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Rainwater Capture and Purification System for Rural Tanzania

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

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ENTITLED

Rainwater Capture and Purification System for Rural Tanzania

BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
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Rainwater Capture and Purification System for Rural Tanzania

By

Audrey Gozali, Nathan Miyashiro, Matthew Sasaki

SENIOR DESIGN PROJECT REPORT

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Rainwater Capture and Purification System for Rural Tanzania

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Abstract

The project was a rainwater capture and purification system for the Buturi community in rural northwestern Tanzania. Recent research indicates the northwestern communities in Tanzania will suffer greatly under the effects of climate change. Using this demonstrated need as impetus, the project created a long-term solution for water accessibility in a community of 57,000 villagers who currently live in extreme poverty. The team visited the Buturi community from March 24 to April 7, 2018 to install the project in the main village, the Makongoro village. The project installation took place at the Buturi Primary School and Community Center. Workshops with local villagers took place to teach and explain how the system works and what maintenance is required. The rainwater capture and purification system should last for approximately 50 years with regular maintenance.

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Introduction

Project Description

This project entailed the design and implementation of a rainwater harvesting and purification system for a small rural community in Northwest Tanzania. The community, called Buturi, consists of six villages located near Lake Victoria as shown in Figure 1. The current population is 57,000 and is comprised of subsistence farmers and fishermen. Like many small developing communities, the Buturi community has limited access to nearby water sources, especially water sources that are clean and safe for drinking (World Health Organization, 2018). This project aimed to provide an additional source of water, both potable and nonpotable for this community that is scalable for homes.

Figure 1. Location of Buturi community in relation to the continent of Africa.

The implementation of this system occurred from March 24, 2018 through April 7, 2018. During that time, the design team visited the Buturi community and installed gutters and rainwater storage and filtration facilities at a central location for the village—the local school. Displayed in Figures 2 and 3, the school has three classrooms and a separate facility for toilets. Two 5000 liter (L) tanks with an attached water purification system serves the school building, and one 5000 liter tank of nonpotable rainwater serves as flushing water for the toilet facilities. Two additional 5000 liter tanks will be attached to the school once more classrooms are constructed on the premises.

Figure 2. Buturi Primary School and Community Center where construction took place.

Figure 3. Bathroom facility for schoolchildren at Buturi Primary School and Community Center.

While the team was at the site, water quality testing was performed on the two water sources currently used in the community. These sources include low-lying retention ponds that pool and flood during the heavy rain season and a borehole near the school. An assessment of the water quality was necessary to establish the needs of the community. The test results indicated the presence of fecal coliform bacteria in both sources of water. The presence of fecal coliform indicates that the community is at risk for typhoid fever, viral and bacterial gastroenteritis and hepatitis A (“Fecal Coliform as an Indicator Organism”, 2003). See Table 1, below, for the results of the water quality testing conducted at the two sources of water for the Buturi community.

Table 1: Water quality testing of the Buturi community borehole and one of the retention ponds.

	Borehole	Pond	World Health Organization Standards
Coliform	YES	YES	NO
pH	7	6	7.0 - 8.5
Turbidity, JTU	10	100	5

The Buturi Project

The Buturi Project is a non-profit organization that works to address the worst effects of extreme poverty in the Buturi region of Tanzania. The Buturi Project introduces and integrates self-sustaining programs and provides tools for future sustainability to encourage and strengthen the bonds within the community. These programs include creating a school for children in the village to attend, installing solar panels to power small appliances, and creating a clinic in which doctors can operate (The Buturi Project, 2015). The Buturi Project is a registered charity in both the United States of America and the United Kingdom and was founded by Judith Smith in 2009. Mrs. Smith grew up in Tanzania and has been able to form a wide network within the country through her father's connections as a land developer.

Project Location

The Buturi area is located within the Rorya District in the Mara Region off the shore of Lake Victoria as depicted in Figure 1. Work was conducted within the Makongoro village. The Makongoro village is the largest of the six villages within the Buturi Region and acts as the exemplar village that The Buturi Project focuses its projects on. Through the implementation of projects in the Makongoro Village, The Buturi Project is able to evaluate the performance of programs, as discussed above, and determine whether these same projects can be implemented in the five other villages.

The school on which this design was built is approximately half of a mile from where the majority of the community lives.

Demonstrated Need for Project

The project, in line with The Buturi Project's mission and the United Nations Sustainability Goals, introduced a self-sustaining, accessible water system for the community (United Nations, 2018). The current issues that can be remedied through an accessible point of water include early degenerative changes in bone and soft tissues and musculoskeletal disorders from head holding water for miles every day (Geere et al., 2010). Women and children generally fetch the water, and the time spent carrying the water results in the lack of time for education for many women and children. Furthermore, the project extends beyond water accessibility by providing a means of sanitation and purification. For up to 50 years, clean drinking water can be achieved through the filtration of at most 10,000 liters with proper operation and maintenance. Currently in the Buturi community, the method of obtaining clean drinking water is through boiling contaminated water. While boiling water is highly effective for water treatment, the method of boiling water is unsafe ("A Guide to Drinking Water Treatment and Sanitation for Backcountry & Travel Use", 2009). In the Buturi community, fires composed of local wood are burned in poorly ventilated huts to boil the water. The lack of ventilation is extremely detrimental to the lungs of the many women and children who cook for their families everyday (White and Sandler, 2017). Additionally, the poor ventilation can be a fire hazard. By developing an accessible point of water for irrigation and flushing toilets, the project will be meeting the current need for water accessibility and purification.

Looking ahead, the need for water accessibility is prevalent due to projected effects of climate change. Like many rural developing communities, the Buturi community lacks an overarching national infrastructure. Research shows that rural communities in northwestern Tanzania, including the Buturi community, are likely to be unable to adapt to the extreme weather conditions associated with climate change (Githinji, 2014). As a result, the stressors that impact rural livelihoods, such as HIV/AIDS, lack of access to clean water and education, among others, are likely to worsen. The most vulnerable community members—single mothers and children—will be most affected and fall into more extreme poverty. The project goals were to not only solve current issues, but also ensure the longevity of the project into the future. The team determined a solution that reflects the mission of The Buturi Project: a self-sustaining program to endure today, tomorrow, and years down the road.

Scope of Work

The scope of work is summarized below:

1) Design and construct a rainwater catchment system to act as an accessible source of water.
2) Develop a durable filtration system using local materials for ease of maintenance.

Design Criteria and Standards

The World Bank Rainfall Data

Tank design began with determining the size of the tank. A well-established source of climate data that the team utilized in water resources engineering courses at Santa Clara University is The World Bank. The World Bank was created in 1944 with a mission to provide temporary loans to low-income countries which were unable to obtain loans commercially (World Bank, 2018). This mission endures, however The World Bank has continued to develop and refine the goals of the organization. Beyond providing financial support, The World Bank also strives to support developing countries through policy advice, research and analysis, and technical assistance. One way in which the organization demonstrates its service-oriented mission is by offering free and accessible data and research on the Internet. This way, in between conferences and meetings, government officials can work towards their own goals independently.

The team utilized the precipitation datasets available for Tanzania for this project. The World Bank's Climate Change Knowledge Portal For Development Practitioners and Policy Makers has countrywide rainfall and temperature data for Tanzania. The average monthly data ranges from 1901 through 2015, and data can be partitioned into 30-year intervals. Although the data is reputable, in the context of the design, concerns arose regarding some components of the data. The World Bank precipitation data for Tanzania consists of monthly averages for the entire country, resulting in large spatial and temporal variability in recorded precipitation. Addressing the former, the Buturi community is located near Lake Victoria, resulting in more rainy seasons compared to the drier and larger areas in Tanzania like the Serengeti National Park. Furthermore, the temporal variability cannot be accounted for using the World Bank's average monthly precipitation data because throughout any given year, there are only a few days that receive very heavy rainfall and most other days receive little to no rainfall. While it was suggested that daily rainfall can be estimated from dividing the total monthly rainfall by each day, the team determined that this method would not accurately represent the dry days that the community must endure. Monthly averages are helpful but do not provide a clear enough picture of daily precipitation, which is important when considering water accumulation and consumption. The team therefore examined another way to account for the variability, namely searching for daily rainfall data.

NOAA Rainfall

The team explored the data from another reputable source of climate data, the National Oceanic and Atmospheric Administration, or NOAA for short. NOAA is a government agency of the United States Department of Commerce whose mission is science, service, and stewardship (National Oceanic and Atmospheric Administration, 2018). NOAA has 14 rain gauge stations throughout Tanzania with the closest rain gauge station being in Musoma, about 50 km away from the project location in Buturi (National Climatic Data Center, 2018). NOAA provided daily rainfall data in Musoma from 1950 through 1989. While this dataset possessed the level of precision that the team desired, some of the daily records were redacted due to incorrect, incomplete, or missing data.

To address this issue, the team performed hydrologic modelling. A scaling factor was developed for the NOAA data with respect to the more reliable World Bank data obtained earlier. With one source of questionable daily data and one source of vetted monthly data, the team combined the two sources of information to create a single, hybrid dataset to produce a more accurate representation of the amount of rain that typically falls in this area. To produce this hybrid dataset, the data points in the daily NOAA data were added for all of the days in each month to obtain a cumulative rainfall total for each month. The corresponding monthly World Bank data was then divided by this monthly sum to obtain a scaling factor for each individual month. Finally, each daily NOAA data point was multiplied by its respective scaling factor to produce a more accurate precipitation dataset. The equation for developing the monthly scaling factors is shown below:

$$Scaling\ Factor\ = \frac{average\ monthly\ World\ Bank\ data}{average\ summed\ monthly\ NOAA\ data}$$

Once a clear picture of the day-to-day rainfall was determined, the team was then able to analyze the data and size the tank. Optimization was used to minimize the amount of empty days, overflowing days, and overall tank cost. Although the empty and overflow days always decreased as tank capacity increased, the decrease in the amount of these empty and overflow days became negligible and was eventually not worth the increase in tank volume and cost. Through this analysis, the ideal tank capacity was determined to be 32 cubic meters (m^3) however, to more closely follow the United Nations High Commissioner for Refugees' (UNHCR) design guide for large ferrocement tanks, which will be discussed later, a final tank size of 30 cubic meters was chosen. Figure 4 below shows the graph produced through the analysis.

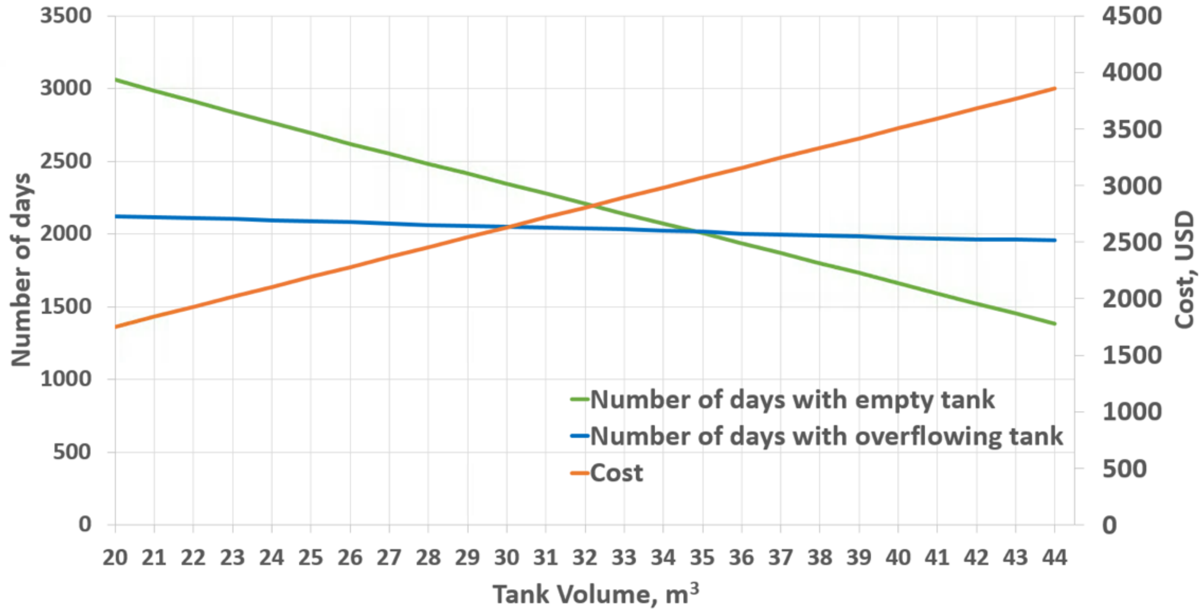

Figure 4: Cost of water storage tank sizes compared with the amount of empty and overflowing days for the tank.

United Nations High Commissioner for Refugees Ferrocement Tank Design

In developing the design of a ferrocement water tank, the team utilized one of the most reputable reference guides for large ferrocement water tanks, the United Nations (United Nations High Commissioner for Refugees, 2016). As an intergovernmental organization dedicated to serving others and maintaining international order, the United Nations is a hub for current and historic information and future plans on international humanitarian aid, sustainable development, human rights, and peace and security (United Nations). One of their programs is the United Nations High Commissioner for Refugees (UNHCR), which focuses on leading and coordinating international action for the world-wide protection of refugees, those forcibly displaced by communities, and stateless people. The primary purpose of the UNHCR is to safeguard the rights and well-being of refugees. Under this pretense, the UNHCR has developed a design guide for large ferrocement tanks to act as a clean water supply for developing communities. "Large Ferro-

Cement Water Tank: Design Parameters and Construction Details" is readily available on the UNHCR website, and it contains pertinent information such as an introduction to ferrocement, a construction procedure, materials needed, and a set of detailed drawings for tank sizes of 45 m^3, 75 m^3, and 90 m^3 (United Nations High Commissioner for Refugees, 2006).

Based on the projected volume of rainwater for the next five years, it was estimated that a 30 m^3 tank would be appropriate for the given site. While the title of the document would insinuate otherwise, the UNHCR guide for large ferrocement water tanks did not have the flexibility of design specifications needed to tailor the design details for this project. Although the guide detailed specifications for the mix design of the foundation, walls and roof, it did not give the necessary calculations for altering their plans to meet this project's needs.

REACH Shirati Design

The team continued to refine the design by looking at other ferrocement tank designs implemented throughout sub-Saharan Africa. One group found to be a good match was REACH Shirati, a non-profit organization dedicated to improving and empowering residents in rural Tanzania. Volunteers from UC Berkeley worked on three ferrocement water tanks in Shirati, Tanzania, which is approximately 60 kilometers away from the Buturi village.

Due to a limited budget, visiting the Buturi community twice would be very challenging, therefore, information was retrieved from existing site conditions from REACH Shirati. The team was most concerned with the type of soil in the area since the existing soil greatly affects the foundation design. Through research, the team was unable to find reliable reports on soil conditions in the Buturi community, therefore it was integral to reach out to the organization to ask for recommendations and advice in approaching a project very similar to theirs.

The UC Berkeley team consisted of one structural engineering student, one psychology professor, and volunteers. Dr. Laura Mason was contacted since the project was already a few years old. She put the team into contact with the UC Berkeley alum structural engineering student, Samantha Vroomen, P.E. Ms. Vroomen was extremely helpful in providing the Bangladesh National Building Code 2012's section on ferrocement design. There continues to be a lack of formalized ferrocement structural design in Tanzania, let alone many other countries around the world, therefore it was agreed that the Bangladesh National Building Code 2012 was a current and reputable source of information for design purposes. Furthermore, the calculations lacking from the UNHCR were readily available in this guide. With the guidelines of the UNHCR and the Bangladesh National Building Code 2012 in mind, the team was successfully able to develop a design of a 30 m^3 tank that would meet the needs of the community.

Water Quality Standards

For water quality codes and standards of water, the team referred to the World Health Organization (WHO) and the American Society of Civil Engineers (ASCE). Information from these organizations guided the design of the filtration and purification system and the extent to which the water collected needs to be treated. Major aspects of water that were considered were the physical, chemical, and biological condition of the water both before and after treatment. Physically, the purification system should filter particulate matter and decrease the overall turbidity of the water (Tarsi, 2015). The filter should also remove chemicals harmful to human health, while also bringing the pH of the water within a typical and acceptable range. WHO specifies that the pH of drinking water should fall between 6.5 and 8 (World Health Organization, 2017). Lastly, and possibly most importantly, the purification system needs to remove biological matter from the water, which could lead to waterborne infections hazardous to humans. These microbial hazards can take many different forms, mainly as bacteria, viruses, and parasites, all of which can lead to serious health complications in humans (World Health Organization, 2017). Thus when deciding on a type of filtration and purification system, the team needed to consider all of these aspects and reduce the risk posed by each to sufficient levels.

Analysis of Alternatives

Description of Alternatives – Storage Tank

Alternative 1: Ferrocement

The original solution that was requested by The Buturi Project was the design and construction of a large concrete tank that would be able to store enough water to serve the Buturi community. A ferrocement tank uses a combination of steel rebar, chicken wire, or other wire mesh, and a mortar mix of cement and sand to form the structure of the tank. The design used was largely based on the UNHCR Design Guide for Large Ferrocement Tanks. To achieve the design capacity of 30 m^3 determined through the hydrologic modeling, a single large ferrocement tank would be used. The circular tank would have an inner radius of 7.5 feet and a height of 6.75 feet. These dimensions would create a tank with a volume of 33.75 m^3. This additional capacity was included as part of a safety factor to ensure that the tank would have enough capacity despite any unforeseen changes during construction. Figure 5 shows a cross-section of the ferrocement tank design.

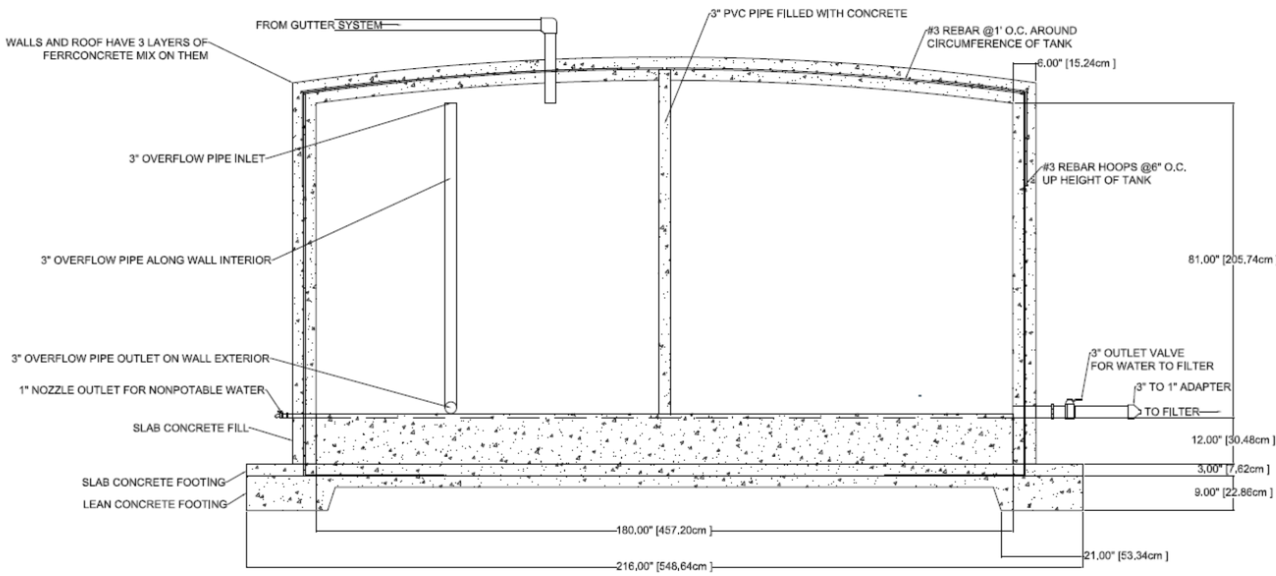

Figure 5: Cross-section of ferrocement tank design.

The construction of the ferrocement tank would be split into three separate portions: the foundation slabs, walls, and roof. The foundation construction would begin with the excavation of a nine (9) foot radius circular hole to act as the form for the first concrete slab. The outer 21 inches of the excavated hole is excavated to a depth of one (1) foot and the remainder of the hole is excavated to six (6) inches deep. The first concrete slab is poured with a ratio of one (1) part cement, three (3) parts sand, and five (5) parts aggregate. On to this slab, an eight (8) foot radius circular rebar grid would be placed. To reduce the difficulty in construction, the rebar grid would consist of two (2) perpendicular rows of No. 3 rebar each spaced at 200 mm on center and tied with metal ties at intersecting points. Figure 6 shows the layout of rebar grid. No. 3 rebar would then be bent at a 90 degree angle one (1) foot in and tied into the rebar grid at every one (1) foot along the circumference of the grid. These rebars would form the cage for the walls of the tank. Once the rebar was in place, a concrete slab with a ratio of one (1) part cement, two (2) parts sand, and four (4) parts aggregate would be poured over to make a more waterproof seal.

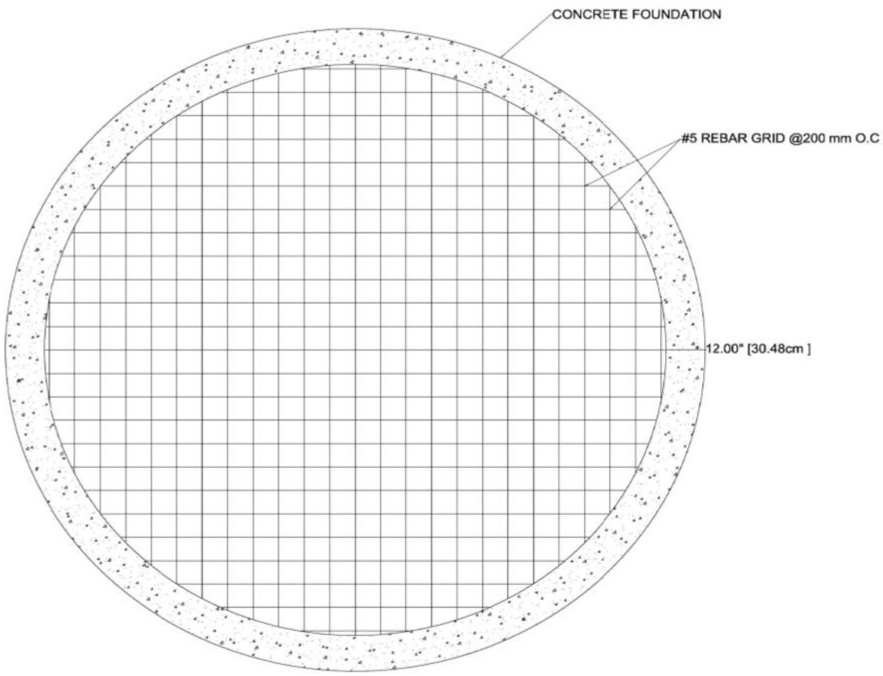

Figure 6: Rebar grid layout.

Once the foundation slabs were set, additional 7.75 foot lengths of No. 3 rebar would be tied to the bent rebars to form the structure for the walls of the tank. No. 3 rebar would then be bent into circular hoops with the same diameter as the foundation. The hoop would be tied to the vertical rebar spaced at six (6) inches for the bottom 4.33 feet of the tank and then spaced at 12 inches for the remaining height of the tank. The increased amount of rebar would account for the increased water loading at the bottom of the tank. To create the rebar cage for the roof, two (2) foot lengths of No. 3 rebar bent at a 45 degree angle would be tied to the vertical rebar. On to the rebar cage, three (3) layers of chicken wire would be tied on to the rebar. Spigots and pipes would be tied into the chicken wire for the outlets and overflow pipe. The spigots would be tied in on opposite sides of the tank, one (1) foot above ground to ensure clearance for a large bucket for dispensing purposes. A mortar mix with a ratio of one (1) part of cement, two (2) parts of sand, and 0.4 parts of water would be mixed. The mortar mix would then be applied to the mesh and rebar in three (3) layers to form a three (3) inch layer with the rebar in the center of these layers.

Eight (8) foot lengths of No. 3 rebar would be tied to the 45 degree angle rebar to form the rebar cage for the roof. On to this, No. 3 rebar hoops would be tied to the rebar. These hoops would decrease in radius by one (1) foot as they approach the center of the tank with a total of eight (8) hoops. Three (3) layers of chicken wire would be tied to the rebar, and the mortar mix used for the wall would be applied to the roof. Two holes would be left in the roof of the tank. One of the holes measures two (2) feet in diameter for maintenance access, and the other hole would be one (1) inch in diameter for air ventilation purposes.

The ferrocement tank was designed to have two (2) outlets with the outlets on opposite sides of the tank, as shown in Figure 5. One outlet would connect to a water filter for potable uses, and the other outlet would dispense water directly out of the tank for non-potable uses. An overflow pipe was designed to ensure that the pipe system leading from the gutters into the tanks would not backup. The overflow pipe would be installed along the inside of the wall with an inlet at the very top of the tank, which is also illustrated in Figure 5. The pipe would have an outlet on the outside of the tank near the bottom. When water reaches a certain level in the tank, it would flow into the overflow pipe and out of the tank. The access hole on the top of the tank would have a cover made of rebar and concrete. Figure 7 shows for a schematic of the manhole cover. The ventilation point of the tank consisted of a five (5) inch length of one (1) inch diameter PVC pipe with slits cut at one end. The pipe would be installed on the roof of the tank to allow air to escape as water flows into the tank.

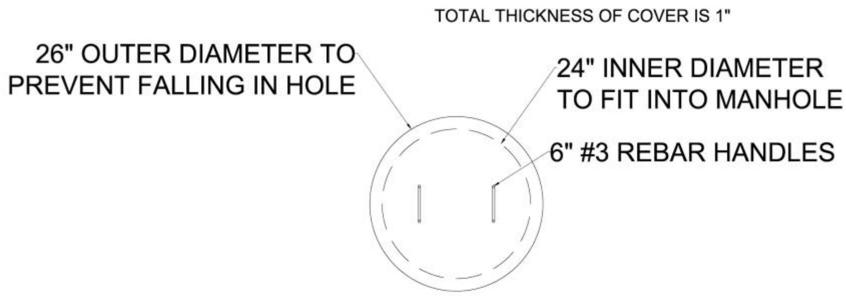

Figure 7: Manhole cover detail.

Alternative 2: Plastic

Through conversations with professionals involved in Collaborate 4 Africa, a forum for those who do work throughout Africa, the project team was advised to look into using large plastic tanks rather than concrete tanks due to their ease of implementation. These plastic tanks range in size with the largest being 20,000 liters to the smallest being 260 liters (“Vertical Storage Tanks,” 2018). To attain the volume needed to properly serve the community, multiple tanks were recommended in place of ferrocement. Some of the plastic tanks would be attached to a water filter for potable uses and the other plastic tanks would be for nonpotable uses.

The plastic tanks were designed with the same ventilation and overflow system as the ferrocement tank. The plastic tanks available near the project site are fitted with holes and lids for maintenance access. Each tank had one outlet, as entire tanks would be specified for potable or nonpotable use.

To properly support these plastic tanks and ensure that water could be dispensed, the tanks were placed on stands. Of the materials available in the village, concrete was the most feasible material to build the stand out of. The stand would be a solid square block with a width larger than the diameter of the plastic tank to reduce the chances of the tank tipping over and off of the stand. A solid square block was chosen as it was the easiest shape to create a form for while at the project site.

Description of Alternatives – Water Filter

Two different alternatives were considered for the design of the water filter: the slow sand filter and the ceramic filter, both of which are used throughout Africa for water filtration (Tarsi, 2015).

Alternative 1: Slow Sand Filter

The slow sand filter consists of layers of gravel and sand within a large receptacle with inflow and outlet pipes. The gravel layer at the bottom supports layers of coarse and fine sand. As water flows through the layers of sand and gravel, a schmutzdecke, or biolayer, consisting of bacteria, fungi, and protozoa forms on the top layer of sand. Once this layer is established, the layer will biologically filter the water flowing through the filter by consuming the harmful bacteria. The water is also physically filtered by the sand as it passes through (Tarsi, 2015).

To maintain a slow sand filter, the biolayer must be maintained at a certain moisture level to ensure that the bacteria does not die. The biolayer needs to be periodically scraped off when it becomes too thick to maintain a proper level of flow through the system (Tarsi, 2015).

Alternative 2: Ceramic Filter

The ceramic filter consists of a ceramic receptacle nested within another larger receptacle. As water passes through the ceramic receptacle, the small pore size of the clay physically filters out viruses, bacteria, and other particulate matter from the water (Tarsi, 2015).

To maintain a ceramic filter, the ceramic receptacle needs to be cleaned periodically. To clean the ceramic receptacle, the receptacle is removed from the larger receptacle and it is scraped and scrubbed gently to remove any buildup.

Description of Alternatives – Gutters

During the design phase of the project, the design team was told by both the client and a representative from the REACH Shirati team that pre-fabricated gutters are not commercially available near the project site for purchase. To address this issue, two different design alternatives were considered to act as rainwater collection channels.

Alternative 1: Sheet Metal

The first alternative considered was using sheet metal, cut and bent into a shape that resembles a rounded gutter. The lengths of formed sheet metal would then be attached to each other using glue. The sheet metal would be supported by welded metal brackets. The metal brackets would be attached to the wooden roof supports of the building using screws. This approach was similar to the one used by the REACH Shirati team.

Alternative 2: PVC Pipe Channels

The second alternative considered was using PVC pipes with a section cut out to form channels. The lengths of pipe would be connected using PVC pipe connectors. The PVC pipes would be secured directly to the wooden roof supports using screws.

Comparison of Alternatives

The ferrocement tank would have a higher construction time and cost as compared to the plastic tanks. The estimated cost for a ferrocement tank based on the design that was created, was $7,820 and would take approximately 28 days to fully complete construction and 28 additional days for the structure to gain full strength. The cost of implementing the plastic tanks was estimated to be $7,300 and would take approximately seven (7) days to fully implement. The cost estimates were created using estimated material costs from the US, estimated transportation costs provided by the client, and a set labor cost of $11 per laborer per day as provided by the client. Along with the longer construction time, a ferrocement tank requires specialized construction and an experienced team. Another factor to consider between the two storage options was the mobility of the tanks. A ferrocement tank must remain stationary after it is constructed, while the plastic tanks can be moved to another location as long as they are elevated. The last factor to consider was the availability of materials for both options. The materials for a ferrocement tank could be sourced from a nearby city 30 minutes away from the project site. The plastic tanks were manufactured in a large city approximately three (3) hours away from the community center and would require multiple trucks to transport them to the project site.

The slow sand filter and the ceramic filter are both low cost and low maintenance. The slow sand filter and ceramic filter can both be made with locally available materials, however, the ceramic filter requires specialized manufacturing facilities to create the large ceramic receptacle. The slow sand filter provides biological filtration on top of the physical filtration, while the ceramic filter only makes use of physical filtration. The level of physical filtration of a ceramic filter is higher than the physical filtration of a slow sand filter.

Description of Final Solution & Logic Behind Decision

System Description

The system consisted of gutters to capture the rainwater off of the community center roof, a pipe system to convey the water from the gutters into the tanks, the storage tanks, and a water filter for potable use.

Gutters

The gutters chosen for this system were the PVC pipes cut into channels. The PVC pipes were chosen over the sheet metal due to time constraints. To create the sheet metal gutters, sheet metal would have to be cut and bent into the proper shape, while the PVC pipes would only require cutting. The PVC pipe gutters did not require brackets to be held up on the roof which reduced the project cost. The sheet metal requires the metal brackets to hold up the sheet metal and also maintain the shape of the sheet metal, as it is more malleable than the PVC pipes.

Storage Tank

Due to the time constraints of the team's trip and the amount of time it would take to construct a ferrocement tank, plastic tanks were determined to be the more feasible option for storing the captured rainwater. Additionally, the construction of a ferrocement tank is very specialized and requires skilled and experienced builders. Although there were builders in the area of the project site who have built ferrocement tanks, the design team did not personally have experience with ferrocement tanks. Even if an experienced team of builders had been on the project, there remains the potential risk for construction defects, which would result in high repair costs. The plastic tank implementation only involved the construction of a concrete stand and piping connections which were both relatively simple as compared to the construction of a ferrocement tank.

It was also determined that the cost of the materials, transportation costs of materials, and the labor costs for the ferrocement tank are much higher than the costs of the plastic tanks, the cost of materials for the concrete stand, the transportation costs for the plastic tanks and their materials, and the labor costs.

The community center at which the project was implemented was still under construction, as will be discussed later in this report, and as a result, the team decided that using a storage option that could be moved to accommodate the new construction would be most appropriate.

Water Filter

The alternative selected for water filtration was the slow sand filter. The slow sand filter was chosen based on the material availability and the manufacturing capabilities of the village and community. If a filter was to break, a slow sand filter could be repaired, whereas a ceramic filter would have to be fully replaced. Since the village does not have the manufacturing capabilities to create large clay receptacles, a ceramic filter would have to be purchased and transported from outside the community, which presents a cost that the community cannot cover. The slow sand filter is made of simple natural materials that require minimal processing.

To ensure the constructability of the slow sand filter, the team developed a prototype of a slow sand filter in the months leading up to travel. In January and February 2018, the team built the slow sand filter prototype according to the specifications of the Centers for Disease Control and David Tarsi (Centers for Disease Control and Prevention, 2014; Tarsi, 2015). Figure 8 shows the assembly of the slow sand filter prototype. The team used sieve shakers to separate fine and coarse sands, and then these sands were washed to remove dirt and particulate matter. Gravel was bought from a local quarry, and a 250 liter rainwater barrel was bought to store the layers of sand, gravel and pipework. The overall cost of building a prototype was $245.

Figure 8: Assembly of slow sand filter.

Pipe System

The pipe system was connected from the gutters to the tanks. The system was simple and constructed using PVC pipes and connector pieces. To address the issue of dirt accumulating on the roof before a storm event, a first flush system was integrated into the pipe system. When the first flow of captured stormwater entered the pipes, it would flow into a separate capped pipe. Once this capped pipe filled up, the remainder of the water would flow directly from the gutters into the tank. Once the storm event was over, the cap could be removed to drain the pipe for use in the next storm event. Figure 9 shows a diagram of the first flush system.

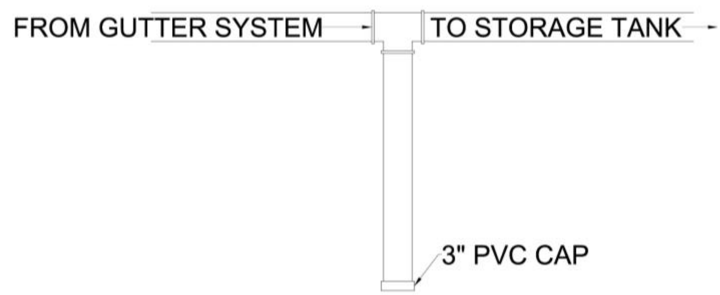

Figure 9: First flush system design.

Design Phase Obstacles

One of the greatest obstacles faced in designing the system was the level of uncertainty that was associated with each item. A survey trip was not conducted and created a heavy reliance on what the client was able to provide in terms of information on materials available and their costs. The REACH Shirati design provided information as to what materials and services are available, however, exact costs and availabilities had changed since the REACH Shirati project had been implemented. The client was unable to provide information on every material that was needed for the design which caused uncertainty in both the economic and logistic feasibility of the project.

Construction of System

Obtaining and Purchasing Materials

When the team arrived in Tanzania, the first order of business was to locate materials and find the lowest costs for those materials. As the team quickly learned, many stores did not have set prices on their items and essentially make up prices for each customer. Due to the fact that the team members were identified as foreigners, store owners typically increased prices. In efforts to find the lowest prices on materials, the team drove from city to city and store to store, talking with store owners and negotiating prices. This difficult process took the first three (3) days that the team was in the country and significantly reduced the amount of time available for construction. Even when items were purchased and ordered, some of the materials could not be delivered until a later date, meaning the team was limited to work only on certain portions with the materials they could buy and take with them while waiting for the remainder of the materials.

Gutter Installation

As mentioned previously, it was thought that the team would have to create their own gutters by cutting PVC pipe into channels that would act as gutters. Fortunately, prefabricated plastic gutters and brackets were available for purchase in a local hardware store. While this made gutter installation simpler, the team did run into challenges installing the gutters due to the nature of the construction of the building, which will be discussed in the *Construction Phase Obstacles* section of this report. To begin gutter installation, gutter brackets were installed and screwed into place every one (1) meter along the wooden eaves of the community center. Brackets were placed at different heights along the eaves to create the desired slope and direction of flow along the gutters. After bracket placement, the gutters could be snapped into the brackets. Figure 10 shows examples of bracket installation. The gutters purchased were three (3) inches in diameter and came in 20-foot lengths. To span the length of the building, gutters were connected using connection pieces made specifically for these gutters. PVC cement was applied at each connection between the gutters and the connection piece to ensure a secure and water tight seal. Figure 11 shows an example of securing the gutters into the brackets. Finally, gutters were further supported with metal ties that wrapped around both the eaves and the gutters at points between the brackets. These metal ties provided additional support during heavy flows of water and would take some stress off the plastic brackets.

Figure 10: Plastic brackets secured on building. Figure 11: Plastic gutters snapped into place.

Concrete Tank Foundations

To optimize the time spent on the construction site, local laborers were hired to work on the concrete tank foundations. These laborers were builders that had experience doing similar work on projects nearby. Each day, anywhere from four (4) to eight (8) builders worked on the tank foundations. As mentioned previously, a square concrete foundation had been designed to support the plastic tanks. The plan was to simply tell the builders how the foundation should be constructed and the work would be carried out, however, the builders had experience building foundations in a cross design rather than a solid block to support plastic tanks. The cross foundation design consisted of concrete blocks laid end to end in a cross and pasted together with a concrete mortar mix. Figure 12 shows the construction of the cross design used. The blocks were stacked upward to the desired foundation height. Once the blocks were in place, a reinforced concrete slab five (5) inches thick would be installed with the rebar in the center of this slab. The team agreed to use this cross design for the potable-use tanks because the structural analysis showed that this design was strong enough to support the tanks, it would cut down on material costs, and would help the builders feel more comfortable in their construction.

Figure 12: First layer of brick for the cross foundation.

The smaller foundations meant to support the non-potable use tanks would be smaller and shorter and thus would not need to be constructed in the cross design. This foundation was circular and had an area slightly larger than the tank to reduce the chances of the tank falling off of the foundation. The slab poured for this stand had rebar installed in a spiral style. The builders decided that this would be the easiest way to reinforce the concrete and were confident that it would be able to handle the load of a full 10,000 L tank. Figure 13 shows the circular foundation used for the non-potable tank.

Figure 13: Finished non-potable tank foundation in the process of curing.

During the time that the team was on the construction site, three tank foundations were constructed: two (2) potable-use tank foundations and one (1) non-potable-use tank foundation.

Plastic Tanks

Work required on the plastic tanks was minimal and consisted of drilling holes at the inlets and outlets. Gaskets were installed in the outlet holes such that piping could be easily connected, and spigots were connected to these gaskets. Figure 14 shows a picture of the tank and the installed gaskets. The potable use tanks were installed with two tanks per collection point. The tanks were installed side-by-side and were connected at the top of the tanks with a single pipe so that water would flow from the first tank into the second tank when the water level in the first tank reached a certain level. This setup would allow for the capacity of two (2) 10,000 L tanks to be used when needed.

Figure 14: 10,000 L tank with brown ¾” gaskets installed at the top and bottom of the tank.

Construction Phase Obstacles

The first big challenge arose when the team arrived at the village and the school building site. Upon arrival, it was discovered that the school building was, in fact, not complete. The team had received blueprints from the client outlining the future goal of the school building. This fact, however, was not communicated and the physical building did not resemble the blueprints. Not knowing this, the team designed the system for the entire, finished building. Additionally, the bathrooms for the community center had been moved to a separate building for a total of two buildings to capture water with. The exact system that had been designed, however could not be fully implemented since the building was not constructed as anticipated. See Figure 15, below, to see the future construction outline for the community center.

Figure 15: Construction progress of Buturi community center as of March 27, 2018. Dirt outline indicates foundation boundary and area of future construction.

Other challenges came as a result of the construction of the school building itself. First, the overhang on the sheet metal roof extended too far over the wooden eaves that support the roof. The overhang needed to be cut to a length such that gutters could be installed and would catch the rainwater, rather than having the water flow over the rainwater capture system. Even with the roof overhang cut to a proper length, installation of the gutter brackets was challenging because of the wooden eaves themselves, which were angled and warped because of poor construction and weather. Different construction techniques and materials caused inconsistent sloping in the roof. All of these factors led to inconsistent sloping of the roof, making gutter installation more difficult and more time consuming than expected. Eventually, the brackets and gutters were installed and were able to capture water effectively, channeling the water to the desired locations.

Weather also played a factor. Although it did not rain during the workday, it rained very heavily every night the team was there. This made the soil in the entire area very saturated and muddy, and every truck that came to deliver materials got stuck in the mud.

Finally, the timing of the travel caused some issues. The stay in the village came during the Easter holiday, which made obtaining materials and contacting people more difficult.

Cost Breakdown

Materials

The material costs were the highest overall cost with a total of $5,726. The materials that factored into this expense were the plastic tanks, cement, gravel, sand, and steel necessary for the tank foundations, the gutters and piping, and other construction tools. Of these materials, the tanks were the largest expense, costing just over $2,300.

Transportation

Transportation of materials also factored into the total project cost. This cost included transportation of the plastic tanks, transportation of all the materials purchased at the hardware store, and the sand and gravel used for the concrete. The sand and gravel were transported from a quarry located approximately 30 minutes from the school building site using tipper trucks. Figure 16 shows one of the trucks used to transport materials to the project site.

Figure 16: Tipper truck delivering sand to the project site.

Labor

The local laborers and builders were paid for their work at the end of each day. Laborers were paid nine (9) dollars per day and the the more experienced builders or bricklayers were paid 11 dollars per day. The total labor cost for this project came out to $1,017 for all the workers over 10 days. It should be noted that the labor costs would have been higher had the ferrocement tank design been selected. This higher cost would be due to the specialized labor and high amount of involvement required for tank construction, as opposed to the straightforward installation of a prefabricated plastic tank.

Total Project Cost

The final overall project cost totalled to $10,257. This figure includes the components mentioned above, as well as ground transportation and lodging for the team, along with other miscellaneous expenses.

Ethics of Solution

Ethical Justification of the Project

Throughout the developing world, access to clean water is a major issue that threatens the livelihood of all who live in these communities (United Nations, 2018). In November of 2002, the United Nations Committee on Economic, Social, and Cultural Rights adopted General Comment No. 15 which stated that "The human right to water is indispensable for leading a life in human dignity. It is a prerequisite for the realization of other human rights." Through Resolution 64/292 adopted on July 28, 2010, the United Nations General Assembly recognized the human right to water and sanitation and acknowledged that access to clean drinking water and sanitation are essential to the realization of all subsequent human rights (United Nations, 2018). At its most fundamental, this project helped address the right of clean water access by providing the Buturi community with the human right to clean water.

Beyond providing the right of clean water to a community in need, this project also focused on Article 25 of the United Nations' Universal Declaration of Human Rights which states that, "Everyone has the right to a standard of living adequate for the health and well-being of himself and of his family, including food, clothing, housing and medical care and necessary social services, and the right to security in the event of unemployment, sickness, disability, widowhood, old age or other lack of livelihood in circumstances beyond his control." The accumulation of up to 25,000 L of rainwater will not only provide access to drinking water but also contribute to the school-run garden and fields. Rainwater is a great source of clean water for plants, therefore the implementation of these rainwater storage tanks will serve the large percentage of the community who are subsistence farmers. Not only will this rainwater sustain the agricultural economy of the community, but it will also provide the necessary access to food for the health and well-being of families around the community.

Furthermore, by developing nearby sources of water for both potable and nonpotable use, this project will diminish the time it takes for young children and women to carry water to their respective homes. The decrease in the time it takes to fetch water miles away from their homes will allow young children and women to instead have the time to go to school. As stated in the United Nations' Universal Declaration of Human Rights, Article 26: "Everyone has the right to education," and the investment in conveniently located water sources will allow for a better educated generation. Studies from the Center of Universal Education show that the lack of education from an early age results in gender, income and regional learning gaps, as well as the underdevelopment of critical skills like reading, writing and math (Agbor, 2016). A more educated community can therefore lead to better community planning for the future, which is imperative for the survival and prosperity of the community. While it may appear that the project tackled only one issue of providing a reliable water source, it did in fact play a part in many other problems faced in the community, such as food and education. The resolution of all of these issues will allow the community to thrive, as future generations will have access to the resources made available as a result of this project.

Moreover, the American Society of Civil Engineers' Code of Ethics stresses that projects like this are crucial to the well-being of the community. Canons 1 and 8 of the American Society of Civil Engineers Code of Ethics state that, "safety shall be held paramount" and "all persons shall be treated fairly" respectively (American Society of Civil Engineers). Thus, upon visiting and living in the community, it would be unethical of the team to not devote time and energy to ensure the fair treatment and quality of life. It is the responsibility as civil engineers to provide these village people with water that is of quality equal to what people in developed countries receive for the purposes of both health and public safety, as well as social justice and equality.

All things considered, this project employs ethical actions such as the utilitarian approach, the justice approach and the common good approach. While the team installed a somewhat costly technology in the community, the long term benefits of the project will quickly outweigh the upfront cost. Consequently, more good will come out of the project rather than harm. Additionally, the justice and common good approaches are addressed throughout this project as the team aimed to serve the community as a whole and treat every individual proportionately. The installation of this project in a centralized location that is accessible to children enrolled in the school and their families, demonstrates the team's attention to the universality of access to the water resource. The interest of one person is not prioritized over another, as it takes the teamwork of an entire community for all to survive.

Conclusion

Despite several challenges and setbacks, the team believes its impact was positive, and the project goals were achieved. It was rewarding to not only work alongside and with community members who are leaders today, but also interact with the future of the community: the children and young adults. By investing time in connecting with community members, the goal of self-sustainability of the project was achieved. The workshop about regular upkeep empowered community members to gain confidence in their ability to maintain their new system. In this way, the project will meet the need of water accessibility for years to come.

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