Spring 2018

Climate Smart Farming for Women in East Africa

Lauren Oliver
Santa Clara University

Cristina Whitworth
Santa Clara University

SANTA CLARA UNIVERSITY

Department of Civil Engineering

I HEREBY RECOMMEND THAT THE SENIOR DESIGN PROJECT
REPORT PREPARED UNDER MY SUPERVISION BY

Lauren Oliver, Cristina Whitworth

ENTITLED

Climate Smart Farming for Women in East Africa

BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF

BACHELOR OF SCIENCE
IN
CIVIL ENGINEERING

6.14.2018

Thesis Advisor — Date

6.14.2018

Acting Department Chair — Date

Climate Smart Farming for Women in East Africa

By

Lauren Oliver, Cristina Whitworth

SENIOR DESIGN PROJECT REPORT

Submitted to
the Department of Civil Engineering

of

SANTA CLARA UNIVERSITY

in partial fulfillment of the requirements
for the degree of
Bachelor of Science in Civil Engineering

Santa Clara, California

2018

ACKNOWLEDGEMENTS

We would like to thank our fearless advisor, Dr. Laura Doyle for her support and guidance. Thank you so much, Dr. Doyle, for dedicating so much of your time and expertise to our project and for travelling with us.

Thank you to the Frugal Innovation Hub, especially Allan Baez-Morales, for helping our project get off the ground and for working with us all year to ensure that things went as smoothly as possible. Thank you for your positive attitude, your hard work, and your dedication to both students and the organizations you work with.

Thank you to Collaborative Enterprise Exchange, especially Annie Power, for introducing us to the women and trusting us with this amazing project. It was a pleasure working with you and having the opportunity to improve the lives of grassroots women all over East Africa.

Finally, we are forever indebted to Comfort, Godliver, Rosemary, and Rose for being the greatest team of women we could have ever imagined working with. You are the strongest, most inspiring women we have ever met. Thank you for working with us, for teaching us, for laughing with us. We will miss you always.

Climate Smart Farming for Women in East Africa

Lauren Oliver, Cristina Whitworth

Department of Civil Engineering
Santa Clara University, Spring 2018

ABSTRACT

According to the United Nations Food and Agriculture Organization, 60% of East Africans live as subsistence farmers. This population is particularly vulnerable to the effects of climate change which has increased the duration and intensity of droughts and floods. Droughts and floods can destroy an entire season's harvest, causing sustenance farmers and their families to struggle for food until the next season. In an attempt to mitigate the severe effects of climate change on these farmers and reduce food insecurity in East Africa, the team has designed a small-scale aquaponic farming system that simultaneously grows fish and vegetables. This system is founded on sustainability, as aquaponics uses significantly less water to grow crops than traditional farming, making it more resilient to both severe droughts and floods, the system also does not rely on external fertilizers, and it uses recycled materials as often as possible.

This aquaponic system was designed for women's collectives in East Africa who requested help in building a portfolio of projects that they can teach to women in rural East Africa. These women's organizations work in rural villages throughout Uganda and Kenya to help local women and their families adapt to the changing climate. Currently, their efforts have been focused on improving the quality and supply of water in the villages by constructing latrines, water filters, and rainwater catchment systems.

During the 2017-2018 academic year, team members designed and built the aquaponic system in Santa Clara, California, then deployed the first prototype in Kampala, Uganda, and trained several of the collective's leaders how to build and operate the system.

TABLE OF CONTENTS

INTRODUCTION

Project Background

In 2015, the United Nations (UN) introduced a series of 17 specific, measurable goals known as the Sustainable Development Goals. The goals were created to "mobilize efforts" to improve the quality of life for people all over the world (United Nations, 2016). Of these goals, Goal 2: Zero Hunger, calls for the end of hunger worldwide. As specified in Target 2.3 of Goal 2, this goal can be achieved, in part, by increasing the agricultural productivity of smallholder farmers in developing countries (East Africa Regional, n.d.).

Target 2.3 focuses specifically on smallholder farmers because in many developing countries, a majority of the population works as famers. In fact, in East Africa, 60% of the 260 million people living in the region rely on agriculture as their primary means of employment (East Africa Regional, n.d.). Despite this fact, a majority of the people in the region, especially those living in rural areas, suffer from malnourishment and food insecurity because their small family farms are highly susceptible to crop failure. As a result, seasonal yields are often minimal and 40% of people in the region are classified as poor (Issala, 2013).

In response to this crisis, the United States Agency for International Development (USAID) Feed the Future team is working with the Comprehensive African Agriculture Development Program (CAADP) to improve agricultural productivity throughout East Africa. By increasing agricultural productivity, more food can be produced to meet the needs of a rapidly growing population and farmers can increase their monthly income. Additionally, because 70% of agricultural workers in East Africa are women, the empowerment and support of farmers is inextricably linked to the empowerment of women (US Government, 2010).

Demonstrated Need for Project

In order to achieve Sustainable Development Goal 2, subsistence farmers in East Africa need a way to farm that is more resilient to both droughts and floods. Currently, women are especially vulnerable to the consequences of these droughts and floods because women are less likely to possess the knowledge and financial capital required to improve their farms. Therefore, women's empowerment and education activities should be prioritized in East Africa in order to increase women's agency and improve communities. The purpose of this project is to do exactly this by providing women community leaders with the training and materials necessary to increase their income and help their families.

Problems Addressed by the Project and Proposed Solutions

This project addressed the following problems facing grassroots East African women by proposing the following solutions, as shown in Table 1.

Table 1: Problems addressed in the Project.

Problem	Solution
Food Insecurity	System can produce high quantity of several types of food
Climate Change Vulnerability	System is resilient to both droughts and floods
Gender Inequality, especially for rural women farmers	System can be constructed by and for grassroots women living in rural areas of Uganda and Kenya

To address these problems and apply the proposed solutions, the team worked with a non-profit organization, Collaborative Enterprise Exchange ("C-Change"). C-Change works with several women's collectives throughout East Africa to support different kinds of women's empowerment activities. These activities are led by C-Changes' leaders, Rosemary Ateino, Rose

Wamalwa, Comfort Hajra, and Godliver Businge. In order to help the women in the collectives, Rosemary, Rose, Comfort, and Godliver travel to rural villages throughout Kenya and Uganda, as shown in Figure 1, training grassroots women how to build water tanks, biosand filters, latrines, and more. By working with C-Change, the SCU team was able to collaborate directly with these leaders to design an integrated farming system that they could train the grassroots women how to build in their villages.

Figure 1: Map of Uganda and Kenya, location of the project deployment.

General Site Details/Description

The first installation and training site is located in Keyanya, a district of Kampala located approximately three miles north of Kampala's city center. In order to train Rosemary, Rose, Comfort, and Godliver, the team met the women at Comfort's home in Kampala and built the first system in her backyard. This system was built in an urban area for training purposes, but future systems will be built in rural villages.

A simple layout of Comfort's backyard is provided, below, in Figure 2. The system was placed directly to the east of the house in order to ensure that plants and fish would receive plenty of sunlight and shade throughout the day. Furthermore, placing the system adjacent to the home's garage allowed the solar components of the system to be placed in a protected space inside while remaining connected to the system via a window into the garage.

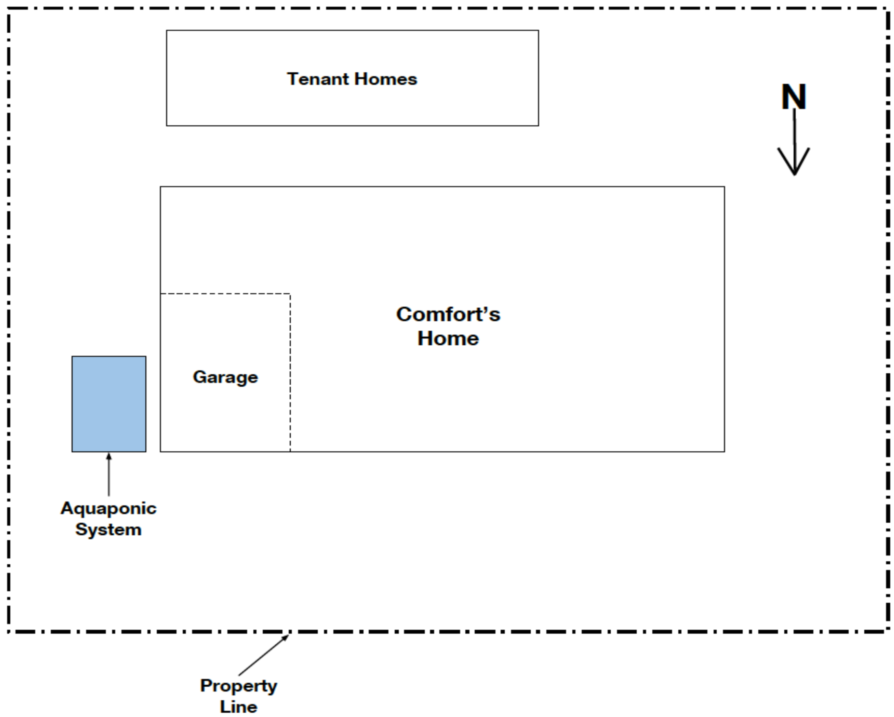


Figure 2: Layout of Comfort's property.

Scope of Work and Organization of Thesis

The main component of this project was the design of an aquaponic system for grassroots women in East Africa to build using locally available materials, allowing the women to raise fish and vegetables together. This system was comprised of a fish tank, flood tank, and two grow beds. After the system was designed, the team built a prototype of the system in Santa Clara's Forge Garden. Building the initial prototype in Santa Clara allowed the team to assess the feasibility of the system using materials like 55-gallon barrels and recycled water bottles, as well as gain practice constructing the system. Additionally, the team used this prototype to learn more about the nutrient cycling process and test different plants. Once this prototype was completed, the team travelled to Comfort's home outside of Kampala to install the first system and train the C-Change leaders how to build the system. The team also made several adjustments to the system based on available materials and the women's feedback.

This report will provide more information about the design process, both in Santa Clara and Uganda. This report will first explain the initial design process and how the system was designed after extensive research into current farming methods and aquaponic systems, then explain the various components of the chosen design and the feasibility. Finally, the report concludes with a discussion of how the chosen design met the needs of the grassroots women and how the system will be replicated in the future.

ANALYSIS OF ALTERNATIVES

The team members were originally challenged with designing a system that could incorporate fish, chickens, and plants while using significantly less water than traditional farming. Additionally, the women needed an affordable design that could be built in rural areas of Kenya and Uganda using locally available materials. The women also repeatedly specified that the prototype design should be "as small as possible," but scalable so that a woman could expand their system if she has the space and means to do so.

To determine the best design for the women, team members first researched and compared different kinds of farming methods, then, after choosing to work with aquaponics, compared different types of aquaponic systems. The following sections will first explain why the team chose to design an aquaponic system, then why the team members chose to design a media-based aquaponic system.

Comparison of Farming Techniques

Brief Description of Alternative Solutions

Team members researched three types of farming techniques for East Africa: traditional farming, drip irrigation, and aquaponics.

1. *Traditional Farming Methods*

   A majority of farmers in East Africa rely on traditional farming methods to grow crops on their land. These methods involve tilling soil, then planting seeds in neat rows, then relying on seasonal rainfall to water the crops. Crops typically grow well in Uganda and Kenya because both countries are located on the Equator. In this tropical zone, crops receive sufficient rainfall and sunlight during normal weather years. Farmers who utilize these farming methods, however, are ill-equipped to adjust to the effects of climate change as both floods and droughts have become more frequent and severe in recent years. Both droughts and floods can destroy crops by causing the soil to be too dry or too moist, respectively.

2. *Drip-Irrigation*

   Farmers in both the developing and the developed world rely on drip-irrigation to reduce water use in farming. Drip-irrigation prevents water waste by installing small-diameter pipes (10 - 20 mm) into the ground and delivering water directly to the roots of each plant. Unlike traditional sprinkler irrigation, water loss is minimal because the plant roots can easily access the water from the drip lines and the water does not evaporate into the air while it is being released.

   While drip irrigation is highly effective during times of drought, this type of irrigation does not protect crops from flooding. Furthermore, the installation price of these types of systems is often too high for rural, impoverished farmers (Issala, 2013).

3. *Aquaponics*

Instead of relying on soil to provide essential nutrients and support to plants, aquaponic systems grow plants in nutrient-rich water and allow for the incorporation of fish into the system. These types of systems typically operate as closed-loop systems with minimal water loss, allowing the plants and fish to be grown using up to 90% less water than traditional farming methods. Furthermore, these systems are typically operated as closed-loop systems, connecting the fish tank to plant grow beds. By doing so, fish provide nutrients to the plants and the plants act as a water filter for the fish. This symbiotic relationship between the fish and the plants reduces the need for costly commercial fertilizer and makes the system more sustainable.

Comparison of Alternatives

When comparing design alternatives, team members were most concerned with choosing a system that would be water efficient, "climate-smart" (resilient to droughts and floods) and allow for the integration of fish into the system. Based on these criteria, the system will be able to minimize inputs while maximizing yields. To choose the best design alternative, team members considered the following advantages and disadvantages of each system in terms of the following criteria provided in Table 2:

Table 2: Comparison of Alternative Irrigation Techniques.

	Traditional Farming	Drip-Irrigation	Aquaponics
Water-efficient	x	✓	✓
Climate Smart	x	x	✓
Can incorporate fish into the system	x	x	✓

Final Logic used to Select Solution

Team members chose to proceed with the design of an aquaponic solution primarily because it was the only solution that allowed for the incorporation of fish into the system. The clients stressed the importance of designing an integrated, water efficient system for fish and vegetables, and an aquaponic system best meets this criteria.

Comparison of Aquaponic Systems

Brief Description of Alternative Solutions

After deciding to proceed with the design of an aquaponic system, team members researched and compared the three types of aquaponic systems: nutrient-film, media-filled, and raft systems.

1. *Nutrient Film Technique (NFT)*

In a nutrient-film system, plants are grown in long tubes with holes cut out for each plant (Bernstein 2011), as shown in Figure 3 to the right. Each plant is supported by a net placed into each hole which allows water to pass through the tubes and into the nets of the plants where the plant roots can absorb the nutrient-rich water. This system requires that water is

Figure 3: Nutrient Film Technique.

constantly pumped through the plant tubes and into a fish tank, where a separate biofilter is installed and the water can be recycled.

2. *Media-Filled Beds*

A media-filled bed system is most similar to traditional farming methods because plants are grown in a growing media such as clay pebbles or small gravel, as seen in Figure 4. This soil provides support to the seeds and plants, but still allows water to flow through the pores of the media. In this system, the nutrient-rich water is allowed to flood and drain the grow beds. The water from the grow beds is then drained into the fish tank, before it is pumped into the grow beds again. Unlike nutrient-film or raft systems, media-filled beds do not require an additional water filter because a layer of bacteria grows on the media and filters the water naturally and the system can support nearly any type of plant.

Figure 4: Media-filled Beds.

3. *Raft*

In a raft system, plants are suspended by a floating raft on top of nutrient rich water, as shown in Figure 5 (Bernstein 2011). Like the nutrient-film system, holes are cut in the raft and plants sit in nets that allow the nutrient-rich water to flow in and out of the nets. Raft systems can be expanded easily to support more plants because additional rafts can be added or more plants added to each raft. This

Figure 5: Raft System.

method works very well for growing vegetables like lettuce or herbs, but cannot support root vegetables like onions or potatoes.

Comparison of Alternatives

To determine the best type of aquaponic system for the clients, team members compared the advantages and disadvantages of the systems according the following criteria: simplicity, whether or not the system requires an additional filter to be installed, the scalability of the system, and the variety of plants that the system can support. Results of this comparison are shown below in Table 3.

Table 3: Comparison of Different Aquaponic Techniques.

	NFT	Media-Filled Bed	Raft
Simplicity	x	✓	✓
Requires a filter?	Yes	No	Yes
Scalable	x	x	✓
Plant Choices	x	✓	x

Final Logic used to Select Solution

After analyzing these advantages and disadvantages and reviewing the clients' needs, team members chose to design a media-filled aquaponic system. Not only is this type of system the simplest to operate, but this system is also the cheapest because it does not require an additional filter to be installed in the fish tank. Additionally, this type of system can grow nearly any kind of plant. This was important for the women because they are accustomed to eating various types of root vegetables which only a media-filled bed can grow.

DESIGN CRITERIA AND STANDARDS

Identification of System/Process Performance Requirements

In any aquaponic system, users must establish a healthy balance between the fish, plants, and bacteria in the system. This balance is established when all components of the system meet certain performance requirements, shown below in Table 4.

Table 4: Requirements and Purpose of Each Component in the System.

Component	Requirement (Bernstein, 2011)	Purpose
Container Volume	1:1 Ratio between grow beds and fish tank	A 1:1 ratio between the fish tank and grow beds ensures that (1) enough nutrients are generated by the fish for the plants and (2) there are enough plants to filter the water returning to the fish.
pH	6.8-7.6	Plants, fish, and bacteria grow best in pH neutral environments but most can tolerate a pH slightly above or below 7.0.
Growing Media	pH neutral	A growing media with a high pH value (i.e. limestone) could leach unwanted chemicals into the water and raise or lower the pH of the system above or below tolerable levels.
	12-18 mm dia.	Growing media must be small enough to protect plant seeds from washing away and support plant roots when seeds begin sprouting, but large enough to allow water to flow easily through the system.
Flow Rate	Fish tank volume cycle 2x/hr	Cycling the volume of the fish tank 2x/hr allows the water to be sufficiently oxygenated for the fish and allows the plants to receive ample nutrients.

Flow Cycle	Grow beds must be flooded and drained	Water should not be constantly filling and draining the grow beds. Instead, the grow beds should be rapidly flooded several times every hour, allowing the water level in the grow beds to rise to 1" below the surface of the growing media. This process ensures that both the plant roots and fish receive enough oxygen.

Identification of Applicable Codes and Standards

Aquaponics is a relatively new technology, developed in the last decade. Although the technology is growing in commercial use and popularity, design codes have not yet been written to regulate system design and operation. Instead, team members used several design manuals written for home growers to guide their design. Specifically, team members relied on Sylvia Bernstein's *Aquaponic Gardening: a Step-by-Step Guide to Raising Vegetables and Fish Together,* for explanations of the different types of aquaponic techniques and the requirements that each design should satisfy. Additionally, team members studied Travis Hughey's "Barrel-ponics" guide to understand how aquaponic systems can be built frugally and sustainably in developing countries.

Identification of Key Values and Assumptions Used in Design Calculations

When designing a system to meet the needs of grassroots women in Uganda and Kenya, team members first assumed the available water would be free of any harmful chemicals. In an aquaponic system, the water added to the system does not need to meet the requirements of drinking water because (1) the water is consumed only by the fish and plants and (2) the plants and bacteria in the system act as a natural water filter. Team members also assumed that the pH of the water added to the system would be close to neutral (6.5-7.5), allowing the water to be added directly to the system without requiring pre-treatment to neutralize the water. In fact, the pH of the municipal water supply available at Comfort's home is more neutral (pH 7.2) than the Santa Clara municipal tap water (pH 7.6) used in the prototype system.

Next, team members assumed that any losses due to friction and fittings in the pipes would be negligible. The total length of all of the pipes in the system was approximately 12 feet and all pipes were composed of smooth plastic (Hazen-Williams C-Value: 140-150). Additionally, nine (9) ninety-degree (90°) pipe elbow fittings were used throughout the system. All pipe fittings were made of a smooth PVC pipe (Hazen-Williams C-Value: 150). No adjustments were, therefore, made in flow calculations to account for losses due to friction or fittings.

DESCRIPTION OF DESIGNED FACILITY

Summary of Design Approach

The design process for this project was slightly more challenging having to produce a design for clients who lived in a developing country they were unfamiliar with. In order to mitigate these challenges the team first researched common farming methods in both the United States and East Africa, as well as alternative techniques. This allowed the team to compare several different methods and establish the best technique to proceed with their design. For example, soil-based irrigation techniques are most commonly used in East Africa, however these systems heavily rely on water which can be extremely scare or expensive during long drought periods. This has caused many crops to be completely destroyed, leaving the farmers and their communities hungry for the season. Hydroponics, a soilless farming technique, is an alternative irrigation technique that is more technical, however it can use 90% less water than typical soil-based irrigation techniques because the water is able to be recaptured and recycled in a closed-loop. This technique would allow the system to be much more water efficient than the current techniques used in East Africa. Hydroponics, however, requires an additional large application of fertilizer such as liquid seaweed. In order to combat this issue, the design team processed with an aquaponic-design, which is a further development of hydroponics that allows fish to be incorporated into the system, which provide a natural form of fertilizer.

After deciding on aquaponics, the team attempted to determine the available materials that could be used to design the system. It was hard to keep strong communication with our clients prior to going to East Africa, so they relied on what they could find on the internet and focused on using simple and recycled materials they believed would be available. It was important they knew how to design each component of the system using different materials in case the were unable to find certain materials when in Uganda. For example, the initial design of the foundation of the system is made of wood, however, a week before going the third-party contact from C-Change claimed that wood would not be available in Uganda. The team thought of other ways to design the base with alternative materials such as clay bricks, however, when the team arrived to Uganda they realized that woods was an extremely popular building material and they did not have to make any redesigns to that component. The prototype system was built using simple available materials, however, the team did redesign some components in order to simplify them for the system that would be deployed in Uganda. Figure # illustrates this design process.

Figure 6: Design Approach.

Detailed Design Results

The designed system consisted of three major components: the fish tank, the grow beds, and the flood tank. The red arrows in Figure 7 illustrate the waterflow of the system.

Figure 7: Prototype in Santa Clara Forge Garden, red arrows illustrate the water flow.

When selecting the materials for the system, the team considered affordability and availability above all else. Recycled blue food-grade 55-gallon barrels were used as the containers for each component. These containers were available both in the US and in Uganda, which allowed the design team to easily find inexpensive recycled barrels to use in both locations.

The ideal growing media for aquaponic systems are clay pellets, as they meet the criteria previously given in Table 4. They are also extremely lightweight. Unfortunately, these pellets were not available in Uganda, which caused the team to reevaluate and select a combination of available growing bed media in order to meet the needs of the system. A mix of large and small pH neutral rocks were combined by having a layer of the large rocks at the base of the grow beds with a layer of the smaller rocks overlayed on top. This layering of the rocks allowed the grow beds to continue to have a similar void ratio to the system if the clay pellets were used. This void ratio was essential when calculating the amount of water that was required to flow into the grow beds each cycle to reach an ideal water level in order for the plants to receive the required nutrients.

A 12V DC pump was selected to deliver the water from the fish tank to the flood tank at a constant rate of 140 gallons/hr at seven ft (7') of head. From there, a variety of PVC pipes and fittings were used to direct the water flow into the grow beds and then back into the fish tank. A water flow analysis was done on the system in order to purchase the appropriate pump and install the appropriate pipe sizes per attachment that would allow the waterflow in the system to meet the needs of the aquaponic system. This flow analysis can be found in Appendix… By using a stacked design, the system only requires one small pump and then relies on gravity for the remaining flow.

Special Features and Innovations

One special feature of the climate smart farming system was the flusher and mechanical timer in the flood tank. These apparatuses established a flood-and-drain water cycle, which allowed the water in the grow beds to fill with the appropriate level of water and then fully drain. This process allows the water to be sufficiently oxygenated through the turbulence created when flowing through the growing media, which is extremely important for a healthy environment for the fish and plants. In order to establish a strong flood-and-drain process for the grow beds, a typical two inch (2”) flush valve, shown in Figure 8, was used in the flood tank in order to hold water in the flood tank until a certain volume of water, before being released into the grow beds. The flushing system was done by connecting the flush valve to a water triggered counterweight that only began to fill once the water level reached a certain height in the flood tank. The desired maximum height in the flood tank was derived by calculating the total volume of water required to fill the grow beds where the water would reach 1 inch (1”) below the surface of the growing media. For this specific design with the 55-gallon barrels and a 40% void ratio in the grow beds with the growing-media, the desired volume the flood tank would reach was 20 gallons. This flow of water allowed the water in the flood tank to reach that volume before triggering the flush valve to open and causing the water to rush through the PVC pipes and into the grow beds. Once the flood tank begins to drain, the counterweight also begins to drain, and once the bottle and flood tank empties, the flush valve closes again, restarting the cycle. This entire process takes approximately 10 minutes and allows for the water to reach the desired level of approximately 1 inch (1”) below the top of the growing media, which is ideal for the plants to receive the necessary nutrients in the water.

Another complexity of the aquaponic farming system is the relationship between the fish and the plants. This relationship is founded on the nitrogen cycle (see Figure …), which allows the fish and plants to establish a beneficial environment where no additional filtration of fertilizer is required. This balancing act is done through a conversion of nutrients. Fish emit ammonia similarly to how humans emit carbon dioxide; a build-up of ammonia in the water is toxic to fish. When the system is first started, a biofilter is established in the grow beds as two types of bacteria--nitrosomonas and nitrobacter--grow on the surface of the growing media. This process is termed "cycling". Together, this bacteria converts the ammonia first into nitrite, then into nitrate. Nitrate is essential to plant growth but at extremely high levels it can be harmful to fish; the plants absorb this nutrient and act as a filter for the water before returning to the fish tank where the cycle begins again. Figure 8 is a simple diagram illustrating this process.

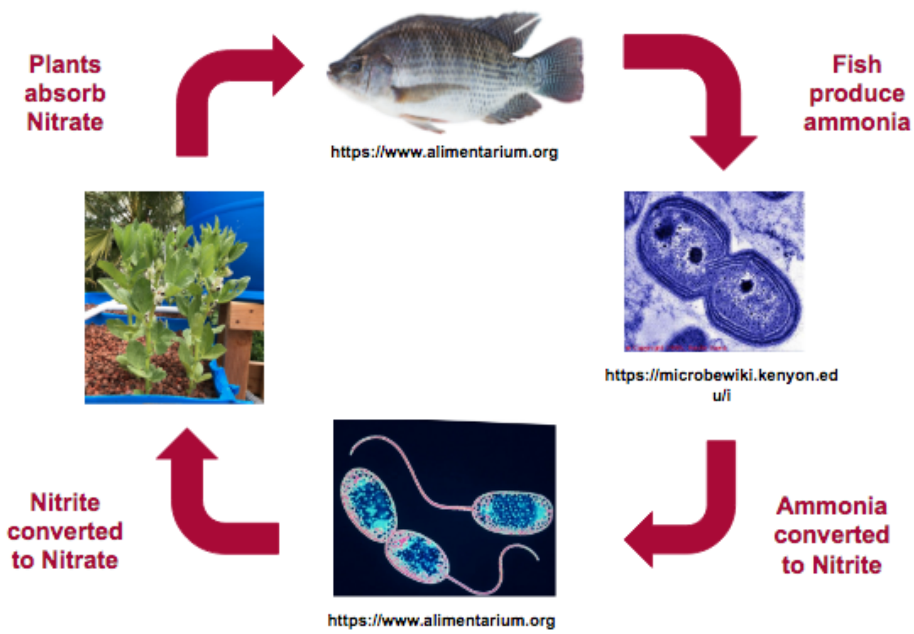


Figure 8: Nitrogen Cycle in an Aquaponic System.

This cycle allows for the water in the system to be constantly recaptured and recycled due to the Nitrogen cycle establishing a healthy equilibrium for both the fish and the plants. This process is how aquaponics is able to use approximately 90% less water than other typical farming techniques and does not require additional fertilizer.

Site-Specific Problem Solutions

The design team came across several challenges during both the design and deployment phases of the project in East Africa. Table 5 summarizes the challenges and creative solutions the team encountered and solved.

Table 5: Site Specific Problems and Solutions.

Problem	Solution
Limited Communication and direction from the clients before arriving in Uganda.	● The design team was able to design a product on a vague "big idea" through educated assumptions when they were unable to receive a response from the clients. ● The team led a workshop during their first day in Uganda in order to share the prototype system and receive feedback from the clients on the system before construction to ensure the system fully addressed their needs. ● Team was prepared to redesign onsite if necessary, however, the clients were eager to proceed with the design.
Limited access to building materials in Uganda, such as necessary drill bits and the toilet flusher made it difficult to proceed with the design.	● This issue is why the team focused on designing a system using materials that would theoretically be available in the area. ● The clients and design team were able to find all the required materials for this implementation and discussed alternative methods to build each component and they also encouraged the clients to purchase the harder materials to find ahead of time from in town where there is greater accessibility to tools and materials.
Limited building materials caused holes for the PVC pipes to not be cut perfectly, causing several large leaks.	● After relentless attempts to fix the leaks using the limited plumbing experience within the team, a local plumber was called and he showed the team how to solve these issues with washers and a thick layer of thread seal tape (PTFE tape).

Permitting, Political and Safety Issues

Due to East Africa having a known food insecurity issue, there are multiple programs and agencies, such as the United States Agency for International Development (USAID), that are encouraging advancements in agricultural technologies. USAID's Feed the Future team is working with the Comprehensive African Agriculture Development Program (CAADP) to improve agricultural productivity (US Government, 2010). Due to this severe and well documented issue, the project was extremely well received by the clients and East African locals, which was important in order for the project to succeed.

Social/Environmental Justice Concerns Addressed

The Climate Smart Farming project addressed a number of social concerns, including food insecurity due to climate change vulnerability and gender inequality.

In East Africa, approximately 60% of the 260 million people living in the region rely on agriculture as their primary means of employment (East Africa Regional, n.d.). In spite of this fact, a majority of the people in the region, especially those living in rural areas, suffer from malnourishment and food insecurity because their small family farms are highly susceptible to crop failure. As a result, seasonal yields are often minimal and 40% of people in the region are classified as poor (Issala, 2013). The system presented focused on allowing these struggling farmers to be able to farm, despite the influence of climate change. The Climate Smart Farming system emphasized the recapturing and recycling of water, allowing the system to use significantly less water than typical irrigation techniques and the integration of fish raising reduced the need of external nutrients.

The project also had a large focus on women empowerment. The clients want to create a hub for grassroot women where they can learn about different kinds of climate smart technologies. This hub, the Women's Climate Change Education and Training hub will be a place where the leaders will provide training programs on different types of technologies and provide loans and additional resources for rural women who wish to implement these systems in their homes. The climate-smart farming system will be one of the many technologies that is offered to these rural women.

COST ESTIMATE

Engineer's Opinion of Probable Cost

One of the major constraints of this project was the budget. The deployment of the project had sufficient funding through grants and donations. Moving forward the product will be replicated throughout East Africa using the limited financial resources of the client, therefore, it was crucial the design team meet the client's budget needs. Unfortunately, the team never received clear guidance on the desired cost range, which caused several risks when trying to proceed with the design without confirmation from the clients.

The team focused on using recycled and reusable material in order to minimize the costs. The prototype built in the United States cost $1063 for all the materials, excluding the costs of power and water. The team knew that similar materials were available in Uganda, therefore this was not an accurate representation of the system's cost. Figure 9 represents the cost break down of the prototype system.

Wood	$80
Barrels	$285
Misc. Building Materials	$342
Pipes	$356
TOTAL	**$1063**

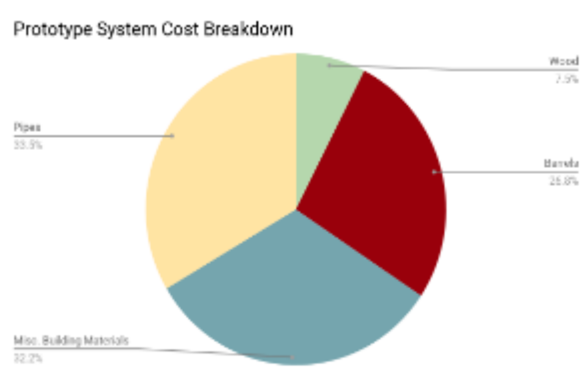


Figure 9: Protype Cost Breakdown.

The material costs once in Uganda were much more affordable, resulting in a total cost of approximately $219 compared to the $1063. In order to account for the common unpredictable electrical outages, the team decided to power the water pumps required in the system using solar power. The design team purchased solar panels, batteries, and hire electrical technicians to install and connect the components, however, this caused the total cost of the system to raise by more than $800. The total cost of the system was $1030. Figure 10 illustrates the cost breakdown of the system in Uganda.

Wood	$20
Barrels	$60
Misc. Building Materials	$35
Pipes	$104
Solar	$811
TOTAL	**$1030**

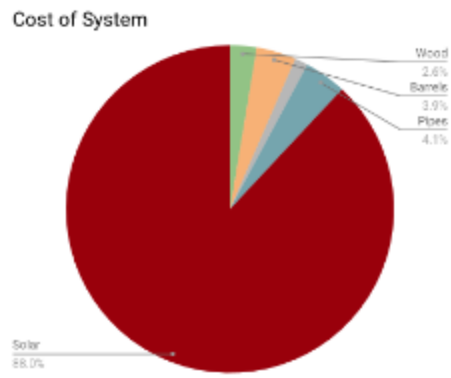


Figure 10: Uganda Cost Breakdown.

CONCLUSION

Although the system design satisfies all project goals, the team members ultimately concluded that the proposed design is not yet feasible for grassroots women. When initially evaluating the needs of the women and the goal of the project, team members assumed that materials in Uganda and Kenya would be relatively inexpensive and that the total cost of the system would not present a major issue. Additionally, team members assumed that total energy demand of the system would be relatively low with a 12 Watt pump and that energy costs would be minimal. In fact, the solar components of the system accounted for approximately 80% of the total cost of the system and the system cost the team members $1030 to install. Initially, the team members hoped that the profits earned from the sale of the fish and vegetables from the first system could be used to fund the next. In Uganda and Kenya, however, fish and vegetables sell for only a few dollars each and as a result, it is not likely that the designed system will pay for itself.

Based on this conclusion, the team members deemed the solar components of the proposed design to be cost prohibitive. To improve the design and ensure that future iterations of the design are economically feasible, engineers should consider how to reduce the total energy demands of the system or consider an alternative source of sustainable energy that is not as expensive as solar. The solar components installed on the deployed system in Uganda are both durable and sustainable, but not feasible.

The detailed design described, however, does sufficiently satisfy the original goals of the project stated in the Introduction and addresses the needs of the grassroots women. The original needs and the solution provided by the design are summarized below in Table 6.

Table 6: Problems Addressed during the Project.

Problem	**Satisfied?**	**Solution**
Food Insecurity	Yes	System designed to raise both fish and vegetables
Climate Change Vulnerability	Yes	System designed to use 90% less water than traditional, soil-based farming methods and cycle water in a closed-loop system
Gender Inequality, especially for rural women farmers	Yes	Training designed for grassroots women in East Africa

Most importantly, the clients were satisfied by the results of the project. The cost of the system was much greater than expected, but the system installed on Comfort's property has been supporting both healthy fish and plant growth since team members left. The women are excited about the potential of the project and are looking forward to replicating the systems in the future.

APPENDIX A: REFERNCES

Africa: Eastern Region [Digital Image]. (n.d.). Retrieved November 29, 2017, from https://www.mapsofworld.com/africa/regions/eastern-africa-map.html

Awad, Y. M., Lee, S., Ahmed, M. M., Vu, N. T., Farooq, M., Kim, I. S., & ... Ok, Y. S. (2017). Biochar, a potential hydroponic growth substrate, enhances the nutritional status and growth of leafy vegetables. *Journal Of Cleaner Production*, *156*581-588. doi:10.1016/j.jclepro.2017.04.070

Barth, B. (2015, July 2). Irrigation 101 [Digital image]. Retrieved November 25, 2017, from https://modernfarmer.com/2015/07/irrigation-101/

Bernstein, Sylvia. *Aquaponic Gardening: a Step-by-Step Guide to Raising Vegetables and Fish Together*. New Society Publishers, 2011.

Best Hydroponic Systems for Getting Started with Indoor Gardening [Digital image]. (2017, March 24). Retrieved November 24, 2017, from https://www.hobbyjump.com/best-hydroponic-systems/

Brennan, D. (2008). Factors affecting the economic benefits of sprinkler uniformity and their implications for irrigation water use. *Irrigation Science, 26*(2), 109-119. doi:http://dx.doi.org.libproxy.scu.edu/10.1007/s00271-007-0077-9

Chu, J. (2017, April 4). New design cuts costs, energy needs for drip irrigation, bringing the systems within reach for more farmers [Digital image]. Retrieved November 29, 2017, from https://phys.org/news/2017-04-energy-needsfor-irrigation-systemswithin farmers.html

Collaborative Enterprise Exchange. (n.d.). "About ." *C Change*. Retrieved 2018, from https://www.ceechange.org

Goal 2 : Sustainable Development Knowledge Platform. (2016). Retrieved 2017, from https://sustainabledevelopment.un.org/sdg2

Issala, B. (Ed.). (2013). African agriculture, transformation and outlook. *New Partnershipfor African Development*. Retrieved October 17, 2017, from http://www.un.org/en/africa/osaa/pdf/pubs/2013africanagricultures.pdf

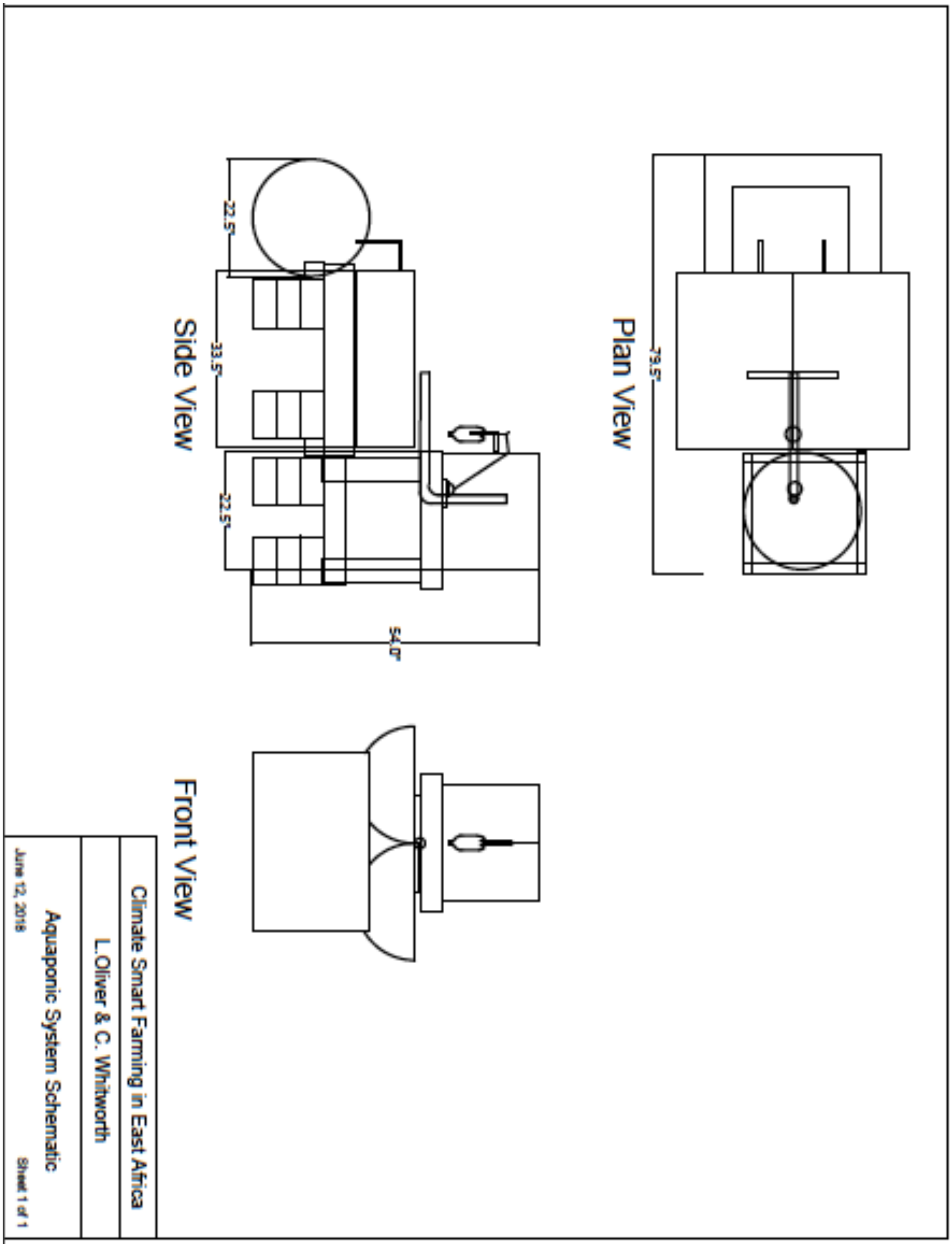
Pillay, T. (1979). ADCP/REP/79/10 - Aquaculture Development in China. Retrieved November 13, 2017

Shoji, K. (1977). Drip Irrigation. *Scientific American, 237*(5), 62-69. Retrieved from http://www.jstor.org.libproxy.scu.edu/stable/24953919

US Government. (2010). *EAST AFRICA FY 2011–2015 Multi-Year Strategy* (pp. 7-16) (United States, USAID)

United Nations. (2016). United Nations sustainable development agenda. Retrieve 2017, from http://www.un.org/sustainabledevelopment/development-agenda/

APPENDIX B: CAD DRAWING



APPENDIX C: FLOW ANALYSIS

$$Grow\ Bed\ Lentgth = 30\ in$$

$$Grow\ Bed\ Width = 20\ in$$

$$Grow\ Bed\ Volume = 25\ gal$$

$$Pore\ Volume = 60\%$$

$$Grow\ Bed\ Width = 20\ in$$

$$\boldsymbol{Water\ Volume = 60\left(\frac{1\text{-}25}{100}\right) = 10\ gal}$$

$$Grow\ Bed\ Water\ Volume = 10\ gallons$$

$$\#\ of\ beds = 2$$

$$Fish\ Tank\ Vol. = 50\ gallons$$

$$\boldsymbol{Water\ Pump\ Requirement = 10 * 2 * 50 * \left(2\frac{cycles}{hr}\right) = 140\ gal/hr}$$

$$Fish\ feed\ rates = 50\frac{\frac{g}{m^2}}{day}$$

$$Growing\ Space = 20\ in * 30\ in * 0.000645 = 0.387\ m^2$$

$$Fish\ feed\ required = 50\frac{\frac{g}{m^2}}{day} * 0.387\ m^2 = 19.35 g/day$$

$$Fish = \frac{19.35}{10} = 1.935\ kg$$