recommendation will not include fertilizer use (unless yields drop as mentioned above). If the yields decrease due to nutrient depletion, an environmental impact assessment will be conducted to determine the effect of the fertilizer on the lake and surrounding area. This analysis would account for the method of irrigation, the style of planting, the method of fertilizer application, and the fertilizer used. Due to the fact that the farmers rely on this crop for food, the goal of the impact assessment would be to determine the least harmful fertilizer that would still provide a good crop for the farmers.

The economic sustainability analysis was more straightforward. In order for the system to be economically sustainable, the team determined it would have to produce a net profit for one growing season. The farmers told the team during the assessment trip that they only have limited access to loans, so it would not be accurate to assume the farmers could take out a loan and pay it off over a 2-3 year period. The inherent assumption regarding the one growing season is that the farmers have enough money saved to purchase the system at the beginning of the season. The interest rates in Rwanda for short-term loans are prohibitively high, so assuming the farmers could obtain a reason loan is not very reasonable. The economic analysis accounted for as many inputs and outputs as possible including the cost of the seed, the wages of workers, the average yield of the field, the market price for the crops, and many more. Please see the computer program section (input Section Title when it is decided) for the complete list of economic inputs and outputs.

The social sustainability of the project was more difficult to quantify. Since there have been numerous studies that researched the social impact of irrigation systems, the team consulted those studies for information on the social sustainability. One paper studied small-scale farming in Nigeria with subsidized petrol (gas) pumps provided by international relief organizations.¹³ Several thousand farmers purchased pumps and dug wells with hopes of irrigating their fields. While this is a very popular mentality by foreigners, the study showed some disturbing results. The most disturbing statistic was the failure of the pumps. In one set of 14 villages, over 50% of the pumps were rendered unusable due to the lack of availability of replacement parts. In another region during one year, 88.6% of the farmers experienced some type of pump breakdown with an average loss of 23 days of productivity. Additionally, the study explored the social impact of this subsidy program. Since some farmers were wealthy enough to purchase a pump and some were not, it created rifts in the social equity. Also, the farmers near an easily accessible water source or available well had a great advantage and were able to capitalize more easily on the pump program. While these results are slightly dated and assess irrigation in Nigeria and not Rwanda, they still provide some strong conclusions to consider for the given project as well as any irrigation project.

Another paper that was consulted discussed sustainable irrigation and gender.¹⁴ Since the farmers are women, this paper provided some very useful information. The first important point was that women are very rarely involved with the planning and design systems, yet perform the majority of the manual labor on the field (tilling, planting, weeding, etc.). While they may have genuine input, they are often too hesitant to speak up or may lack the support of other people involved with the design process. Also, the paper mentioned that women have difficulty operating a treadle pump due to the amount of force required. This would force a woman to hire a man or boy to operate the treadle pump, which would cost a significant amount of money. Finally, rural women very rarely have enough money to invest in an irrigation system. Even treadle pumps are often too expensive for a woman to purchase. While this project will not work directly with the farmers during the design process, this paper provided very relevant information to consider.

The team was able to apply this knowledge to the design considerations in several ways. First, petrol pumps have inherent negative factors that cannot be avoided. From the first paper mentioned as well as the team's assessment trip, there are very few replacement parts available for the pumps. Also, given the 30km distance from the farm to the capital city, it would be very difficult for one of the farmers to make a trip on short notice to obtain spare parts. In addition to that, the pumps are not insured for more than a year, if at all, and skilled labor to repair the pumps is difficult to obtain. Second, while petrol pumps have several disadvantages, treadle pumps do as well. Given the fact that the farmers anticipate working on the farm for at least part of a day, they would have to hire other workers to operate the treadle pump for a long period of time. This would add a daily operating cost to the irrigation system. Third, there is a social inequality that would be created by only the rich farmers having an irrigation system. This issue is compounded by the fact that women generally do not have enough money to purchase a system on their

own. This forced the team to search for the most inexpensive options to make the irrigation system affordable to the largest number of farmers. While this would be done under normal circumstances, the analysis included calculations for scaling the farm. This would allow someone to determine how much of a field one could irrigate with a certain budget. Please see the Modeling section for more information.

Global Irrigation Simulator

With these considerations, the research, and the performance analysis it was concluded that irrigation in Africa is possible, but several adjustments and improvements needed to be made to our system to make it feasible. It was determined that the best way to perform this analysis was through the design of a simulation system that easily allows system parameters to be changed and detailed results to be output.

Modeling/Program

Assumptions

- The size of the field is iterated from the base of the field to the top of the field. A constant width of the field is always considered; only the length changes.
- The maximum number of hours a laborer will work is 5 hours.
- Laborers will be paid for a full day of work, no matter how many hours they work in a day.
- Crop water requirement profiles over time are identical with the exception of two parameters: the maximum water required and the length of the season. This makes it possible to curve fit all of the crop water requirements with the same profile by simply changing these two variables.
- Pump flow rates are determined based upon the maximum height of the field, not by the current location being irrigated. This is to provide the worst case scenario (if all of the water was stored in a tank at the top of the field, and then allowed to run down the field).
- For each pump being used, one worker is required to operate it and one worker cannot operate two pumps simultaneously.

Process

The first step of the program is to calculate the current profit made for varying sizes of the field. This was done by using the crop inputs and field inputs. As mentioned in the assumptions, there were three main components of the profit calculations. The two costs associated with each crop were seed cost and labor cost. The only income associated with the field was if the entirety of the produced crop was sold at local market price. Seed cost, labor cost, and crop revenue were all assumed to scale linearly with the size of the field. Profit of the field was assumed to

be totals revenue less the total costs. [A detailed description of these calculations can be seen in Appendix D.](#) Additionally, the details of these calculations can be seen in Block 1 and Block 2 of the program Pseudocode, shown in Appendix C.

The next step is to calculate the operating cost and capital cost of the system. These are both found as a function of the field size. This requires several intermediate steps and iterations in order to accomplish. The first iteration is to consider the area of the field that is irrigated to be a variable. This allows for results to show what area of the field can be irrigated to make a profit and the maximum or minimum size that must be irrigated to be profitable.

The length of the field can only be iterated up to the location where the maximum head of the pump is reached. Pump performance curves were put into the system as inputs as well as the maximum head that each pump can deliver. The system calculates the required head for each iteration of the size. If the maximum head is reached, then the iteration is cutoff at this location, and the rest of the field is not irrigated. The pump flow rate is then found based upon the maximum head needed for the field.

For each iteration of the size, another iteration also occurs. This iteration considers each day of the season individually. The amount of water needed by the crop each day needs to be calculated. This is done based upon a generic water requirement curve, the peak water requirements of the crop (maximum daily water needed in the season), and the length of the season. The program calculates a new water requirements curve by changing the horizontal and vertical scales of the curve fit. The daily irrigation need can then be found by subtracting the daily average rainfall from the daily water need.

The hours of pumping required each day are found by dividing the daily irrigation need by the flow rate. - When the hours required exceeds any interval of 5 hours, then a new worker and pump are both required. For example, if 11 hours of pumping is required for any given day, then 3 workers and 3 pumps are both required. 3 workers would then be paid a full day's wages. The cost of fuel each day is also found by dividing the hours of pumping required by the pumps hourly fuel consumption multiplying the liters of fuel consumed by the cost of fuel. The cost to pay the labor each day and the cost of the fuel each day is then summed throughout the entire season to give the seasonal operating cost.

The capital cost is then found by determining the maximum number of pumps needed in the season. This will give the pump capital cost. The capital cost of parts such as pipes and junction must also be found. This cost depends on the type of irrigation and the type of pump that are being used. For furrow irrigation, it is necessary to determine the number of vertical runs of pipe. For this, it was assumed that the maximum furrow length is 100 m. The number of vertical runs is then calculated as the width of the field divided by 100 m. Then the total length of pipe can be determined. For drip irrigation, the total length of pipe is equal to the total length of the crop that is being irrigated. It is also necessary to know the diameter of the pipe, as it will have a major impact on the price of the pipe. The diameter must match the diameter of the outlet at the pump. If a treadle pump is being used, no pipe is required for distribution. Each pump would have a hose connected to the outlet, and water would be delivered directly to the crop.

The pump and part capital cost are then summed together to give the total capital cost. The total cost is then found by summing the capital cost and operating cost. The results are then extrapolated across several seasons. The operating cost is summed in each season, while the capital cost is only included in the first season. Depending on the life expectancy of all of the system components, the capital cost may need to be summed into the total cost every time the life expectancy is exceeded.

Inputs/Outputs

To execute the main simulation program, an intermediate program, Rappture, is used to create an online interface and executable. Rappture presents the user with a graphical interface for entering all of the inputs. These inputs have been divided into five main tabs. As Figure 8 shows, these tabs break the inputs into the following categories: Costs and Conversions, Field, Crop, Weather, and Pump.

Category	Value
Base Currency	RWF
Output Currency	USD
Exchange Rate	570
Days of Labor	9
Workers Per Day	10
Length of Work Day	5h
Labor Wage	700
Fuel Costs	780

Figure 8 - Global Irrigation Simulator Inputs

In each of these categories, the user can customize the values for the simulator to run. In the Crop and Pump categories, the user may also select preset values for all of that category's inputs from a drop-down menu. For example, in the Crop screen, they can select values for each of the options by choosing a particular crop that has already been added. There is also an option for uploading and downloading this data, but there are some issues with the version of Rappture being used which is preventing this from working.

Figure 9 below shows the Field Information input category. As the figure shows, when the user moves the mouse over an input, a description appears providing them more information about what the input is. Another benefit of the Rappture interface is the unit conversion; when a unit is specified for an input, the user can input any unit of that general dimension (for example, for specified units of meters, any unit of length will suffice). Once the user has specified their inputs, the simulation is run by using the Simulate button.

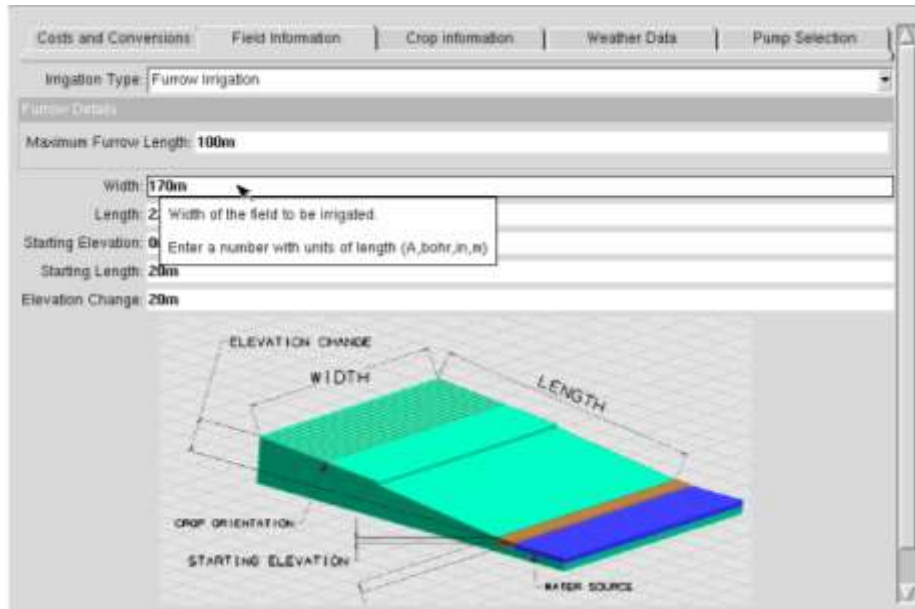


Figure 9 - Field Information Input Screen

The Global Irrigation Simulator has two primary outputs. First, the summary and a brief bill of materials is output showing the capital cost for the configured system. Figure 10 shows this summary output.

Result: GTIA Irrigation Simulator Results

This analysis was run to simulate the effects of irrigating a field of maize using Furrow irrigation. Please use the output menu to review the results and plots.

A recommended Bill of Materials has been summarized below:

Pumps		ITEM COST(USD)	TOTAL COST(USD)
QTY	ITEM		
5	MoneyMaker Treadle pump	260.00	1300.00

Pipes/Parts		ITEM COST(USD)	TOTAL COST(USD)
QTY	ITEM		
20	PVC Pipe; Dia = 32 mm; Length = 6 m	5.26	105.26
0	PVC T-Junction; Dia = 32 mm	4.39	0.00
0	PVC Elbow; Dia = 32 mm	1.05	0.00
		Pipe Total = 105.26	

		Total Capital Cost = 1405.26	

Figure 10 - Global Irrigation Simulator Output Summary

The second part of the program output is a series of graphs. The graphs provide an easy way to present the feasibility of the system by comparing different parameters to the available profit margins. The graphs that are output are listed below.

- Profit in Local Currency vs. Area of Field
- Profit in Output Currency vs. Area of Field
- Field Water Requirements vs. Area of Field
- Field Irrigation Water Requirements vs. Area of Field

- Daily Irrigation Water Requirement
- Field Hourly Labor Requirements
- Field Worker Requirements
- Operating Cost vs. Profit For Varying Field Sizes
- Operating Cost vs. Profit For Varying Field Sizes
- Total Cost vs. Profit For Varying Field Sizes
- Total Cost vs. Profit Over Several Seasons

These graphs can be selected from the drop down menu above the summary. Each of these graphs can be zoomed in on, exported as images, or exported as data pairs. Figure 11 shows an example graph with the legend shown.

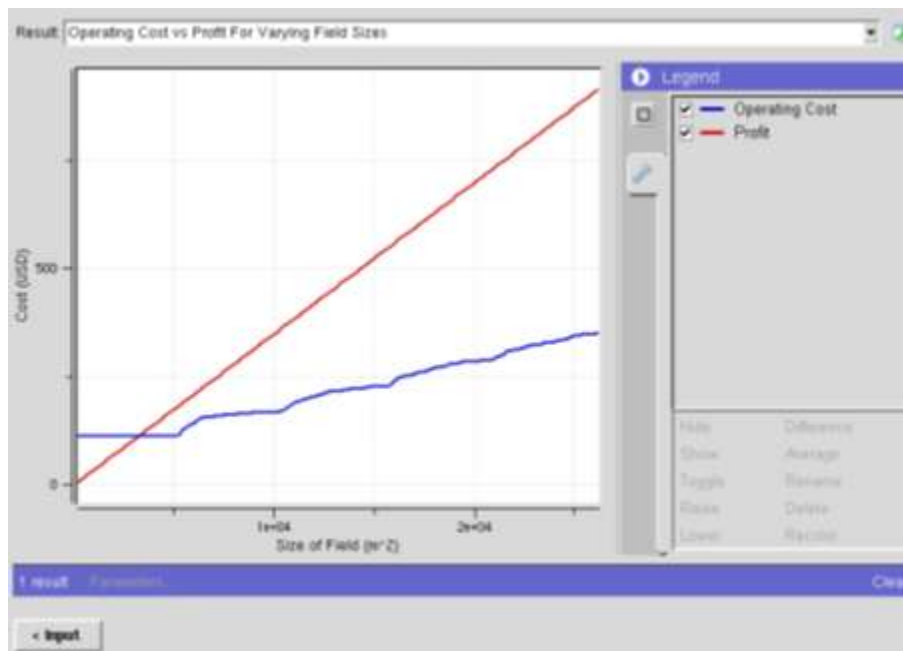


Figure 11 - Sample Operating Cost and Profit Graph

An additional benefit of these outputs is the built-in comparison method. If multiple simulations are run or parameters are changed, the graphs can be overlaid so the user can compare the different results.

This program has been released as a tool on the website GlobalHUB.org. This tool is released as open-source under the GPL and the source can be found on the website as well. This is open for development so that anyone may create a branch of the program and add new crop presets, add pump specifications, or improve the code and calculations.

Conclusions

After completing the semester of work, several conclusions are readily evident. First, it is not economically feasible nor sustainable to irrigate maize during the summer season in the Gashora Sector of Rwanda. This conclusion is supported by the analytical results of the performance analysis as well as the advice of several agriculture experts at Purdue. Second, the performance analyses can be ported to an online, public application to allow access to anyone in the world with internet access. This open-source application will allow the relaxation of the key constraints in this project to create “what-if” scenarios to demonstrate what would make this project feasible. It also allows the analysis to be applied to farms in other places in Africa to assess the feasibility of irrigation in those areas. Third, working with a global team is challenging and difficult, but not impossible. While this project did not achieve optimal performance of the global team, numerous lessons were learned and documented to help future teams.

Reflections

Working on a global team is a process that is inherently more arduous than normal group work. While this team did not function very well as a global team, numerous lessons were learned by both teams. At the end of the project, both groups of students created a short list of reflections on the project. The NUR students list included the following

- We learned that the teams can get good results from working on the same project in different places
- We learned more about the design process and American culture
- We enjoyed planning and working with the American students and seeing their interest in helping the people in Rwanda
- We did not enjoy how we discussed the financial aspects of the project
- We felt the American students did not distribute all of the information and made decisions without our input
- We also did not feel we did not have the opportunity to use our knowledge from classes and this was because of financial issues and not the fault of the American students

The reflections of the Purdue students included the following:

- International teaming can be difficult and time-consuming
- These types of global projects are not documented very thoroughly and information is difficult to find
- We enjoyed learning about Rwandan culture and engineering
- We also enjoyed researching the project, compiling information from various sources, and applying it to our project
- We did not enjoy addressing the communication issues that arose

- We were slightly frustrated about not having fully discussed the financial issues associated with the project and having to deal with the resulting difficulties later

As with any project, both teams were able to learn from each other from the success and difficulties of the project. This reflecting process also allowed both teams to learn about how each other viewed the same situations and arrived at different conclusions (Please see Appendix E for the full list of reflections from both teams). Overall, both teams enjoyed the project and felt it was a success.

Recommendations

The Purdue students also created a list of recommendations for future work with global teams. These recommendations are targeted toward students working on global teams, but are applicable to anyone working with international teams.

- Clearly define funding right away
- Introduce the team members and discuss goals and expectations during first or second meeting
- Don't assume things – Culture is different
- Ask questions to make sure everyone understands
- Maintain communication at all times with everyone on the team (including advisors)
- Discuss expectations of partner universities/groups
- Don't assume someone understands something just because they nod their head
- Clearly define the leadership structure (including advisors/leadership)
- Help make sure everyone understands how the team structure works and is comfortable with it
- Plan on budgeting extra time at meetings for rephrasing questions and responses
- Discuss the projected project timeline and design process at the beginning and take the time to help everyone understand before progressing
- Be patient!
- Try to anticipate difficulties and plan for them as much as possible
- Be careful making promises/definitive statements at the beginning of the project so as to not mislead people unintentionally
- A better medium of communication is necessary if decisions are going to be made jointly. It is much easier to update a group online than it is to discuss and make a decision online, especially if there is a nontrivial language barrier as there was with our projects

Appendices

Appendix A – GlobalHUB.org Reflections and Comments

During this project, the project team has been using GlobalHUB.org as our online presence and collaboration tool. Since we are one of the first global teams to really use the site for all of our project documentation, part of our responsibility was to assist with the development of this site. The goal we were striving for is that aside from e-mail, this should be the only site that we needed for all of our global team needs.

GlobalHUB has proven itself to be an effective way of documenting and recording progress of our project. The site has made considerable improvements since we first began using it in the fall. The wiki format is a very effective way of recording the documents and allowing all users to easily post information and topics. The public resources are also a very nice way to post our presentations and give people public access to some of our files.

While GlobalHUB has worked well, and most requested changes have been made or are being made, there are still a few things that this group would like to see implemented for the site to be a truly effective tool for a global team. The first major addition is a group calendar and events manager. There is a site-wide events calendar, but it would be nice to have a private calendar of events just for group members. The site-wide is good for announcing public events, but should not have to be used for a group's individual meetings and internal events.

The second feature is a private group file manager. In lieu of a shared private drive, our group made exclusive use of the wiki file attachment feature to store our important documents on the site. As mentioned, Resources are a great tool for making documents permanent and/or public, but they need to be approved by the GlobalHUB team. Also, the wiki now has a file list feature for listing all attached files on a particular page. This is one specific addition that we asked for early on and it is very helpful, but you still need to attach files to a wiki page, remember where that page is, and find the link if you want to use the file on a different page. The private file manager should be a separate section (like Discussion) that would ideally have the ability to upload multiple files, give them a title (one major drawback of the FileIndex wiki macro), and potentially have WebDAV or SFTP access. If this was implemented, another handy feature would be to have access to a file list when editing a wiki page. This would ideally be just below the wiki's file attachment frame. One major concern with this would be how much file space is allotted to each group and if the infrastructure can handle it.

Finally, the biggest addition that the site needs is some form of low-graphics, "low-quality" mode. While the site worked very well for the Purdue members of our

team, working with our teammates in Rwanda was very difficult through GlobalHUB due to their lack of connection speed and bandwidth. Here in the US, and in most of Europe, the high-bandwidth, high-graphics version of the site is fine, but working with more under-developed nations, this becomes an issue very quickly. There were times when our teammates could not even load the site to view something we needed them to review. We tried giving them a workaround to disable the images in their browser, but they should have an option to load a less intensive version of the site.

Appendix B – Pulse Smartpen Reflections and Comments

Since the global team used GlobalHUB as a repository for information, three Purdue members used a special device from Livescribe, called a Pulse Smartpen, to digitize their notes and keep a digital design notebook. This device functions like a standard pen, but is used on dot paper and has a small infrared camera that reads the dots and records the writing. The writing can then be downloaded to the computer through a docking station and the notes viewed and searched on the computer. The pen can also record audio and synchronize the recording with the writing; allowing the user to play back the audio that corresponds to a certain written section. The effectiveness of this device is discussed below by the three members who used it.

Tim Bond

This device has proven itself useful a few times during this project, especially when used during interviews or meetings where not all group members could attend. While there were times that it was useful, I do not think that the device was used to its full extent. There are a few things that would make this device easier to use and would have increased its specific functionality in this group. The first is an option to export to a PDF file directly from the desktop software, especially the option to export the entire workbook. A similar feature is included in the Mac OSX Beta of the software, but Windows users must upload the file to the Livescribe website, and then export it as a PDF. The second would be the inclusion of handwriting to text software. There is an option to purchase this separately, but the group came to the conclusion that this was not worth the extra investment. This would have allowed more notes to be easily converted and posted online.

The device would have been a great tool for the project, and most of the features were there, but there were some key components of our project that really hindered our implementation of the pen. With communications issues between our global teammates, and our extensive use of e-mail and GlobalHUB to record information about our meetings and research, there was not an everyday need for this device.

Erin Potrzebowski

Overall, my thoughts on the Pulse Smartpen are positive. The technology that is used in the pen is very useful when it comes to keeping a record in a notebook type format. The most valuable aspect of the pen was its ability to transfer hand drawings. This is really helpful when it comes to sharing ideas and thoughts with teammates. In engineering, pictures can be much more valuable than words and can really help facilitate team discussions.

I also really liked the pen's ability to record conversations/lectures in addition to taking notes. The playback feature that syncs the audio to the written content is very impressive.

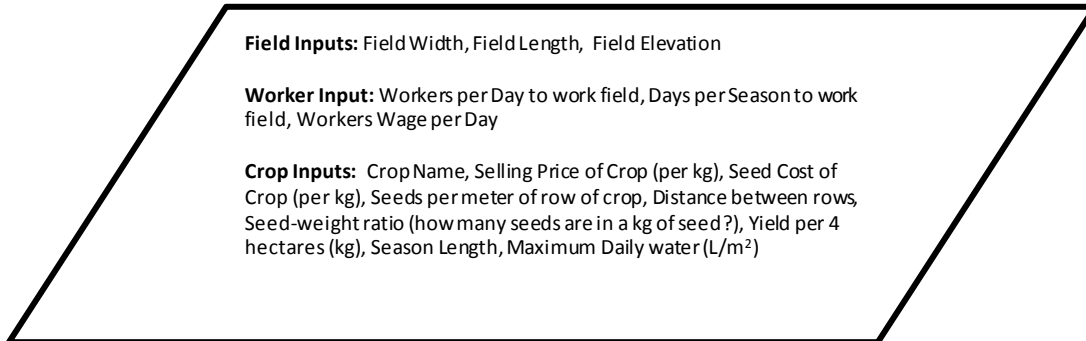
There were a couple of drawbacks to the pen. One, I would really like a flat added to the pen. The Pulse Smartpen has a tendency to roll off every surface, which is kind of annoying. Also, I would like to see the pen made thinner. It's kind of a hefty pen to write regularly with. Also, it would be really useful if there was a quick and easy way to export images to other people that don't have the Livescribe network.

Jeremy Koehler

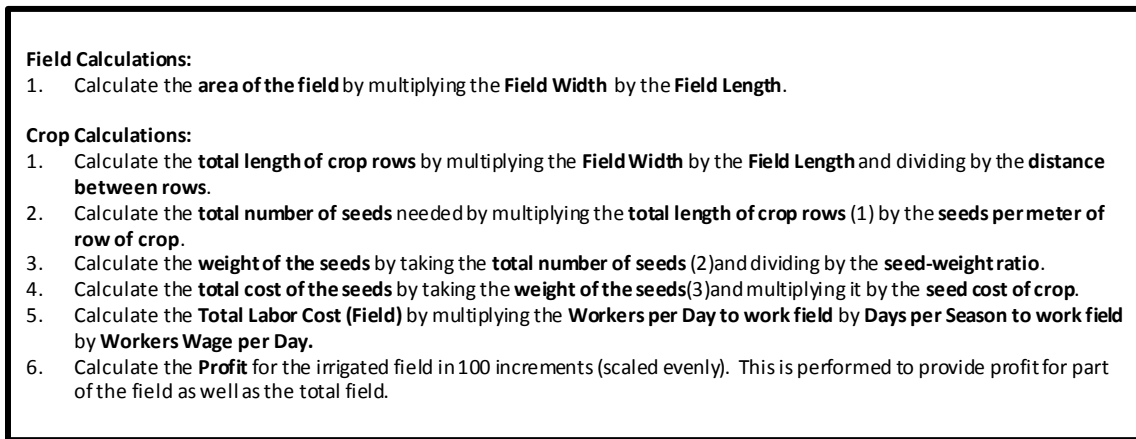
In my opinion, the PulsePen has some advantages, but I do not feel that it was used effectively in this project. We only posted electronic meeting minutes on GlobalHUB once or twice due to the fact that the NUR students did not have the bandwidth to access or download content from GlobalHUB. Since the Purdue students all attended the meetings, it was not necessary to post all of the meeting minutes. We recorded several interviews on the pens, which was very useful. I feel the pen was useful, but not used as effectively as it could be.

Appendix C – Program Pseudocode

Block 1



Block 2



Block 3

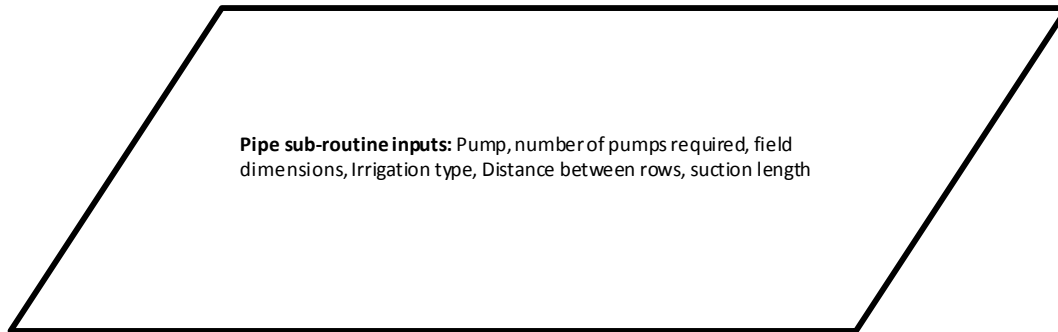
Pump Inputs: Pump name, Pump cost, Fuel consumption, Maximum Head Delivered. Flow rate vs. Head Curve Fit, Inlet/Outlet size



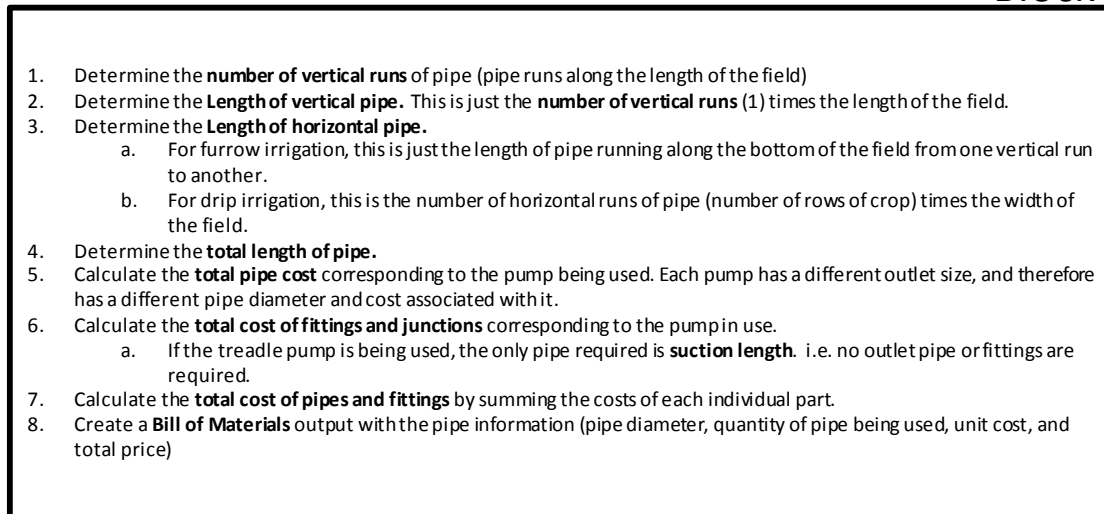
Block 4

1. Calculate the **Area** of the field and the **vertical height change of the field**
2. Calculate the maximum length of the field that the pump can supply based upon the **slope** of the field, the **starting length** of the field, and the **maximum head** delivered by the pump.
3. If the pump can serve more than the whole field, the **maximum length** is set to the length of the field. If the pump cannot serve the whole field the **maximum length** remains the same as the value found in Step 2.
4. The next section is a nested for loop
 - * The outer loop calculates all of the following parameters for different field sizes starting with 0 m² up to the entire field size. This allows the program to provide details about how the system performs with a smaller field.
 - a. The **head** required at each size of the field is calculated based upon the sum of the start elevation and the sine of the slope times the **position of the field** (length being iterated up the field).
 - b. The flow rate at this position is calculated by passing the **head** (a) into the pump performance equation
 - * The inner loop calculates the following parameters for each day of the season. This allows the program to provide details about how the system performs during the season.
 - i. Extract the **daily rain** from the monthly rainfall averages based upon the day
 - ii. Calculate the **amount of water** needed by the crops upon the day of the season
 - iii. Calculate the **amount of irrigation water** needed by subtracting the **daily rain** (i) from the **amount of water** (ii)
 - iv. Calculate the **number of man hours** by dividing the **amount of irrigation water** (iii) by the **flow rate** (b)
 - v. Calculate the **number of workers** needed by dividing the **number of man hours** (iv) by 5 hours and rounding up.
 - vi. Calculate the **labor cost** by multiplying the **number of workers** (v) by the **Workers Wage per Day**.
 - vii. Calculate the **daily cost of fuel** required to run the pump, if a petrol pump is selected, by multiplying the **number of man hours** (iv) by the pumps **fuel consumption** and the **price of fuel**.
 - c. Calculate the **number of pumps** required based upon the maximum **number of workers** (v).
 - d. Calculate the amount of pipe required using the **Pipe subroutine**.
 - e. Record the **cost** of the **pumps, pipes, and fittings** from the subroutine (d).
 - f. Calculate the **Total Operating Cost** by summing the **labor** (vi) and **fuel** (vii) costs of the entire season.
 - g. Calculate the **Total Capital Cost** by summing the **pump, pipe, and fitting** costs.
 - h. Calculate the **Total Cost** of the system by summing the **Operating** (f) and **Capital** (g) cost.
 - i. Scale the **Maximum Profit** based upon the current size of the field
5. The next step is to extrapolate the above results for ten seasons using a for loop with step size of one season from one to ten seasons
 1. Calculate the **Total Cost** of the current season by adding the **Capital Cost** of the system to the **Total Operating Cost** of the previous and current seasons (multiply the **Operating Cost** of one season by the **number of seasons** considered).
 2. Calculate the **Maximum Profit** for the previous and current seasons.
6. Create a **Bill of Materials** output with the Pump information (manufacturer, model number, unit cost, unit counts of units, and total price), Pipe information (pipe dimensions, part numbers, unit costs, unit counts, and total price), and resulting Total Cost of the system.

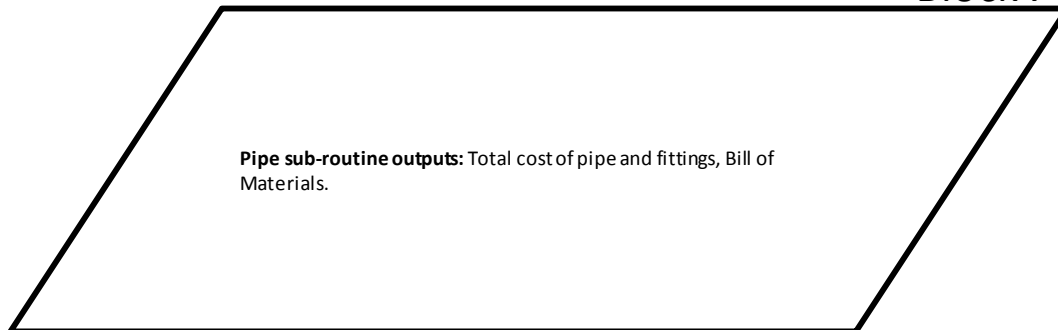
Block 5



Block 6



Block 7



Appendix D – Crop Assumptions and Calculations

The crop and profit calculations were done with the aid of several assumptions. On the assessment trip, the farmers informed us that it took 10 workers a total of 9 days to prepare the 4 hectare field for planting, to plant the field, and to harvest the field when the crop was maize. The first major assumption that was made was that this labor requirement was linearly scalable by size of field. For example, if the field size were to double, the labor requirement would go to 20 workers for 9 days to prepare, plant, and harvest. The second major assumption was that the labor requirements would not change with crop. For example, it would take the same amount of labor to farm tomatoes as it would maize.

The crop calculations used several inputs for each crop. These inputs are listed below:

- Name
- Selling Price of Crop (per kg)
- Seed Cost of Crop (per kg)
- Seeds per meter of row of crop
- Distance between rows
- Seed-weight ratio (how many seeds are in a kg of seed?)
- Yield per 4 hectares (kg)
- Season Length
- Maximum Daily water (L/m²)

Due to the lack of crop information and planting techniques used in Rwanda, many assumptions were made to produce crop input files for a variety of crops. Crop input files originally created were files for maize, tomatoes, beans, and sorghum.

Crop inputs for maize came mostly from information provided by the farmers. The information that the farmers provided included selling price of the crop, seed cost of crop, the yield per 4 hectares, and the season length. Planting specifics for maize came from a summary published by the Food and Agriculture Organization of the United Nations.¹⁵

For all other crop input files (tomatoes, beans, sorghum), market prices came from a July 2008 market price list published by the Rwanda Ministry of Agriculture.¹⁶ The selling price of a crop for a kilogram of product came from the 'actual period' average numbers. The cost of a kilogram of seed cost came from adding 10 frw to the 'actual period' average numbers. This assumption was based on the information about maize provided by the farmers compared to the numbers given in the market price report. It should also be noted that at the time of writing, the July 2008 market price list is the most current data available.

For crop planting data and information, the Food and Agriculture Organization (FAO) of the United Nations website was used once again.¹⁷ In each crop's available report, the inputs of seeds per meter of row of crop, distance between rows, season length, yield per 4 hectares, and maximum daily water use was found. For all numbers, the average of the data provided was used.

One important thing to note is that the yield per 4 hectares for all crops uses an assumption based on the maize numbers provided by the farmers. The yield numbers provided by the FAO are based on ideal commercial yields. Since the actual farms being analyzed are individual, rural farms, these yield numbers do not hold true. The yield numbers provided by the farmers for maize were approximately 10% of the numbers published by the FAO. This 10% factor was thus applied to all other crop yield numbers.

The final information needed for all crops was a seed-weight ratio. This value is the number of seeds per kilogram of seed. This data was compiled from an online gardening website.¹⁸

Appendix E – Lessons Learned/Recommendations

In order to fully document the lessons learned and reflections from each team, a list of questions was answered by both teams. That list is as follows

1. What have you learned?
2. What have you enjoyed?
3. What have you not enjoyed?
4. What areas have you had success in?
5. What areas do you need to make improvements in?
6. What would you do different on future projects?

The following are the unedited responses from the NUR students:

Our experience about the project (gashora irrigation project)

1. In the irrigation project we have learned the way the team can work together the same project at different areas by using internet and get the good results. Secondly we have learned many things about the design process it means that our accounts in that field were increasingly daily in the last four months. Thirdly we have tried to Know more about the American culture .
2. We have enjoyed the way we had planned our work and the commitment the American team was shown us about the project. The American students were interested with African community problems resolution by putting into consideration the community living conditions and we hope will conduct to the sustainable system .
3. We have not enjoyed the way we have discuss about the financial issue ,it has shown us many things in both side (National University of Rwanda and PURDUE) from the first negotiation up to the arrival of Purdue students. It was difficult so our team has taken the last and best decision about that by continuing using their funds in the project and we hope that the sustainable system will be provided to the community. Second think we have not enjoyed with the way the information was been distributed many times the American team take decision without our consideration as their have done to not finish by first may 2009. The last and important think that we have not enjoyed is concern the way we have not get the opportunity to use our Knowledge concern irrigation, design process , topographic survey and CAD program as we have taken it in our curriculum it was not us or American team it was the result of miss financial for facilitating us.

4. We have success in work organisation and the design process even we have not used all of our knowledge about irrigation.
5. We need to improve in some areas like continuing improving Design process and we have realised that we can ask the authorities of our University to introduce in engineering program the special course of design without mixing it in the course. And improve the communication system we use.
6. What we can do different on future projects is good preparation and gathering all information needed before arrival of the team from out of our campus. And make all thinks clear for getting the target by the time preventing confrontation and miss understanding with the teams.
7. We can conclude by giving our thanks to Prof Dan and students from Purdue university mechanical engineering for accepting taking action in the project like this that will be gained by the Rwandan community that they have not know before.

The following are the responses from the Purdue students:

1. We have learned that communication in an international team can be difficult and time-consuming. We have also learned a lot about the timing of a project that includes multiple in multiple locations. Finally, we have learned that with this type of project, research and past work is not typically documented very well and can be hard to locate.
2. We have enjoyed learning about Rwandan culture and engineering practices. We have also enjoyed learning about similar type projects and the different plans of attack for those projects. Overall, we enjoyed the research and work that we put into the project.
3. We have not enjoyed the difficulties in communication between parts of the team. We have also not enjoyed disparities in levels of technology available. We also have not enjoyed the lack of data available in some areas. Also, the pace of the project was at times very slow. It was also frustrating to not have fully discussed the financial aspects of this project.
4. We have had success in the research aspects of this project. We were able to successfully learn about the shortcomings of an irrigation system for a farm during the dry season in Gashora. We were also able to successfully create a model presenting all of the research done. We were also able to identify areas for improvement to make irrigation feasible in the future. We were also able to successfully schedule and attend global meetings on a regular basis.

5. We need to improve in our global teaming communications. The global teaming structure needs to change to include all team members in major decisions. We feel that most of this project was done as separate components of a team, rather than as the team as a whole. We need to improve the flow of information going both ways. This may include making improvements in the method of communication. We believe that one hour weekly G-Chats are not really enough time to adequately give team updates.

6. We would not rely on a website (GlobalHUB) for the sharing of team documents and information. When working with anyone who has poor/unreliable internet connections, it is not reasonable to assume that they will be able to fully understand the content of an entire website. Additionally, more time would need to be set aside for team meetings to ensure that all parties are aware of the project's progress. Finally, both components of a global team need a faculty advisor. As engineering students, this helps the overall team's progress.

Endnotes

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