Designing a Gravity-Fed Water Transportation System for Mlanda Village

Design for Life: Water in Tanzania, January 2020

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Executive Summary

The goal of this project was to design a distribution system to supply the village of Mlanda with clean and accessible water year-round. Mlanda has a population of approximately 3,000 individuals and is composed of six subvillages, spanning a distance of 10 kilometers. The relative flatness of the elevation profile and the large distance over which the population was distributed were problematic when designing the water distribution system. Currently, the cleanest and most reliable source of water for subvillages is a hand pump located at the primary school in Mlanda A. Drawn from the 150 meter bore hole, the water is pumped constantly during the daylight hours and has never run dry. In further subvillages, villagers also heavily depend on a hand pump located in the subvillage of Ilembula. This hand pump draws water from an 18-meter deep hand-dug well from 2005 and consistently supplies water year-round. The constant water delivery despite the relative shallowness of the wells suggests a high water table in this area. However, while these two wells work, many do not. The subvillages of Mlanda B, Nyalawe, and Msombe each had hand pumps installed by the government in 2005 that draw water from 20-m deep hand-dug wells. Each of these hand pumps draws only a limited amount of water each day at best or is completely dry. The final subvillage, Ukang'a, has no hand pump at all. Villagers residing in Mlanda B, Nyalawe, Msombe, and Ukang'a generally resort to collecting water from the local wetlands and river sources. Water tests showed that these natural sources were contaminated with both *E.coli* and coliform, and thus are unsafe for consumption. As the proposed water system will take some time to be implemented, disinfection of the current water sources and the implementation of water pollution prevention measures in the village are highly recommended.

Going forward, the proposed solution for Mlanda consists of a two-phase system which will provide clean water access to 90% of the population. Phase I provides water to the subvillages of Msombe and U'kanga. The system is a solar powered pump and air-hammered bore hole connected to two 10,000 liter tanks; the tanks, placed at the highest point in the village, provide enough change in elevation to flow water through the nearly three kilometers of pipe needed to distribute water to the village. The second phase of the system distributes water to the primary school, Mlanda B, and the future dispensary. The pump utilizes the 150 meter bore hole currently in place in Mlanda A and draws water into two 10,000 liter tanks at the primary school. The system then runs water 1.3 kilometers and features four distribution points. Because the systems are extensive, the pricing for the project was broken down into the cost of each phase. The Phase I design costs $36,500, and Phase II costs $20,000. With the sheer quantity of pipe, Mlanda will provide $5,600 of in-kind contributions for the Phase I system and $2,600 for Phase II in-kind contributions.

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1.0 Contact Details

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1.2 Trip Leads/Instructors

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Dr. Ken Smith	3M Corporation	(651) 336-7273	klsmith@alum.mit.edu

1.3 Prominent Members of Mlanda Village

Name	Title	Subvillage	Phone Number
Gasto Mgeni	Village Executive Officer	Mlanda	+255 076 533 0719
Leonard Kinyonge	Village Chairman	Mlanda	+255 076 606 1409
Peter Mwelela	Pastor	Mlanda-Mdwili	+255 071 348 3270
Helena Hudson	Pastor	Mlanda-Mdwili	+255 076 849 1287

Shaban Kikoti	Headmaster of Primary School	Mlanda A	+255 065 726 4533
Martin Kawage	Fundi (Handyman)	Ilembula	+255 076 538 6500
Agnes Hyamahanga	Treasurer	Mlanda	+255 075 984 4473
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1.4 Mlanda Water Committee

Name	**Title**	**Subvillage**	**Phone Number**
Josephine Mofunga	Water Committee Chairwoman	Ukang'a	+255 075 290 3541
Agnes Temywa	Water Committee Member	Mlanda B	+255 074 340 7406
Germana Moto	Water Committee Member	Ilembula	--

* Note that not all water committee members are included in this list, only those that attended the water committee meeting

2.0 Project Profile

2.1 Project Location

Region: Iringa, Tanzania

Location: Mlanda Village

Coordinates of Village Main Office: 7.915044˚S, 35.742502˚E

Climate: High elevation, wet season: January-May, dry season: June-December.

Figure 2.1 illustrates Mlanda's location relative to Iringa town, the city center of the Iringa region. Mlanda is about 17 km southeast of Iringa. Figure 2.2 shows a detailed map of Mlanda including important landmarks. There are a couple mistakes in the map, so for clarity the right sources will be defined here. To begin, the "pond" contaminated source on the bottom of the map is referred to as the "river" source throughout the paper. There is an additional source at the edge of Msombe referenced as well, which is the "pond" source.

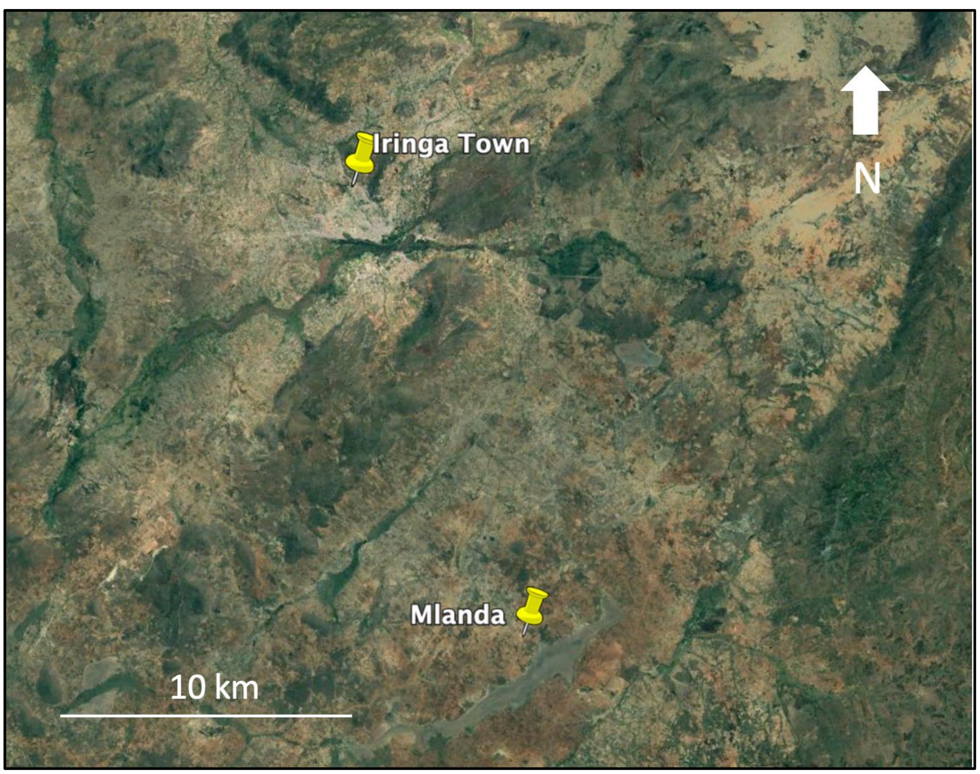
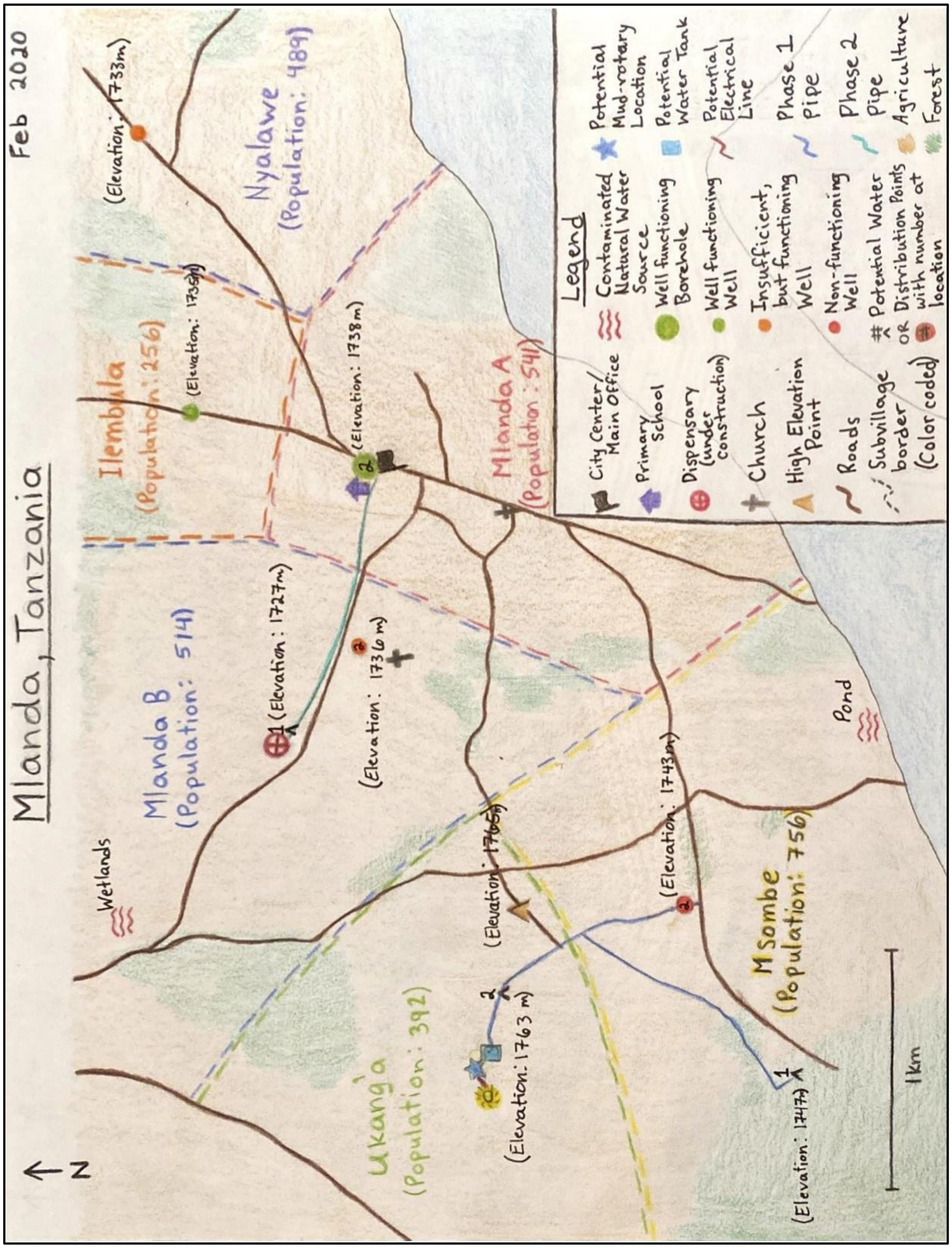


Figure 2.1: Iringa region, showing Mlanda village relative to Iringa Town.

Figure 2.2: Map of Mlanda, Tanzania. Includes important landmarks, paths, and elevations. The map discrepancies include the "pond" at the bottom of the map is referred to as the "river" source throughout the paper. In addition, there is another contaminated source at the edge of Msombe called the "pond" source.



2.2 Project Budget

The required cost for Phase I and Phase II are summarized in Table 2.1 below. The total costs found in this table include the additional 15% contingencies for the direction, oversight provided by the hard-working members of St. Paul Partners, and for unexpected, but allotted for, changes in pricing as the system is implemented. A more detailed pricing list can be found in Section 8.

Table 2.1: Summary of costs for each component of Phase I and Phase II combined. General costs include transportation and labor, borehole, and the materials for the physical system.

Category	**Phase I**	**Phase II**
Mud Rotary Drilling	$8,400	$0
Pump and Power System	$10,500	$4,200
Distribution System	$6,350	$5,090
4x 10,000 L Tanks	$3,180	$3,180
Labor and Transportation Costs	$4,140	$2,030
Subtotal	$34,760	$17,460
SPP Overhead at 15%	$5,210	$2,620
Contingency at 15%	$5,210	$2,620

Total	**$45,190**	**$22,690**
In Kind Contribution	$5,110	$2,960
Required Funds (Total-In Kind Contribution)	**$40,080**	**$19,730**

3.0 Background

3.1 Mlanda Village

After a quick bus ride 17 km southeast of Iringa, we arrived in the village of Mlanda and were greeted by several village representatives, including the Village Executive Officer, the Water Committee Chairwoman, the Fundi (handyman), the Pastor, and several others. We exchanged introductions in Swahili and were given a brief overview of Mlanda before having tea at the headmaster's home. Everywhere we went, we were greeted with effusive gratitude and hospitality, though we had only just arrived. After tea, we were whisked off to the primary school and given a heart-warming performance from the students singing, chanting, dancing, and drumming in a gesture of welcome. Joining in the festivities, we swayed to the music, handing out high-fives and knuckle punches to the curious, yet shy students delighted in running away giggling.

Image 3.1: Students of the primary school welcoming us into the village.

Following the welcome, we went straight to work, attending a meeting with the village representatives. We were shown a map of the village and the relative locations of each subvillage, including statistics on each population. The representatives briefly told us about the current water sources and gave us a rough idea of the priorities for the village as a whole, giving us a great starting point. Afterwards, we journeyed to each subvillage to better understand the current water sources and relative population dependence on each. At each subvillage, we dismounted the bus and walked to the water source, taking pictures and documenting the relative locations and flow rates where applicable. By the end of the first day, we obtained enough information to create a map of the village with current water sources and populations in each subvillage. We were surprised by the vastness and flatness of the terrain in the village, knowing it could prove challenging in the design. At dusk, we headed back to the headmaster's house for a delicious dinner of rice, vegetables, and chicken. After a long day of hard work, we returned to our accommodations with full stomachs to get rest for the next.

On the second day, we attended a meeting with the water committee, returned to water sources to conduct water testing, explored priority subvillages for potential water distribution ideas, and returned to the village center to enjoy mingling with the villagers. The morning started with a meeting with the water committee. The goal of this meeting was to determine which subvillages were deemed priorities and the selection criteria. The water committee, created in 2018, consists of one representative from each subvillage and meets once a month to discuss the current water needs of the community. The committee is split equally between men and women, ensuring that all opinions and water needs are heard. The committee had prepared for our arrival, making a list and agreeing upon the priorities of the community. Although they had not yet specifically started collecting funds for the project, they had a system in place to collect 1000 shillings (approximately equivalent to $0.50 at this time) from each household when repairs or maintenance on current water sources were required.

We were inspired by the altruism of the villagers, as the subvillages unanimously agreed to contribute funds even if the project would not be installed in their respective subvillage. With several details clarified in the meeting, we revisited each subvillage to perform water testing and assess the cleanliness of the water sources. At many water sources, we ran into villagers collecting water of their own, and we asked for their personal anecdotes relating to how far they travel to get water, how long it takes, how many trips they take, which sources they use, among others. After a full day of data collection, we returned to the village center at Mlanda A to relax and interact with the villagers. Kids swarmed at the sight of candy, and it was not long before we had given out all five bags. The children were also fascinated by gifts of small, colorful rings and tiny bottles of bubbles. After laughing and playing with the kids and seeing their smiling faces, it was hard to fathom how people who had so little could be so joyous and carefree. It was at this moment each and every one of us became determined to help supply them with clean, accessible water.

Images 3.2 and 3.3: Pictured left Peyton handing out candy to the kids in Mlanda A. Pictured right is an image of the Mlanda team with the Water Committee Chairwoman, Josephine in the subvillage of Ukang'a. From left to right: Peyton, Rayna, Paul, Josephine, Jake, Vail, Rachel, Janelle.

On day three, we awoke to gloomy skies and thunderstorms, paralleling the general emotional climate for the day, as we had to leave our new friends to return to Iringa. Before departing, we attended mass at the Lutheran church, listening to uplifting songs and prayers. To show our immense thanks for their hospitality, we sang "Asante Sana" for the congregation, and although we tried our best, our voices could not compare with those of the villagers. After church, we gathered for a final meal, collected our things, and prepared to depart. The women sang and presented the women of the group colorful skirts as we boarded the bus, noticing that we had worn the same skirt 3 days in a row. Because of their generosity and beautiful hope, we left Mlanda with sadness in our hearts, leaving the place we felt so warmly welcomed and at peace.

Image 3.4: Mlanda Team pictured with several prominent members of the community at Mlanda just before departing to return to Iringa.

3.2 Current Water Sources

Mlanda currently uses a variety of different surface water sources in combination with five hand pumps in different states of repair (and disrepair). There are three predominant main surface sources used throughout Mlanda. The first, a wetlands surface stream in the north west corner of the village, Image 3.5 and 3.6, services the people of the Ukang'a subvillage. The source of the small stream is used for drinking water by the villagers, and the downstream is utilized for livestock.

Images 3.5 and 3.6: The wetlands source used by the people in Ukang'a. Left: Children gather with their mother to help collect water to bring home. Right: A closer view of the stream near the rock source it sprouts from.

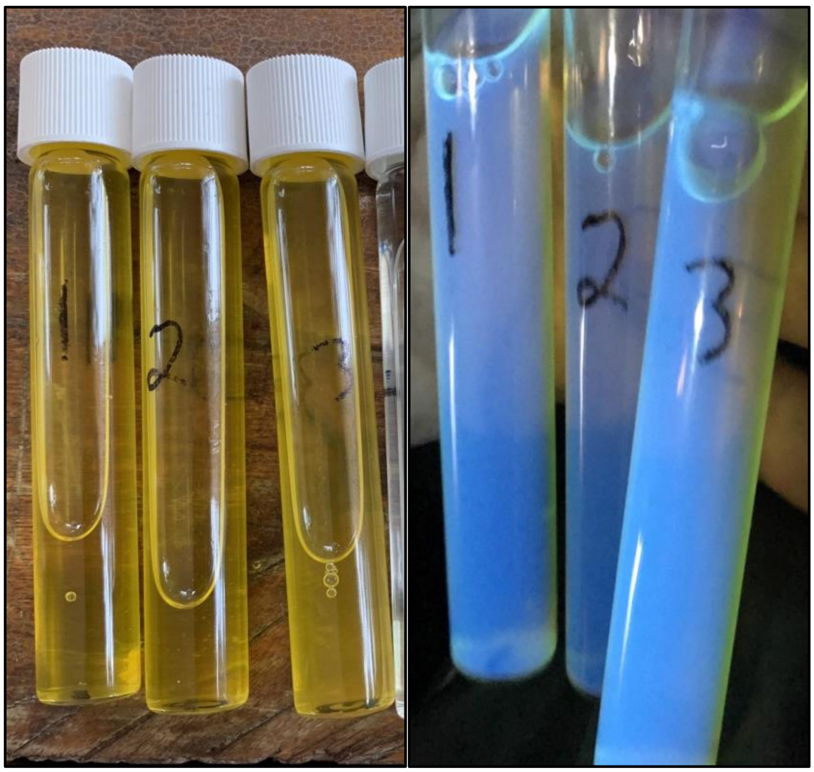
Along the steep banks of the stream where drinking water is collected were piles of feces from the cows. The livestock may be kept away from upstream the source to prevent contamination, but the runoff from them is not. Because of the feces and the unknown stream origin, the drinking water portion of the stream tested positive for both coliform and *E. Coli* bacteria. When a village woman was asked about whether she boiled the water at home prior to consumption, she replied that she knew she was supposed to boil it, but an hour-long round trip prevented her from having the time to do so.

In a similar situation to the wetlands stream, a large pond exists during the wet season in the south western parts of the Mlanda. This source is shown in Image 3.7 below. Primarily used by the Msombe subvillage for bathing and washing clothes, it was blatantly clear as to why the source was not used for drinking water. With cows milling nearby and tadpoles and other small animals swimming in the murky water, it was unsurprising that the source tested positive for coliform and *E. Coli* bacteria. While the pond was not used for drinking water, it is still an unsafe surface source for bathing. Villagers may not have been drinking the water, but the water comes in contact with the mouth, nose, and eyes when bathing and can still cause illness.

Image 3.7: Pond source utilized by the people of Msombe. This source is not typically used for drinking water but for washing clothes and bathing. In the background, a woman lays her clothes out to dry.

Images 3.8 and 3.9: River source that provides drinking and washing water by the people of Msombe. This source is a misnomer as the stagnant water collects in small pools and does not actually flow, increasing the risk of disease.

Further east of this pond, about 700 m from the road, is a small sister surface water source. This is the source used by the population of Msombe for drinking water and washing clothes. The river source is depicted in Images 3.8 and 3.9. Contaminated with coliform and *E. Coli* bacteria and only available in the wet season, this river source is unreliable and underservices the huge population living in Mlanda. When we asked a local if he boiled the water before drinking it, the response was the same. He knew he was supposed to, but after spending hours gathering it, it took him too long to boil it properly. In addition to the contamination of each of the described surface sources above, they are all located on the outskirts of the village and daily journey back and forth poses a health and safety risk to the villagers, compounding the lack of safety of the water. The results of the water test samples are shown in Images 3.10 and 3.11 below.



Images 3.10 and 3.11: These images show the water test results from the wetlands (1), the pond (2), and the river (3) locations. The image on the left, shows that all three locations test positive for the presence of coliform due to the yellow color of the water. The image on the right indicates that all three locations test positive for the presence of *E. Coli* due to their fluorescence in black light.

In addition to the three surface sources outlined above, the village has access to four shallow hand dug wells between eighteen and twenty-one meters deep built by the Tanzanian government in 2005. Each of the wells has a hand pump installed with them. Located in Msombe, Mlanda B, Ilembula and Nyalawe, only one — the pump in Ilembula — of the original wells functions enough to provide sufficient water for the community; the pumps at Nyalawe and Ilembula are shown in Images 3.12 and 3.13. The other three pumps either provide less than sixty liters of water a day or none at all. The well in Msombe has been dry since 2007, forcing the villagers to either walk 1 kilometer to the aforementioned surface sources, or 3 kilometers to Mlanda A for clean drinking water. The wells in Mlanda B and Nyalawe are in similar states of disrepair; each well is able to produce a maximum of 120 liters of water per day, insufficient for the needs of the subvillages using them. Like the people of Msombe, the villagers of Mlanda B and Nyalawe are forced to wait for the pump in hopes of obtaining enough water or walk kilometers to a surface source, or Mlanda A. The functioning wells were tested for coliform and *E. Coli*, and all tested negative for both forms of bacteria. The four government-made hand dug wells from 2005 are in varying states of operation 15 years later, causing water problems for the village.


Images 3.12 and 3.13: Functioning or semi-functioning handpumps for Nyalawe (left) and Ilembula (right).

Years after the hand pumps were implemented, Mlanda was lucky enough to have a 150 meter air-hammered bore hole and hand pump donated to them by Epic in 2017. This bore hole is located in Mlanda A, steps from the main road and 50 meters from the primary school. The bore hole is a reliable source of water even in the dry season and provides more than enough water for Mlanda A and any villagers from other subvillages who make the trek. When the hole was initially dug, the water output was tested and was able to fill a 10,000-liter tank in 90 minutes. This water output test indicates a potential output of 6,500 liters per hour from the bore hole. However, because the village had no access to electricity, only the hand pump was installed. During our conversations with the village leaders, they told us that since the pump's inception, the disease rates decreased greatly. This pattern was reinforced as the water from the deep well tested negative for coliform and *E. Coli* bacteria. Due to the well's proximity to the primary school, students typically are expected by their families to bring an empty bucket to school, fill it during the day, and return with a full bucket of water for the family. At the surface, this request seems reasonable; however, students from Nyalawe walk 1.75 kilometers and students from Msombe walk nearly 3 kilometers with a bucket weighing over 40 pounds. Even so, the donated bore hole at the heart of Mlanda is the main source of clean water for many of the village residents and is constantly used.

3.3 New Water Source

Because of the relatively flat and dry landscape of Mlanda, it was determined that the best source to provide sufficient water for Mlanda was to tap into the same subsurface water source that the 150-meter-deep borehole in Mlanda A uses. As outlined above, there are no clean surface sources to utilize in our design, so the remaining source is the subterranean aquifer. This source tested clean for all the handpumps, so contamination is not a major concern. Additionally, although Mlanda A has a 150-meter-deep borehole, the water level generally sits around 20 meters deep, indicating the large aquifer reservoir beneath the village. Because of the cleanliness of the water and the vast quantity of water available in the reservoir, the aquifer will be the main source of water in design plans.

3.4 Demand and Priorities

The village of Mlanda conducted a census in 2018 and tallied a total population of 2,948 people. The census also included the number of households, which was found to be 420, meaning that on average, there are around seven people per household. The population for each subvillage can be seen in table 3.1.

The system was designed using the 2030 projected population to account for population growth and to ensure that the system will provide sufficient water for the population in years to come. As per Tanzanian design guidelines, each individual should have access to 25 liters of water per day for all of their activities, including drinking, washing, and cooking. While at a school, each student should have access to 10 liters of water per day. Approximately 670 students attend the Mlanda primary school as of 2020, which when extrapolated with the previous growth method makes for 781 students in 2030. These students account for an additional water demand of 7,810 liters per day in Mlanda A.

Table 3.1: Mlanda subvillage populations broken up between the 2018 census population and the projected population, along with their projected water consumption needs. The population of the village in 2030 was calculated using an expected 1.5% increase in population per year.

Subvillage Name	Population 2018	Population 2030*	Water Required per Day [L]
Ilembula	256	306	7650
Mlanda A	541	647	16,175
Mlanda B	514	615	15,375
Msombe	756	904	22,600
Nyalawe	489	585	14,625
Ukang'a	392	469	11,725
Total	**2,948**	**3,525**	**88,150**

Mlanda formed a water committee in 2018 that is composed of representatives from each subvillage. The water committee meets once a month to discuss the current water situation in each subvillage. When maintenance is needed, each household in the village of Mlanda contributes 1000 shillings. Should the water system be implemented, they plan to continue this fund-raising method for power source payments or maintenance. Additionally, in the case that families are unable to contribute, the head of the village keeps a list of families in need of assistance and excuses them from contributing. The water committee also confirmed that the village is ready to provide in-kind contributions, such as digging the trenches for the pipes in the water system.

During our discussions with the village's water committee, the water committee presented their priorities based on the current situation in the subvillage and distance travelled to collect water. Their highest priority was the subvillage of Ukang'a, which lacks any water source. This was determined due to their seclusion and distance from the wetlands stream source that was 1.5 kilometers away. According to the Ukang'a representative, parents are concerned for the safety of their children while retrieving water, for the path to the sources available to them is both long and heavily forested, and assaults have occurred in the past. The second priority was the subvillage of Msombe. Msombe was chosen due to the lack of access to clean water sources, the distance from the nearest water source, and the concern for the safety of young women and children while retrieving water. In the dry season, most of the villagers from Msombe walk to the pump in Mlanda A multiple times per day, with each round trip taking well over an hour. The third priority expressed was the subvillage of Mlanda B. This is largely due to the new dispensary currently under construction and anticipated to be completed in October 2020.

Image 3.14: Shows the progress (as of January 2020) on the dispensary being built in Mlanda B and expected to be completed in October 2020.

According to the water committee, the dispensary will be staffed with a government-appointed doctor to treat illnesses and injuries in the village; in particular, common waterborne illnesses such as typhoid and cholera will be treated. The fourth priority was the subvillage of Nyalawe. This subvillage currently has no reliable source of water, as their shallow hand dug well outputs insufficient amounts of water to support the population. Nyalawe is over one kilometer away from Ilembula, which is their closest reliable water source. After that, the subvillages of Mlanda A and Ilembula are to be prioritized equally as both currently have hand pumps that sufficiently meet the demands of the population.

4.0 Design Criteria

4.1 Tanzania Water Code

Our proposed design was largely shaped by Tanzania's Water Code, which is a set of guidelines created to help increase the longevity of implemented water systems. This water code was used to calculate Mlanda's daily water demand and is attached in Appendix I. The subvillages that were indicated to be high priority areas by village leaders were incorporated in our design. A summary of the demand is shown in Table 4.1, with a focus on the demand of high priority areas. As per the Tanzania Water Code, our calculations were made to accommodate the village's population in ten years. The population data estimated 2030 populations were determined assuming a 1.5% annual increase. The code also requires 25 L per person, each day, with the exception of school students getting an additional 10 L per student per day.

Table 4.1: Water system demand for current and future populations of Mlanda with the breakdown of each system and population.

Location	Location Breakdown	2018			2030 (estimated with 1.5% annual increase)		
		Population	Demand Per Capita (L/c/day)	Total Demand (L/day)	Population	Demand Per Capita (L/c/day)	Total Demand (L/day)
Ukang'a	Residents	392	25	9,800	469	25	11,714
Msombe	Residents	756	25	18,900	904	25	22,591
Phase I Demand				28,700			34,305
Mlanda B	Residents	514	25	12,850	614	25	15,360
	Dispensary Patients	30	25	750	36	25	900
Mlanda A	Residents	541	25	13,525	647	25	16,167
	Primary School Students	600	10	6,000	717	10	7,172
Phase II Demand				33,125			39,598
Total				61,825			73,904

5.0 Proposed Design

5.1 Design Overview

The village of Mlanda proved to be a difficult village for system design due to its large population, flat landscape, and the expansiveness of the village. The village in 2018 reported a population of 2,950 people. When extrapolating the population for growth over the next 12 years, the population is expected to reach 3,530 people in 2030. The water system design seeks to serve this projected population to maximize the effects that it could have on the village. Mlanda is very flat with an elevation change of less than 50 meters. This elevation change is experienced over an area that is over 20 square kilometers. Previous systems implemented by St.Paul Partners generally bring water to roughly 1,000 people and have close to 80-100 meters of elevation to drive a gravity fed pipeline. With these factors in mind, it was determined that creating a single system to serve the village would be impractical and unnecessarily expensive.

Due to the geographic realities of the village, a two phase design utilizing three boreholes was created to fulfil as many of the village priorities as possible. If a system were to be designed for Mlanda, it should aid as many people as possible despite the capital cost. For simplicity of the multi-system design, the design has been broken down into chronological phases. Phase I of the design includes a simple system in Nyalawe and a complex system to serve Ukang’a and Msombe. Nyalawe is very distant from the rest of the village and slightly uphill making it difficult to deliver water there. As a result, a mud rotary borehole features a hand pump to inexpensively supply this isolated area. The Ukang’a and Msombe system utilizes a mud rotary borehole at the higher altitude of Ukang’a to feed water by gravity to itself and Msombe in two different locations. Due to the remote location of Ukang’a, this part of the system must be solar powered. Phase II of the design consists of a grid-powered system to supply water to Mlanda A (home to the primary school), Mlanda B, and the new dispensary. The current bore hole in Mlanda A has a hand pump installed. This hand pump is to be removed and replaced with a pump that pulls water from the aquifer to fill tanks. These tanks then supply the aforementioned locations via a gravity fed pipeline. Phases I and II are shown working in harmony in Figure 5.1 to supply water to nearly every subvillage in Mlanda. Neither phase delivers water to the subvillage of Ilembula as they currently have a working hand pump that provides their population potable water year round.

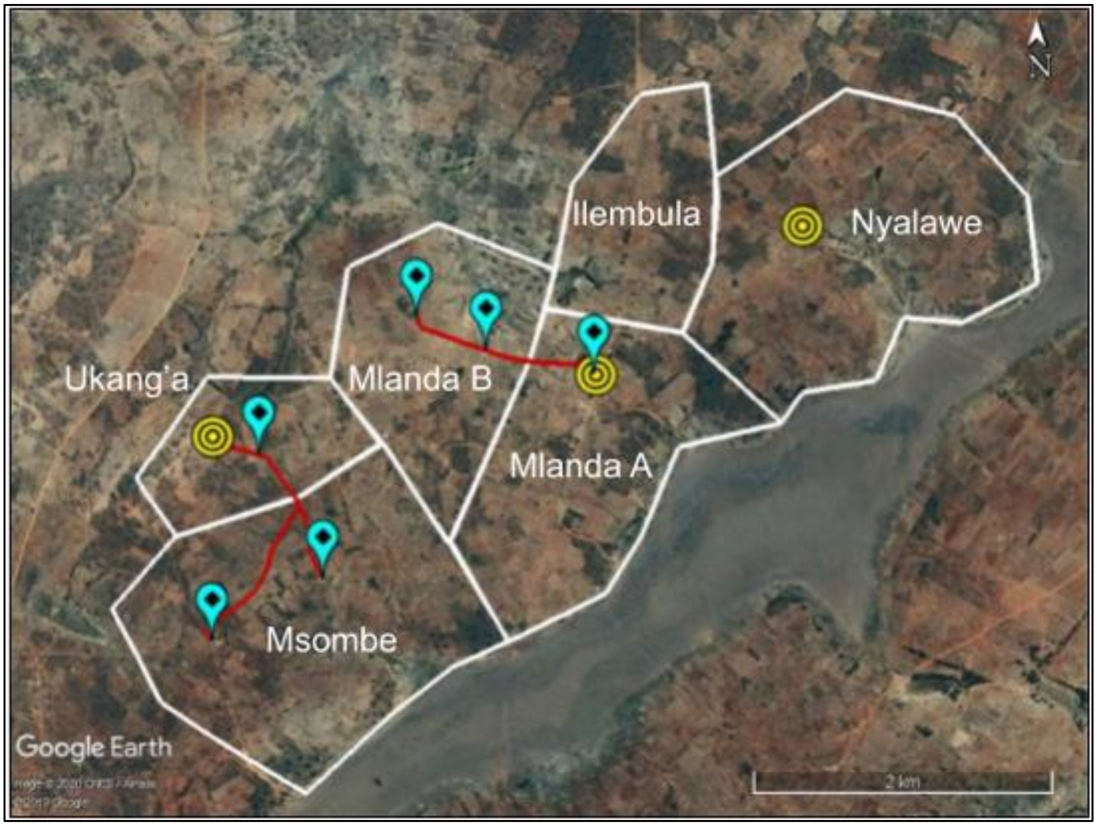


Figure 5.1: This figure displays the two phases of this multi-system design. The yellow targets highlight borehole locations, the blue bubbles point out distribution points, and the red lines mark the pipeline paths. Phase I encompasses the southwest system serving Ukang'a and Msombe along with the hand pump to the northeast in Nyalawe. Phase II serves the central region of Mlanda A and B.

Each borehole and tank location were chosen at relative highpoints to allow for a gravity powered pipeline for each phase. Mlanda A did not have a favorable enough elevation to distance ratio to serve the Msombe area. Ukang'a is the highpoint of the entire Mlanda village, but the lack of grid power meant that the pump could not run 24 hours per day and would likely not be able to output enough water to serve both Msombe and Mlanda B. These considerations resulted in the idealized Phase I and II design described. This design caters to the village's top four water priorities. Phase I occurs first because Phase II repurposes the current bore hole already at Mlanda A, rendering it temporarily inaccessible. One could imagine that during Phase II construction, the village would have no access to their primary source, so it is important to first establish reliable water in Phase I before disrupting the village center. Residents of Mlanda A will be forced to travel to another distribution point (henceforth referred to DP) to obtain water for a brief time, but the new system will make reliable, clean water accessible to many.

After determining the general layout for each phase, the required pipe sizes and paths to deliver sufficient water flow rates to meet the Tanzanian design guidelines for each DP were determined. Additionally, the water velocities were ensured to be above 0.5 m/s to be efficient but lower than 1.5 m/s to avoid water hammering, which damages pipes causing them to fail much sooner than expected. It was demonstrated that no vacuum (negative) or high (greater than pipe ratings) pressures were created when different valve combinations were modeled. The following subsections, 5.2 and 5.3, will begin with a deeper description of the phase at hand and then transition into pipe design considerations given the elevation and demands of each unique path.

5.2 Phase I: Nyalawe and Ukang'a/Msombe Water Systems

Phase I consists of two parts: a solar powered pump supplying a gravity fed pipeline and a mud-rotary hand pump. The solar powered portion serves both Ukang'a and Msombe. Both of these subvillages are currently without access to clean well water and resort to traveling long distances to collect surface waters. As described in Section 3.2, these surface waters were tested and found to have both coliform and *E. Coli*. This phase will be constructed as shown in Figure 5.2, located below.

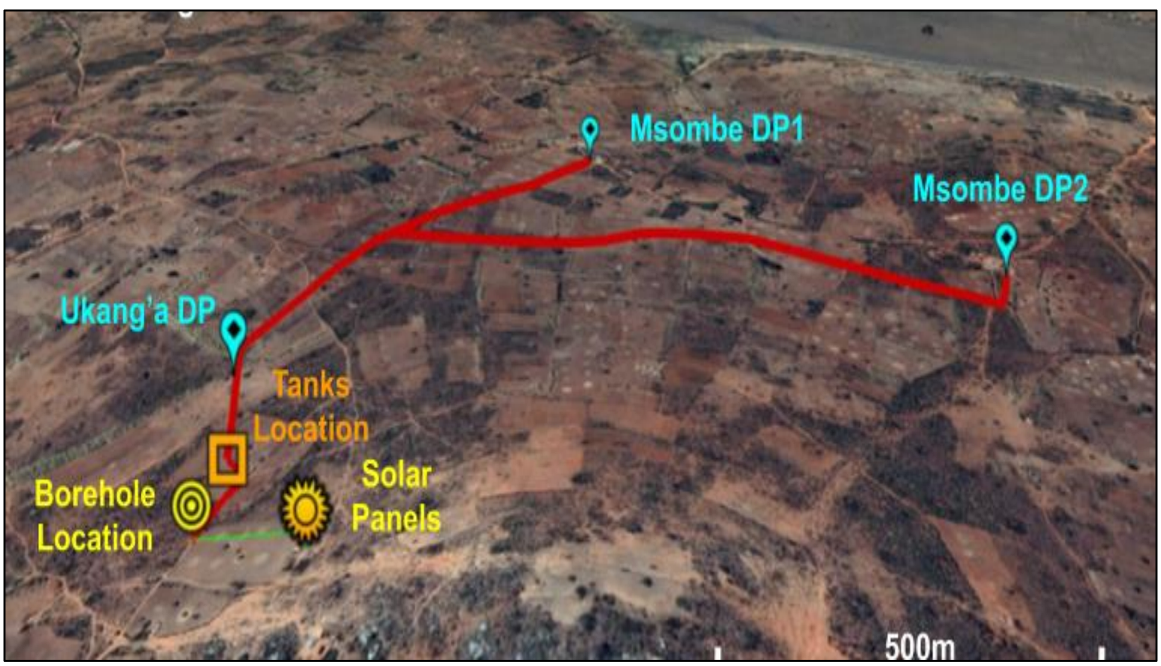


Figure 5.2: This Google Earth screenshot depicts the Phase I water delivery system. The three distribution points are marked in light blue. The system starts with solar panels to installed atop of a water committee member's home. This solar power runs to the newly drilled borehole

marked by the yellow target and fills the nearby tanks adjacent to the borehole. The gravity fed pipes, marked by the red path, flow out of the tanks to Ukang'a and two additional points in Msombe by means of a pipe split between the two subvillages.

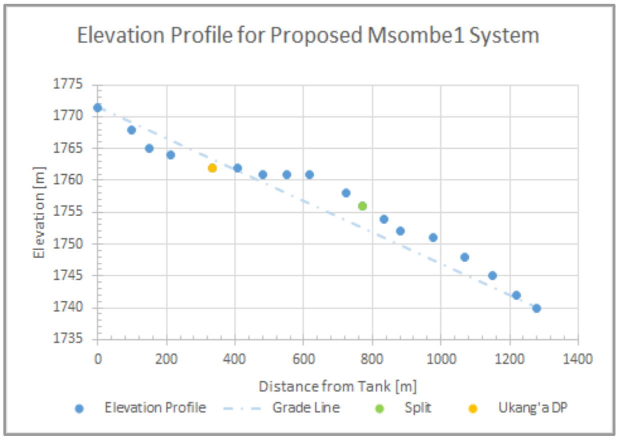
The solar panels, shown as the sun in Figure 5.2, will be installed on top of Josephine's house. Josephine is the chairwoman of the village's water committee. She and her family can then act as 'security' to watch over the expensive solar panels. In addition, the remote location of her home acts as another deterrent. The number and cost of solar panels was calculated using the average solar irradiation data for Tanzania year round and can be found in Appendix E. A power line will then be buried underground from her house about 100 meters from the borehole location, shown by the yellow circles. This bore hole is to be mud rotary dug and a pump dropped into the bore hole. Mud rotary was selected due to the strong evidence that a relatively shallow aquafer exists in this region.

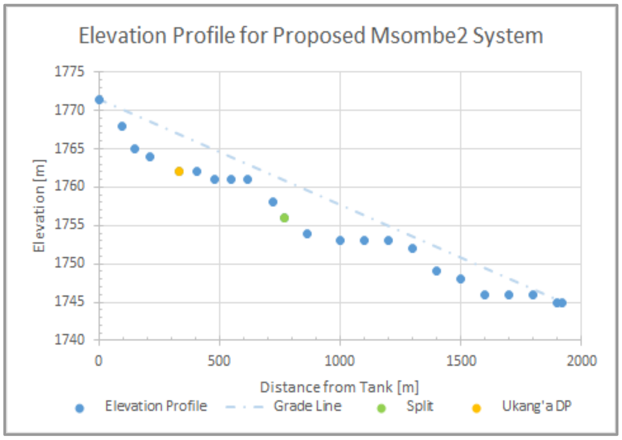
This submerged pump pumps water to two 10,000 liter SIM Tanks located a short distance away and represented by the orange square in the referenced figure. From the tank location, the pipe is laid underground to connect the tanks to the different DPs. The pipe is shown by the red line while the DPs are shown by the blue pins. The DP's are all located in places where the village's water committee noted to be the center of the subvillage. During our visit, it was observed that the locations identified by the water committee for DP's happened to be the most populated areas of the respective subvillages. The DP in Ukang'a is a double DP, meaning it possesses four valves to be utilized by the citizens of the subvillage. This is also the case for the Msombe DP1 because of the large populations of these locations as Tanzanian design guidelines recommend one DP for every 250 people. The Msombe DP2 is a single DP, only having two spigots.

The pipes' path and size were chosen using engineering modeling tools. Modeling analyses include the usage of the Energy and Mass Conservation Equations, which are used to analyze water flow through a pipe distribution system, assuming a steady state flow has been achieved in the pipe network.[1] The Energy Equation was solved using the commercial software package Engineering Equations Solver software to simultaneously solve a system of nonlinear equations in conjunction with the mass conservation constraints. Our code and summarized outputs are found in Appendix A of this report. The pipe path was chosen so that the pipe primarily stayed below a grade line, while following existing landscape features to minimally disturb the farm fields/infrastructure as much as possible. The pipe paths are shown below in Figure 5.3 with more detail.

This system supplies water for the nearly 1,400 people that live in Ukang'a and Msombe. The paths, shown in red, were created by following currently existing environment conditions and to be minimally invasive to the farm fields in the area. These paths were analyzed for their elevation change so that they could be optimized to avoid creating vacuum conditions in the pipelines or excessive pressures that might result in pipe failure. If the pipe were to be found above the grade line, a vacuum could be induced. Therefore, these points were analyzed as the valves were opened/closed within the system to guarantee that there was never a vacuum under numerous operating conditions. These grade lines and elevation profiles can be seen in Figure 5.4 and 5.5.

Figure 5.3: This figure displays the paths taken to connect the borehole to the tank to the different distribution points in Ukang'a and Msombe.





Figures 5.4 and 5.5: Figure 5.4 (left) shows the elevation profile from the tank to the Msombe DP1, while Figure 5.5 (right) shows the elevation profile from the tank to the Msombe DP2.

The elevation profiles are shown in the figures above and show the elevation every 75 meters as per Google Earth. It is important to note that the elevation profile for the Msombe1 System does cross over the grade line. The path was analyzed at these “high points” using EES. With EES, it was determined that the proposed path would still be a viable solution to deliver water. With the paths optimized for the elevation profile of the area, water demands were found for the served subvillage. These water demands drove the number of spouts installed at each distribution point. The proposed solution for Phase I is shown in a skeleton format below. It is followed by the results of EES computations proving that the design would fulfill the needs of the village.

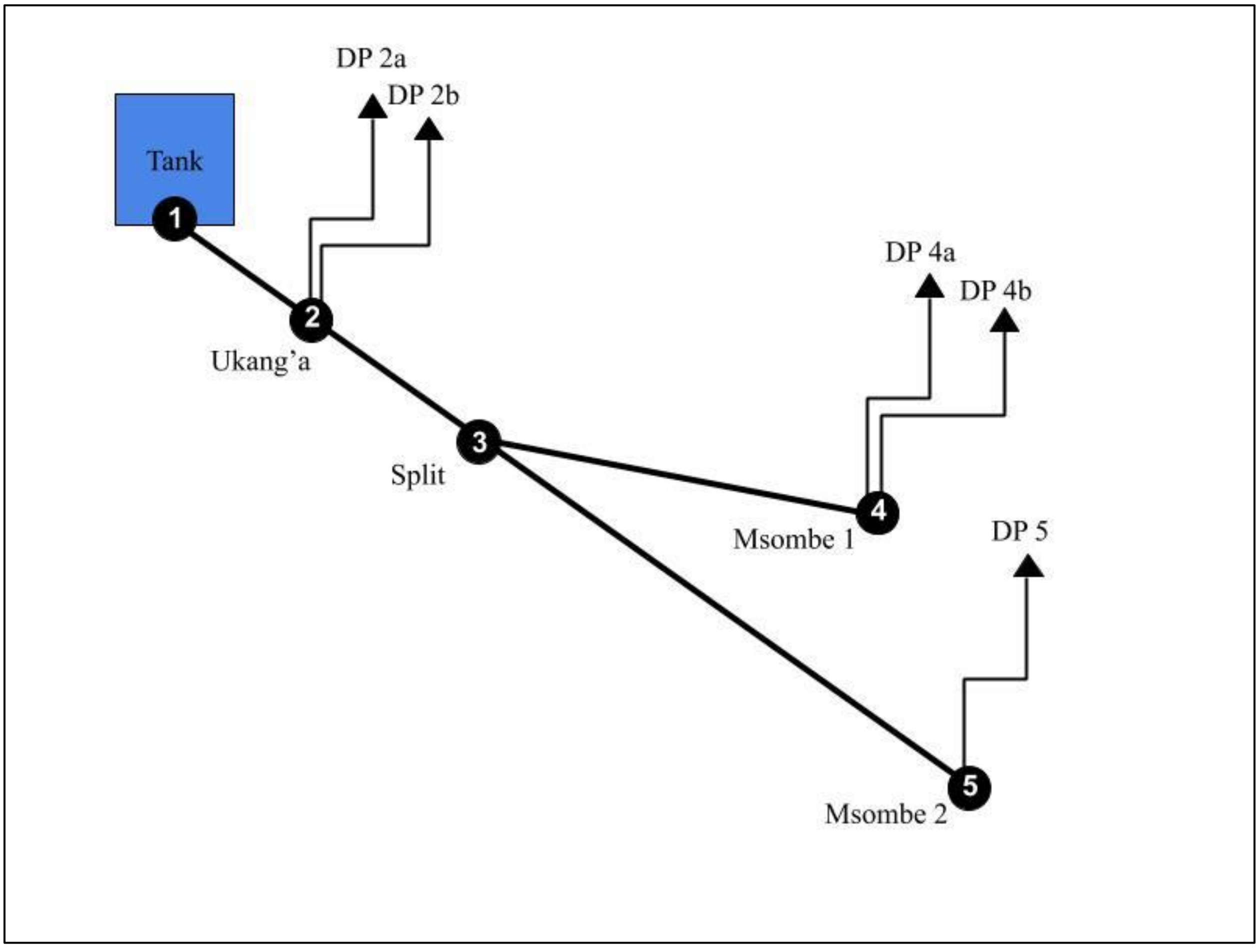


Figure 5.6: A simplified version of the piping network including the number of distribution points at each location.

Table 5.1: This table displays the optimized length, pipe size, and water output compared to the required output for each branch of the skeleton diagram in Figure 5.6.

Branch	Distance [m]	HDPE Class B Pipe Outer Diameter [mm]	Required Flowrate*[LPH]	Simulated Flowrate** [LPH]
1 → 2	350	63	6300	8100
2 → 3	440	63	4700	6200
3 → 4	520	40	3100	3200
3 → 5	1160	50	1600	3000
2 → DP2 (Ukang'a)	20	50	1600	1900
3 → DP4 (Msombe 1)	20	40	3100	3200
3 → DP5 (Msombe 2)	20	40	1600	3000

*Based on population data in 2018 and extrapolated to 2030, following Tanzanian design guidelines
**Simulated flow rates were calculated at peak hours assuming all valves are open at each DP. For the simplicity of this table, the double DPs have been combined.

When analyzing the required and simulated flowrate columns, it is evident that the designed system supplies enough water for the subvillages. As noted below the table, these values are during peak hours when all spigots are open. When one spigot closes, the simulated flowrate at the other spigots increases - thus exceeding requirements further. The DP piping is larger than normal for this system. This increase in diameter is done to avoid a vacuum within the pipe network. Having larger DP piping increases the pressure seen at point 3 (the split of the main pipe into two) - thus avoiding the vacuum. For the whole system, the B rating HDPE piping is sufficient due to the low pressures seen in the system from the lack of large elevations.

5.3 Phase II: Mlanda A, Mlanda B, and Dispensary Water System

Phase II of the Mlanda water delivery system utilizes a grid-powered pump to supply water to three strategic distribution points: Mlanda A, Mlanda B, and the dispensary. Mlanda A is the social center of the entire village and hosts the primary school, the community soccer field, and the town hall. Mlanda A was not identified as a top five priority, however, it is believed essential to automate access to water in an area that is used by so many people. Furthermore, the hand pump at Mlanda A is largely used by children at the primary school under the age of 10, and is quite difficult for them to operate. For reference, it took an entire minute for an athletic adult to fill a 20-liter bucket pumping as fast as possible. In addition, Mlanda B and the dispensary were third on the village priorities and encompass a significant portion of the population, which makes them essential to serve in Phase II of the overall system design. An overview of the Phase II system featuring important locations and paths exists in Figure 5.7.

Figure 5.7: This Google Earth screenshot depicts the Phase II water delivery system. The three DPs are marked in light blue. The system starts at the pre-existing borehole marked by the yellow target and fills the nearby tanks adjacent to the primary school. The gravity fed pipes, marked by the red path, flow out of the tanks, around the primary school, and along the road to the other DPs.

The Phase II system will be supplied with grid power and expected to reach Mlanda A by the end of 2020. The power lines are already in place, and come into the village along the road from the northwest. The grid powered system allows the pump to run 24 hours a day if needed to continuously fill two 10,000 liter tanks located next to the school. The village has agreed to pay the ongoing electricity cost and has a tax system in place to pay per household, for those able to pay. For grid electricity to run the submersible pump, a power line will branch from the main line to a control box where the voltage can be stepped down to practical levels. These considerations are included in the final pricing estimate later in the report.

This subsystem has the capacity to serve nearly 1,200 people in addition to the 700 students at the primary school and 30 daily patients at the dispensary. The Mlanda A DP is a double spout setup resulting in 4 spigots to service this area in accordance with the Tanzanian design guidelines. The Mlanda A DP is designed to be placed anywhere within 20 meters of the tanks, so some flexibility is allowed. The Mlanda B DP is also a double setup to supply its approximately 600 inhabitants and is located across the road from the old, underperforming Mlanda B hand pump. This location was chosen because Mlanda B likes where the pump currently resides, but we moved it slightly further downhill and closer to the road to maximize efficiency. Lastly, a single DP will be placed at the dispensary for the convenience of staff and as a potential overflow from other subvillages. This DP can be located anywhere within 20 meters of the dispensary coordinates.

After the DPs had been decided, a pipe path was chosen to deliver water from the tanks. Luckily for Phase II, all of the DPs are easily serviced from a main road. The pipes easily follow alongside the road, which prevents the disruption of farm fields and avoids trees and roots. The pipeline follows a reasonably steady grade as depicted in Figure 5.8.

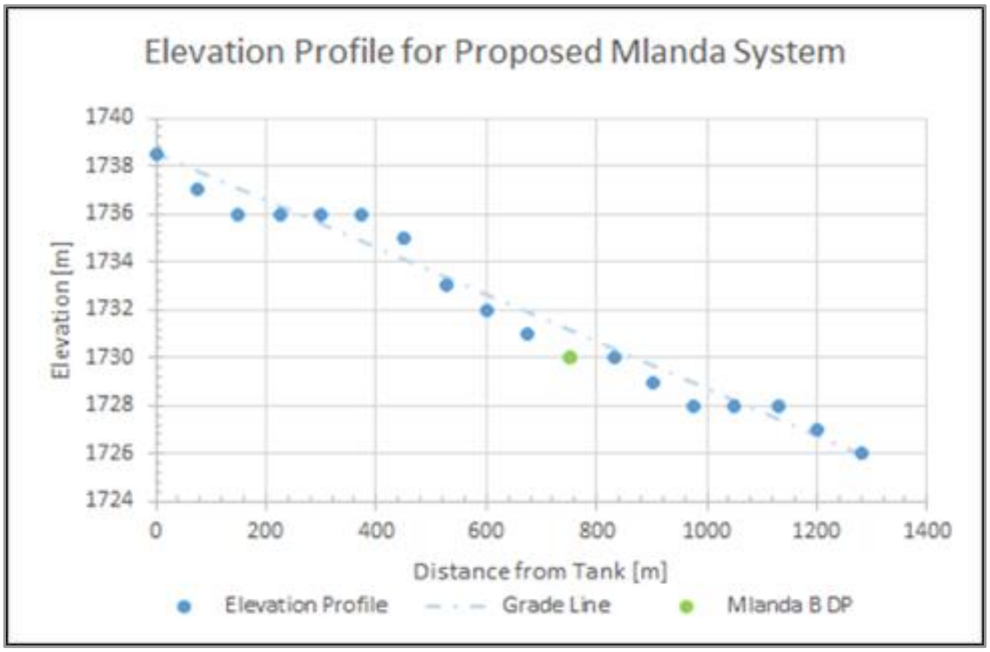


Figure 5.8: The gradeline and pipe elevation of the Phase II system starting at the tank and ending at the dispensary.

Any deviations above the gradeline are at risk for unsafe pipe pressures and are checked in Appendix A. After the pipe path was determined, the pipe diameters for each section were optimized to provide sufficient flow rates using the design guidelines. Similar to Phase I, an engineering analysis using the Energy and Mass Conservation equations were used to determine the flow rates based on pipe size, pipe length, and elevation change. Several iterations occured to determine the optimal pipe sizes. The pipe choices, required flow rates, and simulated flow rates are summarized in Table 5.2 . The system of equations developed to create this table are located in Appendix A along with a table outlining the flow rates and pressures given different valve combinations. Due to the relative flatness of Mlanda, low pressure class B pipe can again be used. A skeleton schematic of Phase II exists in Figure 5.9 to specify the nomenclature of our pipe branches.

It is evident from Table 5.2 that the Phase II design exceeds expectations and delivers a surplus of water to each target area.

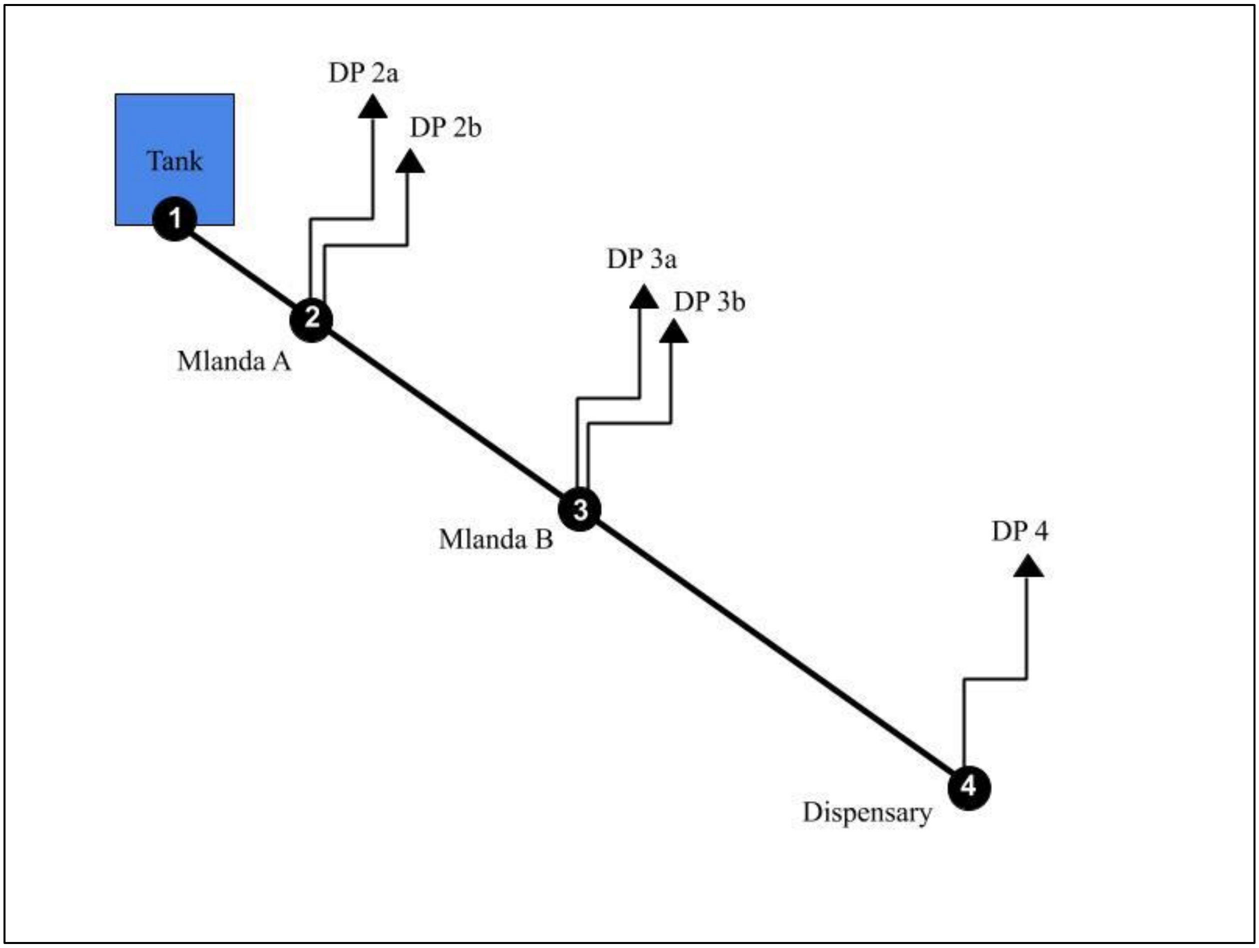


Figure 5.9: The essential points in our engineering analysis of Phase II are shown. The flow of water is represented as flowing from left to right, and from top to bottom in this schematic. This figure is expanded on in detail in Appendix A.

Table 5.2: Phase II Final Pipe Dimensions and Flow Rates by Branch

Branch	Distance [m]	HDPE Class B Pipe Outer Diameter [mm]	Required Flowrate*[LPH]	Simulated Flowrate** [LPH]
1 → 2	5	63	8200	10200
2 → 3	800	63	3500	5200
3 → 4	550	32	200	900
2 → DP2 (Mlanda A)	20	32	4700	5000
3 → DP3 (Mlanda B)	20	40	3300	4300
4 → DP4 (Dispensary)	20	32	200	900

*Based on population data in 2018 and extrapolated to 2030, following Tanzanian design guidelines
**Simulated flow rates were calculated at peak hours assuming all valves are open at each DP. For the simplicity of this table, the double DPs have been combined.

6.0 Alternative Design

6.1 General Information

This section focuses on potential setbacks that may occur during the construction of each phase and the reactive measures that the team recommends to ensure project success. Some alternative designs modify the drilling depth and locations which may impact pricing. In this case, alternative pricing is quoted in the itemized cost analysis of appendix H. Minor issues that do not affect the general design layout will be left to the discretion of the St. Paul Partners employees overseeing implementation.

6.2 Phase I Alternative

In the event where using a mud rotary borehole in Ukang'a does not strike water, an air hammer borehole will be drilled in a similar location. Air hammer drilling is capable of reaching deeper depths than mud rotary. Therefore, if water is not found with mud rotary, air hammer will be used to reach the rich aquifer that is expected to exist below the village of Mlanda.

6.3 Phase II Alternative

In the event that the pre-existing borehole at Mlanda A cannot be transitioned from a hand pump to a submersible pump, we recommend that a mud rotary hole be drilled within 50 meters to minimally alter the Phase II layout. If mud rotary is unsuccessful, a larger capital cost must be committed to attempt air hammer drilling to achieve a greater depth.

If grid power does not reach Mlanda A by the end of 2020, Phase I will continue as planned. The decision whether to switch Phase II to solar power will be determined at the end of Phase I construction. At the discretion of St. Paul Partners, Phase II may be delayed until power is confirmed or a transition to solar power is proposed. If solar power is determined to be the best course of action, the design plan is to place solar panels atop the primary school.

6.4 Additional Considerations

For both the primary and alternative designs for Phase I and Phase II, the locations of each of the distribution points and paths set for the pipe are subject to change as the design is being implemented. For example, if the ground is too hard to dig trenches in one area, the path will be shifted over to make it possible to lay the pipe. In most cases, the trenches will also be dug around farmland rather than through it unless absolutely needed and with the agreement of the impacted farmer. The distribution points were chosen based on the water committee's advice on where they would best help the villagers. However, in order to best help Mlanda, if a location is found to be better when the water system is being built, the distribution point will be placed there instead. These changes will occur as needed in order to continue to do what is best for the people of Mlanda. Another aspect of the alternative designs is the increase in price of the systems. Mud rotary drilling was originally chosen because of the expected high water table in Mlanda and the added benefit of a lower cost borehole. However, calculations were made to prepare for the possibility of air hammer being needed in both Mlanda A and Ukang'a. These new calculations are in Appendix H.

7.0 Impact of Design

7.1 Health and Safety

The proposed systems will decrease cases of waterborne illnesses in Mlanda such as cholera, typhoid, stomachache, and diarrhea. This decrease in illness is because the boreholes will be able to access clean water and the simtanks will allow for sanitary storage and protection from ground contaminants such as agricultural runoff. Mlanda's residents currently travel to other villages for health care, but the new dispensary will be built by early 2020. The completion of the dispensary will be wonderful for the village; however, without the water system, the dispensary will have to rely on the wetlands surface source or buckets of water brought from Mlanda A. The system is set to serve the dispensary where clean water is an invaluable resource for treating patients. The system will also lessen the dangers of walking for water for women and children. Mlanda has had previous cases of assaults on girls when they walk for water alone in the dark along the forest that leads to the wetlands, where not many villagers live. Introducing water distribution points in town within 500 meters of the residents will prevent children from walking long distances in secluded areas, keeping girls safer.

7.2 Environmental Impacts

The environmental impacts of the Mlanda system will be centered around digging the borehole in Ukang'a. Heavy equipment will need to be driven into the Mlanda area. However, because Mlanda is relatively flat and has well planned roads, this should cause little harm to the area. The proposed distribution point is within the middle of the Ukang'a subvillage and will be accessed through a villager's farmland with their permission. The farmland will recover from the effects of driving heavy equipment through it by the next planting season, so the economic losses will be minimized.

7.3 Economic Impact/Operating Cost/Sustainability

The design for Mlanda will significantly reduce the time it takes for villagers to get water each day. With less time spent getting water, villagers will have more time to farm or come up with other ways of making money to support their families. There will also be less time spent boiling water for cooking, decreasing the time women must spend preparing food each day. As the women would not have to boil the water, there would be less smoke inhalation as well. On top of this, children will be able to focus more on their education rather than getting water to their families.

Mlanda already has an established water committee with members from each subvillage. The committee currently collects 1000 shilling from each household per month for the maintenance of the Mlanda A borehole and other water systems. This money will be continued to be collected to support the electrical and maintenance costs for both the Mlanda and Ukang’a systems, and a meter will be used to charge villagers per liter collected if possible. The local fundi will be in charge of maintenance for both boreholes and the proposed distribution points.

8.0 Implementation Budget

8.1 Phase I and Phase II Budget

The prices for the budget were calculated using estimates from Cotex Industries and DPI Simba, solar power estimates from Sunnrgy Systems, and previous project budgets with a 5% price increase for each year to account for inflation. Tanzanian prices were exchanged using the current rate of 1 USD = 2,300 Tanzania Shilling (TSH), and the breakout of the system costs are in Tables 8.1 and 8.2 below.

Table 8.1: Budget for the Phase I design

Phase I					
Category	**Product**	**Description**	**Quantity**	**Per Unit Cost**	**Total Cost**
Raw Materials	Storage SIM Tank	10000 L	2	$1,140	$2,280
	Cement, reinforcement	Tank Foundation	2	$200	$400
	Sand and stone	Tank Foundation	2	$250	$500
	Tap fittings	5 DP = 10 taps	5	$220	$1,100
	Tank fittings, galv. steel	Connection for tank and pipe	2	$150	$300
	DP Concrete	Concrete DP locations	5	$250	$1,250
	Class B 63 mm HDPE PN 6	790 m/150 m= 5.3 rolls	5	$277	$1,384
	Class B 50 mm HDPE PN 6	1180 m/150 m = 7.9 rolls	8	$169	$1,348
	Class B 40 mm HDPE PN 6	560 m/150 m =3.7 rolls	4	$121	$483
	Piping Adaptors & Fittings	15% of HDPE Cost	$3,215	$0	$482
Pumping	Borehole Pump	0.5 HP Pump	1	$2,000	$2,000

System	Control Unit	Control for borehole in pump	1	$960	$960
	DC Wire	300 m at Ukang'a at $302/70 m	5	$302	$1,510
	Pump Adaptors & Fittings	10% of PVC Cost	$156	$0	$16
	Class E 32 mm uPVC	Borehole pipe for Ukang'a	19	$8	$156
	Cover Plate		1	$89	$89
	Safety Rope		1	$56	$56
	Solar Panels	250 W	14	$200	$2,800
Transportation	Pipe	Truck &/or Tractor	1	$200	$200
	Storage Tank	Truck &/or Tractor	2	$200	$400
	Concrete	Truck &/or Tractor	1	$200	$200
	Solar System	transportation, installment, and commission	1	$2,114	$2,114
Labor	Distribution Points	$10 per DP	5	$10	$50
	Trench digging	$2 per meter	2530	$2	$5,060
	Local Plumber	Sum	1	$700	$700
	Design and Supervision support by SPP Engineer	Per Day	2	$150	$300
	Mud Rotary Borehole	Ukang'a + Nyalawe	2	$4,200	$8,400
Health and Training	Training of scheme attendant and provision of basic tools		0.5	$350	$175
	Health and hygiene sanitation training		0.5	$100	$50
Funding	Preliminary Total				$34,762

Calculations		
	15% Contingency	$5,214
	SPP Charges at 15%	$5,214
	Total	**$45,191**
	In Kind Contribution (Labor Costs)	$5,110
	Required Funds (Total Cost - In Kind Contribution)	**$40,081**

Table 8.2: Budget for the Phase II design.

Phase II					
Category	**Product**	**Description**	**Quantity**	**Per Unit Cost**	**Total Cost**
Raw Materials	Storage SIM Tank	10000 L	2	$1,140	$2,280
	Cement, reinforcement	Tank Foundation	2	$200	$400
	Sand and stone	Tank Foundation	2	$250	$500
	Tap fittings	5 DP = 10 taps	5	$220	$1,100
	Tank fittings, galv. steel	Connection for tank and pipe	2	$150	$300
	DP Concrete	Concrete DP locations	5	$250	$1,250
	Class B 63 mm HDPE PN 6	805 m/150 m= 5.4 rolls	6	$277	$1,660
	Class B 40 mm HDPE PN 6	40 m/150 m = .3 rolls	1	$121	$121
	Class B 32 mm HDPE PN 6	630 m/150 m = 4.2 rolls	5	$68	$338
	Piping Adaptors & Fittings	15% of HDPE Cost	$2,119	$0	$318
Pumping System	Borehole Pump	0.5 HP AC Pump	1	$2,000	$2,000
	Control Unit	Control for borehole in pump	1	$960	$960

	AC Wire	140 m Mlanda at $151/70 m	2	$151	$302
	Pump Adaptors & Fittings	10% of PVC Cost	$73	$0	$7
	Control Hut Construction	1	1	$217	$217
	Class C 32 mm uPVc	Borehole pipe for Mlanda	13	$6	$73
	Cover Plate		1	$89	$89
	Safety Rope		1	$56	$56
	Power Line Extension	per meter	100	$5	$500
Transportation	Pipe	Truck &/or Tractor	1	$200	$200
	Storage Tank	Truck &/or Tractor	2	$200	$400
	Concrete	Truck &/or Tractor	1	$200	$200
Labor	Distribution Points	$10 per DP	5	$10	$50
	Trench digging	$2 per meter	1455	$2	$2,910
	Local Plumber (all plumbing including piping, borehole and DP's)	Sum	1	$700	$700
	Design and Supervision support by SPP Engineer	Per Day	2	$150	$300
Health and Training	Training of scheme attendant and provision of basic tools (pipe wrench, screw drivers and spanners)	each	0.5	$350	$175
	Health and hygiene sanitation training	each	0.5	$100	$50
Funding Calculations	Preliminary Total				$17,457
	15% Contingency				$2,619
	SPP Charges at 15%				$2,619
	Total				**$22,694**

	In Kind Contribution (Labor Costs)	$2,960
	Required Funds (Total Cost - In Kind Contribution)	**$19,734**

The total cost for both Phase I and Phase II combined is $59,814. While this price may seem very large, it is important to consider that this is one of the largest systems ever designed by this study abroad program. Mlanda is expansive in terms of size, about 10 km in diameter, but also in terms of locations of village centers. The subvillages themselves are spread far apart from one another, and each of these areas has its own center of congregation. It will take long stretches of pipe to serve each of those centers within Mlanda. This pipe is also large in diameter to avoid head losses as the water flows the long distances through the pipes. With this is the consideration of what the villagers themselves will be providing for the village, digging trenches these pipes must lay in, building tanks' concrete stands, and the continual maintenance and implementation of the distribution points. The people of Mlanda have agreed to provide these services and will contribute a total of $8,070 to the system.

8.2 Lifetime Cost Analysis

The current water committee in Mlanda charges each family a tax of 1,000 shilling per month to cover upkeep of the current borehole at Mlanda A and will continue charging this fee to cover maintenance costs of the proposed system. An important question posed to the water committee was that not all those who pay the water tax will be beneficiaries of the system, specifically Ilembula which has a water pump in good condition. The committee assured us that Ilembula would be happy to continue paying this tax because, "they love their neighbor and want what's best for the village." The Mlanda water committee keeps track of the individuals who cannot afford to pay the water tax each month, and has families that sponsor those families by paying their tax as well as their own. If meters are put into place at each distribution point, the committee discussed charging a small fee per bucket to cover miscellaneous costs of the water system.

A unique addition to our system that is not commonly found in other systems is the addition of a solar power system in Ukang'a instead of a power line extension. This was done because the ideal location for a borehole for the Phase I design was located in an area that would not be provided power for the foreseeable future and on raised elevation, away from any trees or other sunlight obstructions. Because of this decision, the upfront costs of the Phase I system are much higher. However, this also means the people of Mlanda will only have to pay the monthly power costs for Phase II rather than both Phase I and Phase II. Table 8.3 shows the monthly costs for the power systems for each phase. Each phase will also have a monthly cost associated with it for repairs and general upkeep. These can be seen in Tables 8.4 and 8.5. From these tables it can be seen that Mlanda will be able to run these systems on their current collection of 1,000 shillings per household because the projected monthly cost for both repairs and grid power will be about 100 shillings per person (approximately 5 cents) and the average household is about seven people.

Table 8.3: Cost Analysis for the power systems of each phase.

Power System	Upfront Cost	Monthly Cost
Phase I - Solar Power	$10,500	$0.00
Phase II - Grid Power	$2,400	$30.63

Table 8.4: Phase I lifetime cost analysis estimate.

Item	Cost (USD)	Lifetime Years	Cost/Year
Piping	$6,346.79	15	$423.12
Tank	$2,280.00	20	$114.00
Spigots	$1,100.00	10	$110.00
Solar Panels	$2,800.00	25	$112.00
Total	$647.12		

2018 Population	2,948
Cost per person/year (USD)	$0.22
Cost per person/year (TSH)	506 TSH

Table 8.5: Phase II lifetime cost analysis estimate.

Item	Cost	Lifetime Years	Cost/Year
Piping	$5,087.00	15	$339.13
Tank	$2,280.00	20	$114.00
Spigots	$1,100.00	10	$110.00
Total	$563.13		
2018 Population	2,948		
Cost per person/year (USD)	$0.19		
Cost per person/year (TSH)	440 TSH		

9.0 Appendices

Appendix A - Phase 1 EES Code

This section includes code that can be copied into Engineering Equation Solver to solve a system of Bernoulli’s and mass conservation equations. The outputs of the equations are organized in Appendix C along with an additional copy of the pipe schematic from section 6.

Tank to DP Code

{Ukang'a Sub System Head Equations}

{Initializing global parameters}

g = 9.81

rho = 997

f = 0.025

population = 1373

{DP Givens (ID’s)}

d_DP2 = 43.75/1000

d_DP4 = 35/1000

d_DP5 = 35/1000

L_DP = 20

{Elevations}

z1 = 1771.5 {added 2m to z1 the elevation to account for 1m pedestal and 2m of water}

z2 = 1764

z3 = 1758

z4 = 1741

z5 = 1747

{Pipe Lengths}

L12 = 350

L23 = 440

L34 = 520

L35 = 1160

{Pipe Diameters [m] (ID's)}

d12 = 55.125/1000

d23 = 55.125/1000

d34 = 35/1000

d35 = 43.75/1000

{Valve State (10 is open, 10e9 is closed)}

Kv2a = 10e9

Kv2b = 10e9

Kv4a = 10e9

Kv4b = 10e9

Kv5 = 10e0

```
{Main Junctions - Bernoulli}

{1-2}   p2/(rho*g) + z2 - z1 + V12^2/(2*g)*1.05*f*L12/d12 = 0

{2-3}   (p3-p2)/(rho*g) + z3 - z2 + V23^2/(2*g)*1.05*f*L23/d23 = 0

{3-4}   (p4-p3)/(rho*g) + z4 - z3 + V34^2/(2*g)*1.05*f*L34/d34 = 0

{3-5}   (p5-p3)/(rho*g) + z5 - z3 + V35^2/(2*g)*1.05*f*L35/d35 = 0


{DP's - Bernoulli}

{dP2A}   -p2/(rho*g) + V2DP2a^2/(2*g)*(1.05*f*L_DP/d_DP2 + Kv2a) = 0

{dP2B}   -p2/(rho*g) + V2DP2b^2/(2*g)*(1.05*f*L_DP/d_DP2 + Kv2b) = 0

{dP4A}   -p4/(rho*g) + V4DP4a^2/(2*g)*(1.05*f*L_DP/d_DP4 + Kv4a) = 0

{dP4B}   -p4/(rho*g) + V4DP4b^2/(2*g)*(1.05*f*L_DP/d_DP4 + Kv4b) = 0

{dP5}  -p5/(rho*g) + V5DP5^2/(2*g)*(1.05*f*L_DP/d_DP5 + Kv5) = 0


{Mass Conservation}

V12*d12^2 = V23*d23^2 + V2DP2a*d_DP2^2 + V2DP2b*d_DP2^2

V23*d23^2 = V34*d34^2 + V35*d35^2

V34*d34^2 = V4DP4a*d_DP4^2 + V4DP4b*d_DP4^2

V35*d35^2 = V5DP5*d_DP5^2


{Convert to LPH}

Q12 = 3600000*pi*d12^2/4*V12

Q23 = 3600000*pi*d23^2/4*V23

Q34 = 3600000*pi*d34^2/4*V34
```

```
Q35 = 3600000*pi*d35^2/4*V35

QDP2A = 3600000*pi*d_DP2^2/4*V2DP2a

QDP2B = 3600000*pi*d_DP2^2/4*V2DP2b

QDP4A = 3600000*pi*d_DP4^2/4*V4DP4a

QDP4B = 3600000*pi*d_DP4^2/4*V4DP4b

QDP5 = 3600000*pi*d_DP5^2/4*V5DP5


{Time to fill a bucket}

time_2 = QDP2A * 20 / 3600

time_4 = QDP4A * 20 / 3600

time_5 = QDP5 * 20 / 3600


{Finding Total Flow}

Flow_total = (2*QDP2A) + (2*QDP4A) + QDP5
```

Pump to Tank Code

```
{Constants}

g = 9.81

rho = 1000

f = 0.025


{Input Values}
```

```
Q_LPDay = 34325

d = 26.2/1000

L = 110

kv = 10 {is there a Kv if it flows straight into tank?}

z1 = 1770

z3 = 1670



{Intermediate Calculations}

Q_ms = Q_LPDay/(24*3600*1000)

A = pi*d^2/4

v = Q_ms/A

d_in = d*39.4


 {Pump Calculations}

W_pump = rho*v*A*g*(z1 - z3) + rho*v*A*v^2/2*(1.05*f*L/d+kv)

Loss = rho*v*A*v^2/2*(1.05*f*L/d+kv)

W_total = W_pump/(0.9*0.6)


{Final Values}

W_totalHP = W_pump/741

PercentLoss = Loss/W_pump*100
```

Appendix B - Phase 2 EES Code

This section includes code that can be copied into Engineering Equation Solver to solve a system of Bernoulli’s and mass conservation equations. The outputs of the equations are organized in Appendix D along with an additional copy of the pipe schematic from section 6.

Tank to DP Code

```
{MLANDA SUBSYSTEM}


{Initializing global parameters}

g = 9.81

rho = 997

f = 0.025


{Elevations - does not include buried 1m because it goes down and back up}

z1 = 1739 {TANK, Google earth = 1737m + 1m foundation + 2m water - 1m elevated DP}

z2 = 1737 {MLANDA A, ground level from Google earth}

z3 = 1731 {MLANDA B, ground level from Google earth, GPS range = 1724->1732}

z4 = 1727 {DISPENSARY, GPS elevation = 1730m - 2m foundation - 1m GPS in hand,
google=1726}


{Pipe Distances}

L12 = 5

L23 = 800

L34 = 550
```

L_DP = 20 {standard}

{Pipe Diameters - HDPE Class B}

d12 = 55.125/1000 {OD 63}

d23 = 55.125/1000 {OD 63}

d34 = 28/1000 {OD 32}

d_DP2 = 28/1000 {OD 32}

d_DP3 = 35/1000 {OD 40}

d_DP4 = 28/1000 {OD 32}

{Valve Conditions}

Kv2a = 10e9

Kv2b = 10e9

Kv3a = 10e9

Kv3b = 10

Kv4 = 10e9

{Main Junctions - Bernoulli}

{1-2} p2/(rho*g) + z2 - z1 + V12^2/(2*g)*1.05*f*L12/d12 = 0

{2-3} (p3-p2)/(rho*g) + z3 - z2 + V23^2/(2*g)*1.05*f*L23/d23 = 0

{3-4} (p4-p3)/(rho*g) + z4 - z3 + V34^2/(2*g)*1.05*f*L34/d34 = 0

{DPs - Bernoulli}

```
-p2/(rho*g) + V2DP2a^2/(2*g)*(1.05*f*L_DP/d_DP2 + Kv2a) = 0

-p2/(rho*g) + V2DP2b^2/(2*g)*(1.05*f*L_DP/d_DP2 + Kv2b) = 0

-p3/(rho*g) + V3DP3a^2/(2*g)*(1.05*f*L_DP/d_DP3 + Kv3a) = 0

-p3/(rho*g) + V3DP3b^2/(2*g)*(1.05*f*L_DP/d_DP3 + Kv3b) = 0

-p4/(rho*g) + V4DP4^2/(2*g)*(1.05*f*L_DP/d_DP4 + Kv4) = 0


{Mass Conservation}

V12*d12^2 = V23*d23^2 + V2DP2a*d_DP2^2 + V2DP2b*d_DP2^2

V23*d23^2 = V34*d34^2 + V3DP3a*d_DP3^2 +  V3DP3b*d_DP3^2

V34*d34^2 = V4DP4*d_DP4^2


{Convert to LPH}

Q12 = 3600000*pi*d12^2/4*V12

Q23 = 3600000*pi*d23^2/4*V23

Q34 = 3600000*pi*d34^2/4*V34

QDP2a = 3600000*pi*d_DP2^2/4*V2DP2a

QDP2b = 3600000*pi*d_DP2^2/4*V2DP2b

QDP3a = 3600000*pi*d_DP3^2/4*V3DP3a

QDP3b = 3600000*pi*d_DP3^2/4*V3DP3b

QDP4 = 3600000*pi*d_DP4^2/4*V4DP4
```

Pump to Tank Code

```
{Constants}
```

```
g = 9.81

rho = 1000

f = 0.025


{Input Values}

Q_LPDay = 38450

d = 40/1000

L = 70

kv = 10 {is there a Kv if it flows straight into tank?}

z1 = 1740

z3 = 1689



{Intermediate Calculations}

Q_ms = Q_LPDay/(24*3600*1000)

A = pi*d^2/4

v = Q_ms/A

d_in = d/25.4


 {Pump Calculations}

W_pump = rho*v*A*g*(z1 - z3) + rho*v*A*v^2/2*(1.05*f*L/d+kv)

Loss = rho*v*A*v^2/2*(1.05*f*L/d+kv)

W_total = W_pump/(0.9*0.6)
```

{Final Values}

W_totalHP = W_pump/741

PercentLoss = Loss/W_pump*100

Appendix C - Phase 1 Valve Conditions Affect on Outputs

In this section, the valves at each DP are tested with different open and closed configurations to verify velocities, flow rates, and pressures. The schematic of pipe and DP routes has been included again for the ease of the reader.

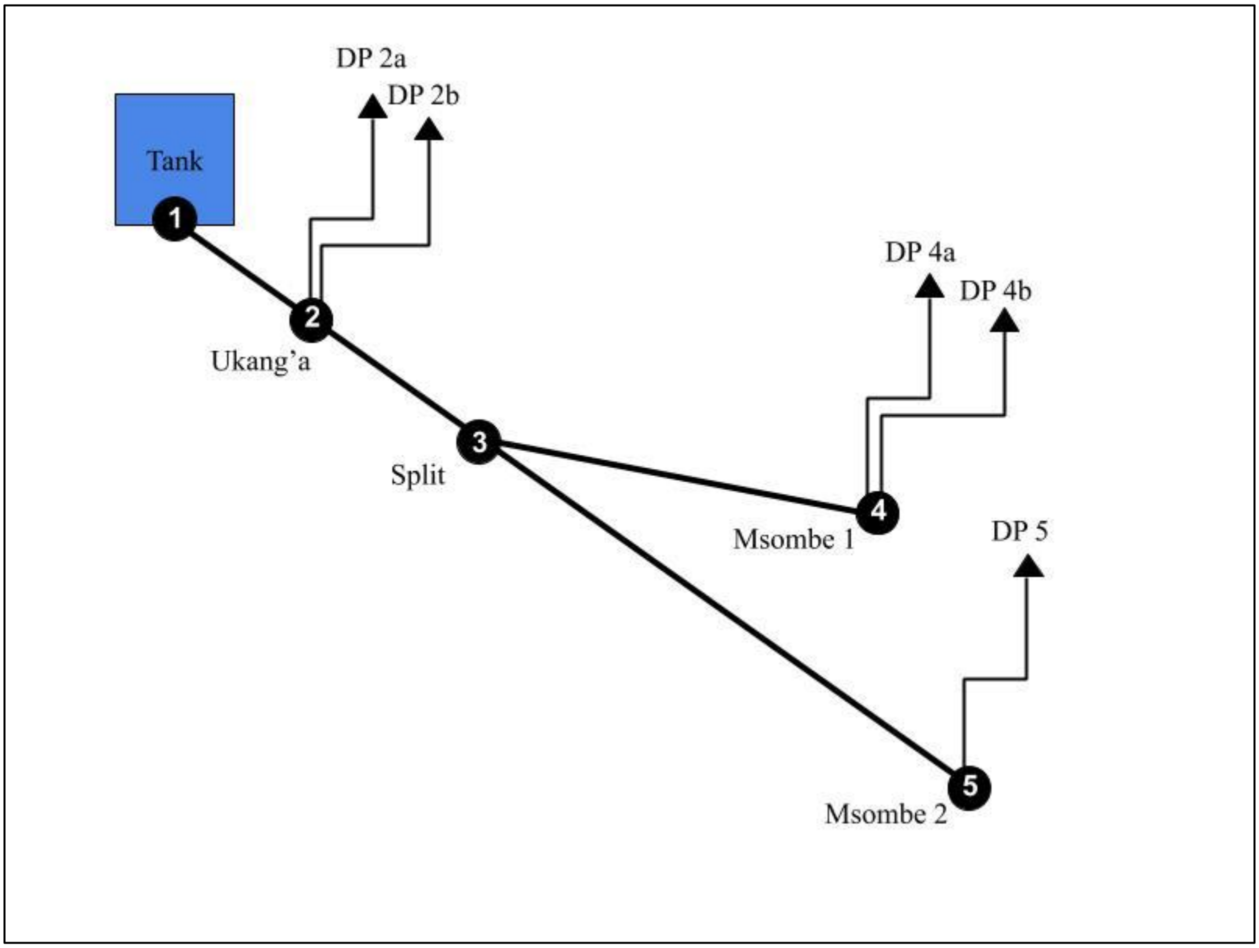


Figure C.1: Copy of pipe schematic

Tables C.1-3: Outputs of EES Code

Ukang'a Subsystem									
Valve Conditions						Branch Velocities [m/s]			
1= Open, 0 = Closed	Ukang'a		Msombe Main		Msombe Further	Ukang'a	Ukang'a to Split	Msombe Main	Msombe Further
Test	2A	2B	4A	4B	5	1-2	2-3	3-4	3-5
1	0	0	0	0	0	0	0	0	0
2	1	0	0	0	0	1.29	0	0	0
3	1	1	0	0	0	0.9	0	0	0
4	1	1	1	1	0	0.93	0.42	1	0
5	1	1	1	1	1	0.94	0.72	0.93	0.55
6	1	1	0	0	1	0.93	0.4	0	0.64
7	0	0	1	0	0	0.45	0.45	1.1	0
8	0	0	1	1	0	0.46	0.46	1.14	0
9	0	0	1	1	1	0.76	0.76	0.98	0.59
10	0	0	0	0	1	0.46	0.46	0	0.73

Ukang'a Subsystem										
Valve Conditions						Q - Flow Rates [LPH]				
1= Open, 0 = Closed	Ukang'a		Msombe Main		Msombe Further	Ukang'a		Msombe Main		Msombe Further
Test	2A	2B	4A	4B	5	2A	2B	4A	4B	5
1	0	0	0	0	0	0	0	0	0	0
2	1	0	0	0	0	6991	0	0	0	0
3	1	1	0	0	0	3878	3878	0	0	0
4	1	1	1	1	0	2205	2205	1781	1781	0
5	1	1	1	1	1	937	937	1612	1612	2956
6	1	1	0	0	1	2268	2268	0	0	3429
7	0	0	1	0	0	0	0	3883	0	0
8	0	0	1	1	0	0	0	1981	1981	0
9	0	0	1	1	1	0	0	1693	1693	3178
10	0	0	0	0	1	0	0	0	0	3941

Ukang'a Subsystem									
Valve Conditions						Branch Pressures [BAR]			
1= Open, 0 = Closed	Ukang'a		Msombe Main		Msombe Further	Ukang'a	Msombe Split	Msombe Main	Msombe Further
Test	2A	2B	4A	4B	5	2	3	4	5
1	0	0	0	0	0	0.8	1.3	3	2.4
2	1	0	0	0	0	0.2	0.8	2.4	1.9
3	1	1	0	0	0	0.05	0.7	2.3	1.7
4	1	1	1	1	0	0.02	0.4	0.03	1.5
5	1	1	1	1	1	0.003	0.05	0.03	0.09
6	1	1	0	0	1	0.02	0.4	2.1	0.1
7	0	0	1	0	0	0.6	1	0.2	2
8	0	0	1	1	0	0.6	0.9	0.04	2
9	0	0	1	1	1	0.3	0.3	0.03	0.1
10	0	0	0	0	1	0.6	0.9	2.6	0.2

Appendix D - Phase 2 Valve Conditions Affect on Outputs

In this section, the valves at each DP are tested with different open and closed configurations to verify velocities, flow rates, and pressures. The schematic of pipe and DP routes has been included again for the ease of the reader.

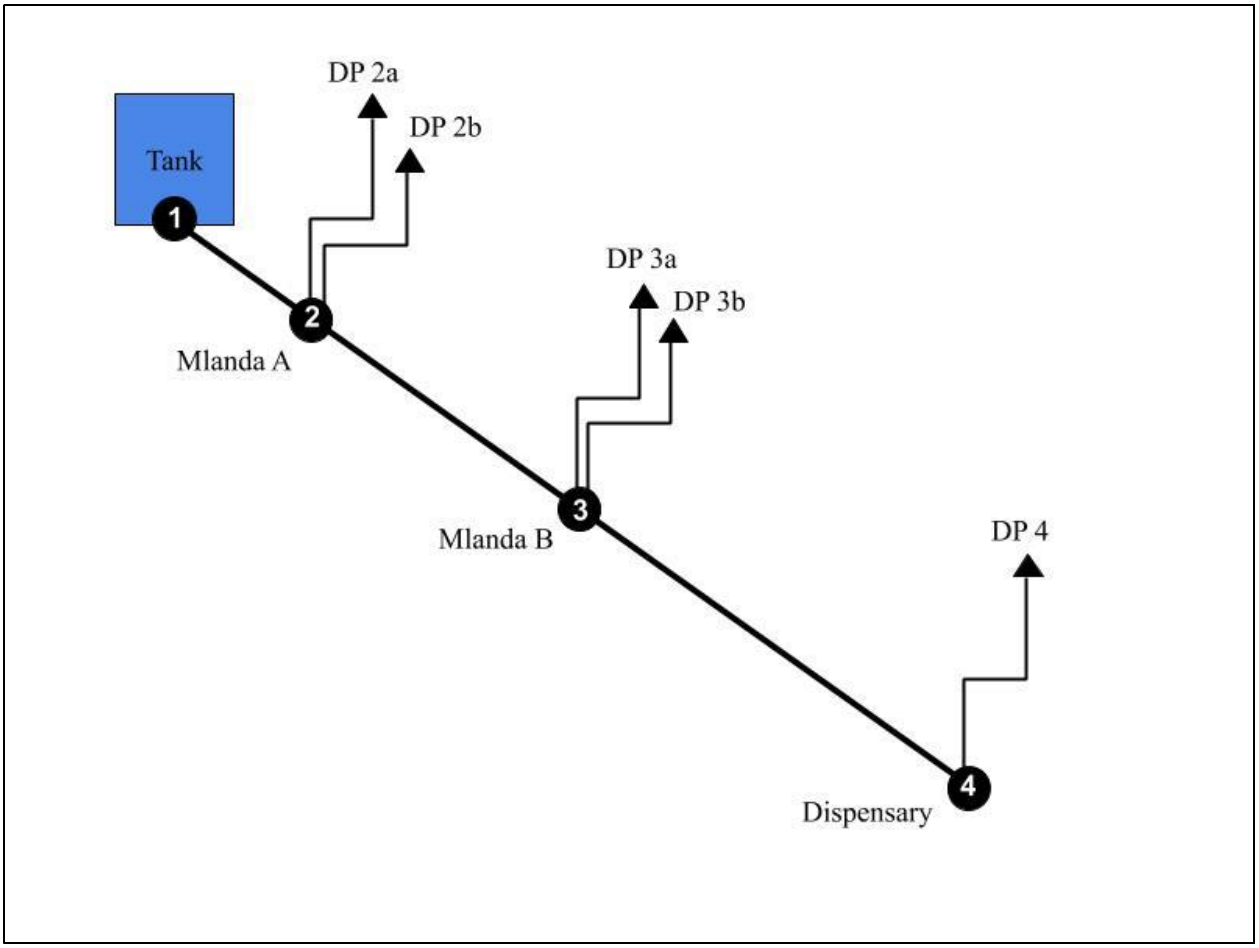


Figure D.1: Copy of pipe schematic

Tables D.1-3: Outputs of EES Code

Mlanda Subsy									
Valve Conditions					Branch Velocities [m/s]				
	Mlanda A		Mlanda B		Dispensary	Mlanda A	Mlanda B	Dispensary	Max
Test	2A	2B	3A	3B	4	1-2	2-3	3-4	DP
1	0	0	0	0	0	0.001	0.0001	0.0001	0.0001
2	1	1	1	1	1	1.19	0.6139	0.4	1.12
3	1	1	0	0	0	0.59	0.0001	0.0001	1.15
4	0	0	1	1	0	0.61	0.61	0.0001	0.77
5	0	0	0	0	1	0.166	0.17	0.65	0.65
6	0	1	0	0	0	0.3	0.001	0.0001	1.2
7	0	0	0	1	0	0.54	0.54	0.0001	1.34

Mlanda Subsystem										
Valve Conditions						Q - Flow Rates [LPH]				
	Mlanda A		Mlanda B		Dispensary	Mlanda A		Mlanda B		Dispensary
Test	2A	2B	3A	3B	4	2A	2B	3A	3B	4
1	0	0	0	0	0	0.13	0.13	0.43	0.43	0.34
2	1	1	1	1	1	2476	2476	2191	2191	893
3	1	1	0	0	0	2562	2562	0.43	0.43	0.34
4	0	0	1	1	0	0.14	0.14	2621	2621	0.21
5	0	0	0	0	1	0.14	0.14	0.42	0.42	1425
6	0	1	0	0	0	0.14	2583	0.44	0.44	0.34
7	0	0	0	1	0	0.14	0.14	0.23	4644	0.25

Mlanda Subsystem								
Valve Conditions						Branch Pressures [BAR]		
	Mlanda A		Mlanda B		Dispensary	Mlanda A	Mlanda B	Dispensary
Test	2A	2B	3A	3B	4	2	3	4
1	0	0	0	0	0	0.2	0.78	1.17
2	1	1	1	1	1	0.18	0.05	0.02
3	1	1	0	0	0	0.2	0.77	1.17
4	0	0	1	1	0	0.2	0.07	0.46
5	0	0	0	0	1	0.2	0.73	0.06
6	0	1	0	0	0	0.2	0.78	1.17
7	0	0	0	1	0	2	0.22	0.61

Appendix E - Solar Panel Effectiveness in the Area and Related Calculations

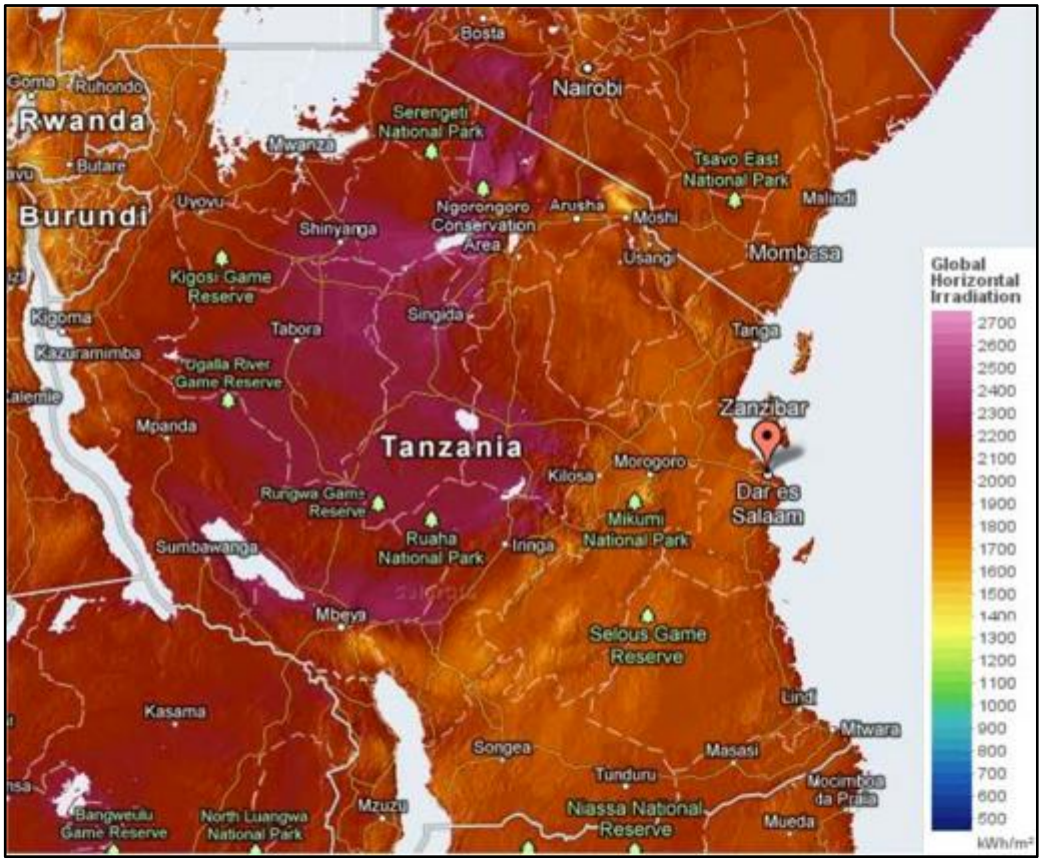


Figure E.1: Map of the global horizontal irradiation distribution for Tanzania used to determine the solar power available in Mlanda.

Calculations for the solar system were done using the total amount of water needed to serve the Phase I design and breaking this down into the rate needed to fill the tank each day in liters per hour. The pump was considered to only be usable for 8 hours per day because the solar panels are only operable during peak daylight hours.

$$Water_{needed} = 34{,}000 \left[\frac{L}{day}\right]$$

$$Pumping\ Rate = 34{,}000 \left[\frac{L}{day}\right] \times 8 \left[\frac{pumping\ hours}{day}\right] = 4250\ [LPH]$$

The energy required to pull this much water out of the tank each day was then calculated using the 4250 LPH converted to 35 m^3/day and the 100 m elevation change the water has to overcome to make it into the tanks from the borehole.

$$E = mgh = V\rho gh = 35\left[\frac{m^3}{day}\right] \times 1000\left[\frac{kg}{m^3}\right] \times 9.81\left[\frac{m}{s^2}\right] \times 100[m] = 31\ \left[\frac{MJ}{day}\right]$$

The total energy available per hour was estimated using the irradiance distribution map. In this case Mlanda is slightly southeast of the city of Iringa, so the estimated value used was 2 MJ/m^2. With a pump efficiency of 60%, an electrical efficiency of 90%, and an overall pumping efficiency of 15%, the actual energy that could be obtained from the original 2 MJ/m^2 was calculated.

$$E_{available} = 1.5\left[\frac{MJ}{m^2}\right]$$

The area needed to be covered to absorb the total power to fill the tank was then calculated using the energy needed divided by the energy available per square meter.

$$Area = 31\left[\frac{MJ}{day}\right] \div 1.5\left[\frac{MJ}{m^2}\right] = 21\ [m^2]$$

The number of solar panels could then be found using the average size of the Sunnrgy solar panels, about 1.5 m^2. The total cost to install these panels could then be calculated using the Sunnrgy invoices from past Design for Life systems.

$$Number\ Panels = 21[m^2] \div 1.5[m^2] = \mathbf{14\ panels}$$

$$Price = 14\ [panels] \times 200\left[\frac{\$}{panel}\right] = \$\mathbf{2,800}$$

Appendix F - Water Testing Results

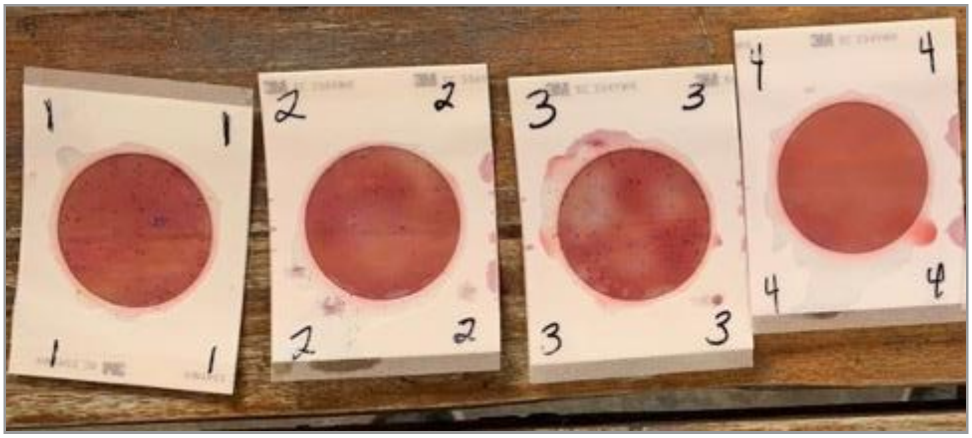


Figure F.1: Water test results for the three surface sources and Mlanda A handpump (4). The blue colonies indicate the presence of *E. Coli* and the red colonies indicate coliform. The pond source is (1), the river source is (2), and the wetlands source is (3).

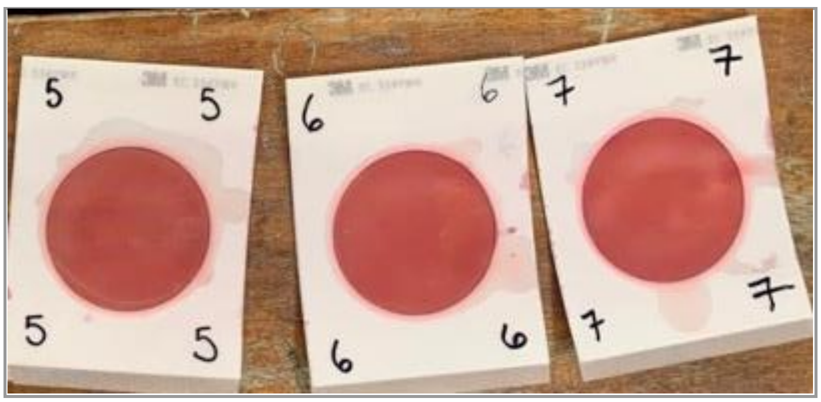


Figure F.2: Water test results for the working hand pumps in Mlanda. No coliform or *E. Coli* colonies were present for any sample. The handpump in Nyalawe is (5), the handpump in Ilembula is (6), and the handpump in Mlanda B is (7).

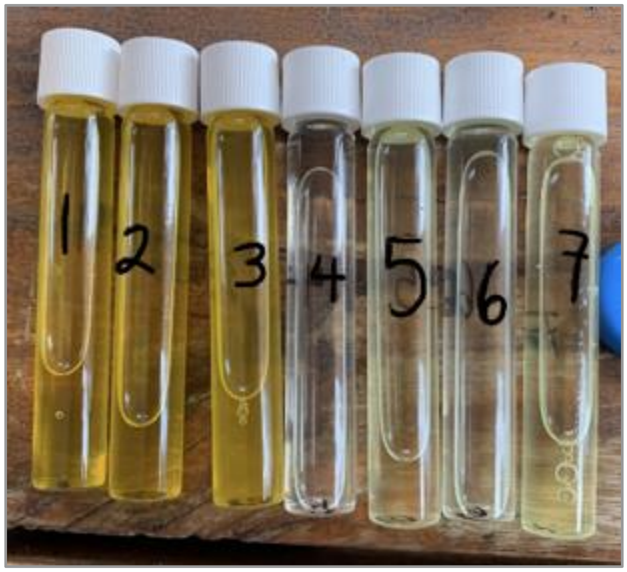


Figure F.3: These images show the water test results from the wetlands (1), the pond (2), and the river (3) locations. The image on the left, shows that all three locations test positive for the presence of coliform due to the yellow color of the water. The image on the right indicates that all three locations test positive for the presence of *E. Coli* due to their fluorescence in black light. The hand pump in Mlanda A is (4), the hand pump in Nyalawe is (5), the hand pump in Ilembula is (6), and the handpump in Mlanda B is (7).

Appendix G - Mlanda Current Water Sources Summary Table

Table G.1: Summary of the current water sources used in Mlanda.

Subvillage	Source(s)	Status	Contamination
Mlanda A	Borehole hand pump	Sufficient Output	Clean
Mlanda B	Shallow hand pump Wetlands	Insufficient Output N/A	Clean E. Coli and Coliform
Ilembula	Shallow hand pump	Sufficient Output	Clean
Nyalawe	Shallow hand pump	Insufficient Output	Clean
Msombe	Shallow hand pump River Pond	No Output N/A N/A	N/A E. Coli and Coliform E. Coli and Coliform
Ukang'a	N/A	N/A	N/A

Appendix H - Alternative System Pricing

Table H.1: Summary of costs for each component of the alternative designs for Phase I and Phase II.

Category	**Phase I**	**Phase II**
Mud Rotary Drilling	$13,800	$9,600
Pump and Power System	$10,500	$4,200
Distribution System	$6,350	$5,090
4x 10,000 L Tanks	$3,180	$3,180
Labor and Transportation Costs	$4,140	$2,030
Subtotal	$40,160	$27,000
Contingency at 15%	$6,020	$4,100
SPP Charges at 15%	$6,020	$4,100
Total Cost	$52,210	$35,170
In Kind Contribution	$5,110	$2,960

Required Funds (Total-In Kind Contribution)	$47,100	$32,210

Table H.2: Itemized cost analysis of alternative Phase I design.

Phase I					
Category	**Product**	**Description**	**Quantity**	**Per Unit Cost**	**Total Cost**
Raw Materials	Storage SIM Tank	10000 L	2	$1,140	$2,280
	Cement, reinforcement	Tank Foundation	2	$200	$400
	Sand and stone	Tank Foundation	2	$250	$500
	Tap fittings	5 DP = 10 taps	5	$220	$1,100
	Tank fittings, galv. steel	Connection for tank and pipe	2	$150	$300
	DP Concrete	Concrete DP locations	5	$250	$1,250
	Class B 63 mm HDPE PN 6	790 m/150 m= 5.3 rolls	5	$277	$1,384
	Class B 50 mm HDPE PN 6	1180 m/150 m = 7.9 rolls	8	$169	$1,348
	Class B 40 mm HDPE PN 6	560 m/150 m =3.7 rolls	4	$121	$483
	Piping Adaptors & Fittings	15% of HDPE Cost	$3,215	$0	$482
Pumping System	Borehole Pump	0.5 HP Pump	1	$2,000	$2,000
	Control Unit	Control for borehole in pump	1	$960	$960
	DC Wire	300 m at Ukang'a at $302/70 m	5	$302	$1,510
	Pump Adaptors &	10% of PVC Cost	$156	$0	$16

	Fittings				
	Class E 32 mm uPVC	Borehole pipe for Ukang'a	19	$8	$156
	Cover Plate		1	$89	$89
	Safety Rope		1	$56	$56
	Solar Panels	250 W	14	$200	$2,800
Transportation	Pipe	Truck &/or Tractor	1	$200	$200
	Storage Tank	Truck &/or Tractor	2	$200	$400
	Concrete	Truck &/or Tractor	1	$200	$200
	Solar System	transportation, installment, and commission	1	$2,114	$2,114
Labor	Distribution Points	$10 per DP	5	$10	$50
	Trench digging	$2 per meter	2530	$2	$5,060
	Local Plumber	Sum	1	$700	$700
	Design and Supervision support by SPP Engineer	Per Day	2	$150	$300
	Mud Rotary Borehole	Nyalawe	1	$4,200	$4,200
	Air hammer Borehole	Ukang'a	1	$9,600	$9,600
Health and Training	Training of scheme attendant and provision of basic tools	each	0.5	$350	$175
	Health and hygiene sanitation training	each	0.5	$100	$50
Funding Calculations	Preliminary Total				$40,162
	15% contingency				$6,024
	SPP charges 15% (project direction and oversight)				$6,024

	Total	**$52,211**
	In Kind Contribution (Labor Costs)	$5,110
	Required Funds (Total Cost - In Kind Contribution)	**$47,101**

Table H.3: Itemized cost analysis of alternative Phase II design.

Phase II					
Category	**Product**	**Description**	**Quantity**	**Per Unit Cost**	**Total Cost**
Raw Materials	Storage SIM Tank	10000 L	2	$1,140	$2,280
	Cement, reinforcement	Tank Foundation	2	$200	$400
	Sand and stone	Tank Foundation	2	$250	$500
	Tap fittings	5 DP = 10 taps	5	$220	$1,100
	Tank fittings, galv. steel	Connection for tank and pipe	2	$150	$300
	DP Concrete	Concrete DP locations	5	$250	$1,250
	Class B 63 mm HDPE PN 6	805 m/150 m= 5.4 rolls	6	$277	$1,660
	Class B 40 mm HDPE PN 6	40 m/150 m = .3 rolls	1	$121	$121
	Class B 32 mm HDPE PN 6	630 m/150 m = 4.2 rolls	5	$68	$338
	Piping Adaptors & Fittings	15% of HDPE Cost	$2,119	$0	$318
Pumping System	Borehole Pump	0.5 HP AC Pump	1	$2,000	$2,000
	Control Unit	Control for borehole in pump	1	$960	$960
	AC Wire	140 m Mlanda at $151/70 m	2	$151	$302

	Pump Adaptors & Fittings	10% of PVC Cost	$73	$0	$7
	Control Hut Construction	1	1	$217	$217
	Class C 32 mm uPVc	Borehole pipe for Mlanda	13	$6	$73
	Cover Plate		1	$89	$89
	Safety Rope		1	$56	$56
	Power Line Extension	per meter	100	$5	$500
Transportation	Pipe (4 rolls per trip)	Truck &/or Tractor	1	$200	$200
	Storage Tank (1 tank per trip)	Truck &/or Tractor	2	$200	$400
	Concrete	Truck &/or Tractor	1	$200	$200
Labor	Distribution Points	$10 per DP	5	$10	$50
	Trench digging	$2 per meter	1455	$2	$2,910
	Local Plumber (all plumbing including piping, borehole and DP's)	Sum	1	$700	$700
	Design and Supervision support by SPP Engineer	Per Day	2	$150	$300
	Airhammer Borehole	Mlanda A	1	$9,600	$9,600
Health and Training	Training of scheme attendant and provision of basic tools (pipe wrench, screw drivers and spanners)	each	0.5	$350	$175
	Health and hygiene sanitation training	each	0.5	$100	$50
Funding Calculations	Preliminary Total				$27,057
	15% contingency				$4,059
	SPP charges 15% (project direction and oversight)				$4,059
	Total				**$35,174**

In Kind Contribution (Labor Costs)	$2,960
Required Funds (Total Cost - In Kind Contribution)	**$32,214**

Appendix I - Tanzanian Design Guidelines

Tanzania Design Guidelines

- The design period should be for a minimum of 10 years. Recent population data should be inflated at a rate of 1.5% per year. This means that all designs should design for a 16% population growth, i.e. $(1.015)^{10} = 1.16$.

- Water demand should be based on 25 liters per person per day. For schools the design should be for 10 liters per student per day.

- The system should be designed to accommodate 2.5 times the average rate of demand. Hourly water demand is bimodal, with the largest peak in the morning, followed by a lull around noon, and a second peak in the late afternoon. The average rate of demand is determined by the total daily demand divided by a 12-hour day.

- The system should have a minimum water storage capacity equal to 50% of the average daily demand

- The minimum capacity of each 'spigot' should be 10 liters/min. Each DP (distribution point) should be designed with a T having 2 spigots, so each DP should be able to provide 20 liters/min.

- The pipe surface roughness: PVC and HDPE 0.01 mm; galvanized steel 0.15 mm (relative roughness epsilon/d is roughness divided by internal pipe diameter)

- The maximum working pressure for a pipe should be approximately 80% of rating. For example: a HDPE pipe is rated at PN8. PN8 stands for 8 bars or 116 psig. Therefore, it shouldn't be used in environments where the pressure exceeds 0.8*116 psig, or 93 psig.

- Design for a total water loss of 20-25% (leaks, valves left open, etc.)

- Washout valves and air bleed valves may be required for undulating pipe layouts, low points and high points, respectively.

- Isolation valves need to be used at all branches and at 3 km intervals on straight sections.

- One DP can serve a maximum of 250 people. Maximum walking distance to a DP is 400 m.

- The velocity of water in a pipe should typically be in the range of 0.5 – 1.5 m/sec. Slower than 0.5 m/sec usually means you pipe is too large, larger may lead to water hammer.

- Lines should be buried a minimum of 1 meter. Sunlight degrades HDPE and farming practices can damage pipes laid near the surface.

- All minor losses should be modeled at 5% of major losses. Treat valves separately

- Add 15% to pipe costs for fittings; add 20% to supply costs (pipe/tank/concrete) for shipping