University of Minnesota
Design for Life: Water in Tanzania
2020

Water Supply System for Mibikimitali, Tanzania

"Tall Tree"
S 08° 07.209' E 35° 32.528'

Maji Ni Uhai
"Water is Life"

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Executive Summary

Mibikimitali is home to 1284 people that reside throughout three sub villages: Masimike, Mibikimitali, and Ulangala. Currently, the citizens of the villages collect water from various natural sources, shallow wells, and boreholes. These wells are less than 50 meters deep, and many of these sources are already dry within three months of implementation. Many of these sources, both wells and natural sources, were tested and E.Coli was present in all but one of them. For a small remote village in central Tanzania, the village had an extremely large number of cows, more than 500 cows. It was apparent that the main source of income for the village is livestock and agriculture. The village built a permanent concrete structure for use as a cow wash where the village cows are washed every Friday. This cow wash is located near a natural source and contributes to the contaminated water sources that are used by the residents of the village. When touring the dispensary we were informed that close to 200 people come in every month for illnesses that are linked to unsafe drinking water. Knowing this, there is a great need for a clean and sustainable water system in the village of Mibikimitali.

The topography of Mibikimitali made for a rather challenging as Mibikimitali is fairly flat in elevation, except for two relatively high points of elevation; one of the higher points in the village is the village center located in Masimike. The other high point of elevation was located in the southern portion of Mibikimitali in the sub village of Ulangala. This high point is located on the top of a hill named Kotanga. Kotanga is approximately 3 kM away from the village center and is fairly unpopulus. Leveraging this highpoint, the proposed design specifies that a borehole is to be estabilited at this location, which is expected to require air hammer drilling. This borehole will then be outfitted with a pump and connected to two 10,000 liter storage tanks; as the village is on grid power, and the pump would be powered by grid electricity.

A gravity-fed distribution system will allow the flow of water to Masimike and Mibkimitali from the storage tanks. Using 2.4 km of buried HDPE piping will lead to three distribution points in Masimike and two distribution points in Mibikimitali. In Masimike, HDPE piping starts at the storage tanks and travels 237 meters to the village center, where the first distribution point is located. Then, the pipe branches into two directions, including the dispensary and primary school. For the Mibikimitali sub-village, the pipe will reach an area of high population density, which is near the Lutheran church. The system will reach approximately 1,066 people. The total cost for Phase 1 of is $33,150, while the village will provide twenty percent of the cost as in-kind contribution ($6750). The price per person is $17.60.

The people of Mibikimitali appear to be extremely eager to start the work to achieve a more sustainable water system. They have expressed their desire to better the health of the village, leading to fewer visits to the dispensary and providing a better use of time for their women and children.

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2.0 Project Profile

2.1 Project Location

Region: Iringa, Tanzania
Place: Mibikimitali Village
Coordinates of Village Center: S 08° 07.209’ E 35° 32.528’
Climate: Medium elevation, wet season January-May, dry season June-December

Figure 2.1 below shows Mibikimitali’s location in the central highlands of Tanzania. Mibikimitali is approximately 60 Km southwest of Iringa, which is where the lutheran center is located. A map, generated by this group, details the landmarks of Mibikimitali is shown in Figure 2.2. This map shows both physical and topographical landmarks in the village. Mibikimitali is approximately 12 kM North to South and 8 kM East to West. The map details a 4 kM by 4 kM of the more populous regions of the village. The village is home to approximately 1284 people and 284 families. The three sub villages and subsequent populations are also labeled on the map along with churches, schools, the city center, dispensaries, and known water source locations.

Figure 2.1: Map of the Iringa Region

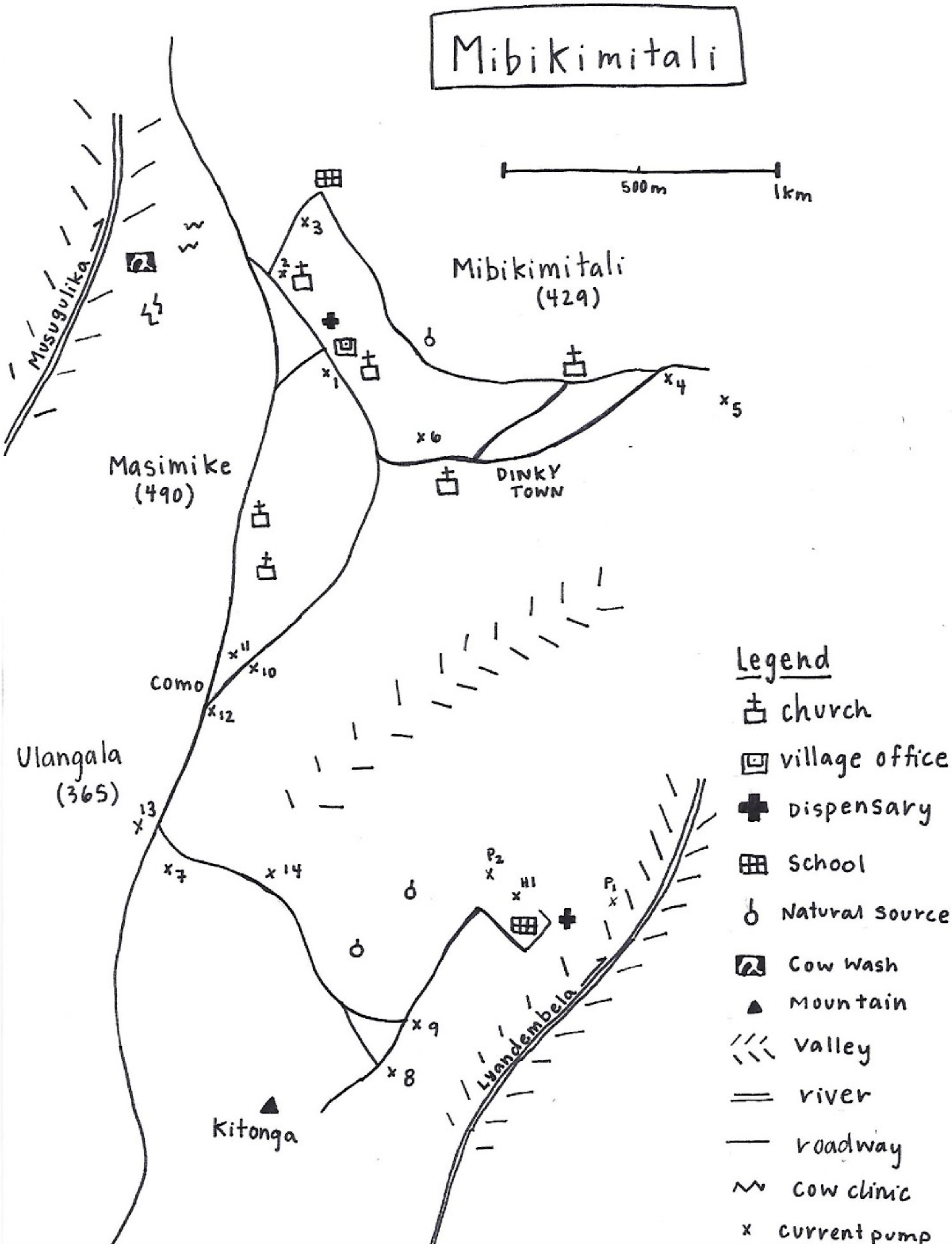

Figure 2.2: Map of Mibikimitali Village

2.2 Project Budget

An overview of the estimated budget is shown in Table 2.1. The itemized costs are shown in **Appendix D**. The in-kind contribution will be provided by the citizens of the village, including labor. Their contribution accounts for various items of the budget, but it will cover over 20% of the total cost of the design. The total cost is itemized in Figure 2.3.

Table 2.1. Summarized Costs

Total Cost	$31,500
In Kind Contribution	- $6,750
Final Cost	$24,750
Price Per Person	$16.50

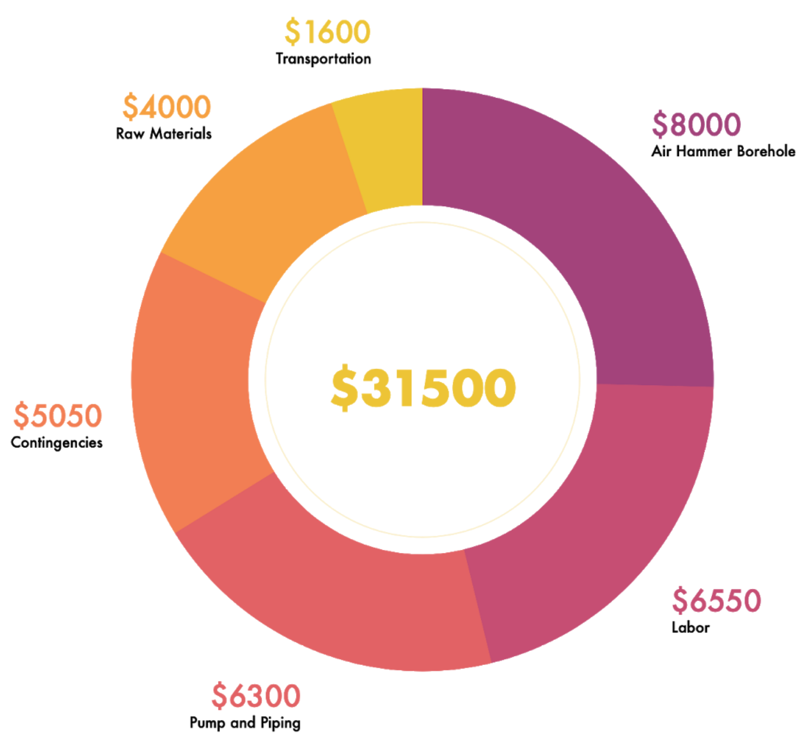

Figure 2.3: Overview of the Summarized Costs

3.0 Background

3.1 Mibikimitali Village

Mibikimitali is a village in the Iringa region of Tanzania. It is located to the southwest of Iringa about 60 kilometers from the Lutheran center. Mibikimitali was formally established as a village in 1982. The origin of Mibikimitali's name, meaning "tall tree", comes from a time when the village did not have a center at which to congregate. They would instead meet under a tall tree, however the location of this tree is unfortunately unknown according to the Village Executive Officer. Mibikimitali has 1284 occupants as of January of 2020. This population however omits those that attend St. Therese's Secondary school. Amongst the 1284 people, there are 284 families living in Mibikimitali. Mibikimitali has three sub villages within its borders. Masimike is the largest of the three with 490 occupants and is located in the northwest portion of Mibikimitali. The next largest sub village is Mibikimitali (sub village) with a population of 429 people and is located in the northeastern portion of the village. Lastly, Ulangala is the smallest of the three sub villages at 365 people and is in the southern half of Mibikimitali.

Mibikimitali is a fairly flat village with the exception of two mountains, one to the South (Kitonga) and the other to the North East. The village is bordered by two rivers, the Musugulika River to the West and the Lyandembela River to the East. These rivers create small valleys, leaving the general population of Mibikimitali at a higher elevation than most of their water sources. Mibikimitali has a large number of agriculture fields and livestock, proving to contribute a substantial part of the income for their village.

The village center of Mibikimitali is located in Masimike shown in Figure 3.1. The village center is a building where village officials meet and is a central gathering point of the village. This is where our team met with the water committee upon arrival, and also houses important documents such as the village map.

Figure 3.1: Masimike Village Center

Mibikimitali has two schools, both a primary and secondary school. Primary schools in Tanzania are similar to our K-6 in the U.S., while Secondary schools are similar to our 6-12 or high school. Instead of "grades", their school ranking systems are "Forms". The primary school (Figure 3.2) is located in Masimike and was established the same year at the village in 1982.

The headmaster of the school is Ezekiel Rkiduncui. The primary school has approximately 365 students attending, some of which walk multiple kilometers a day to attend school. The school only serves the children of Mibikimitali, nearby villages each have their own primary schools. The primary school is taught entirely in Swahili. Children are required by law to attend primary school.

Figure 3.2: Mibikimitali Primary School Classroom

The Secondary school is Saint Therese's Secondary school, located in Ulangala. This school is an all-girls boarding school currently with around 302 students and 31 staff members. Students attending Secondary schools are not necessarily from the village in which the school is located. The school staff includes 18 teachers, 7 cooks, a nurse, cowboy, guard, secretary, driver, and operator. To attend secondary school, children must pay tuition and thus it is not legally mandated. St. Therese's School has an annual fee of 1.5 Million Tanzania Shillings (Tish), which is the equivalent to ~$652 in the U.S. This tuition covers the cost of their room, board, education, and other expenses. Secondary schools in Tanzania are taught entirely in English.

Mibikimitali has two dispensaries. A dispensary is similar to our doctor but is not equipped with the westernized equipment we are used to seeing in the U.S. The dispensary distributes medications given by the CDC, treats most illnesses, and has a few rooms primarily for childbirth. One of the dispensaries is located in Masimike shown in Figure 3.3. This dispensary is open to all the people of Mibikimitali. The other dispensary is located at St. Therese's secondary school in Ulangala. This dispensary is only open to the girls that attend the secondary school.

Mibikimitali has six churches within its extent, all of which are located in Masimike and Mibikimitali. The Roman Catholic Church, Pentecostal Church, Assembly of God Tanzania Church (AOG), and Hope for All Nations Tanzania Church (HOFAN) are located in Masimike.

While the Lutheran Church, and Evangelical Assembly of God Church (EAG) are located in Mibikimitali. The churches range anywhere from a couple hundred to a dozen attendees each week. Churches are central gathering places for many of the villagers and often have fairly high population densities nearby.

Figure 3.3: Masimike Dispensary

Figure 3.4: Lutheran Church (Highly Populated Area)

3.2 Current Water Sources

Upon arrival at the village, we noticed that there were many existing hand pumps, thirteen of which were implemented in November 2019. Of the pumps we located thirteen of them were hand dug hand pumps, 4 of them were borehole hand pumps, and the remaining three were borehole pumps located at the secondary school. The borehole hand pumps reached deep underground aquifers and ranged anywhere from 25-150 meters in depth when they were drilled with an air hammer drill. The four borehole hand pumps were installed 5-15 years ago. After being drilled, the boreholes were fitted with concrete caps and hydraulic hand pumps. The hand dug hand pumps were fairly shallow and varied anywhere from 5-25 meters deep. After having been excavated by hand, the pumps were fitted with a concrete cap and hand pump made from readily available parts such as NPT pipe and fittings. These hand dug hand pumps were built by a fundi, or handi-man, that the village hired to do the work. In the time we had in the village we were unable to identify what, if any, organization helped with the funding and installation of these hand dug hand pumps. See Figures 3.5 and 3.6 for pictures of the borehole hand pumps and hand dug hand pumps respectively. In January of 2020 during the rainy season, at three months post installation, the fact that most of these hand pumps were either running dry or not functioning provides evidence for a faulty design. To rehabilitate these pumps would require continuous sanitization of the wells due to their depth and proximity to livestock manure, or deepening the wells to reduce this risk. In addition, the fitting of different hand pump models is also recommended due to the lack of durability for the current ones. The number of wells are shown in Table 3.1.


Figure 3.5 and 3.6: Hydraulic hand pump on borehole and hand pump on a hand dug well

The natural sources were distant from the village center and far from the densely populated areas, requiring anywhere from thirty minutes to an hour to travel by foot. The village people led us to various sources shown in Figure 3.7 and 3.8.

Table 3.1 Functional Water Sources as of January 2020

Sub village	Total New Wells	Broken New Wells	Total Old Wells	Broken Old Wells
Ulangala	8	5	1	0
Masimike	3	0	2	1
Mibikimitali	2	1	1	1


Figure 3.7 and 3.8: Village People Guiding the Group to Natural Sources

Of the hand pumps and water sources that were tested, six out of eight sources were positive for E. Coli and Coliform. The Colilert test tubes were used for water quality tests shown in Figure 3.9. Water samples were taken from various sources and placed in each respective test tube. Images of the test tubes were taken, and the samples were incubated for twenty-four hours. At twenty-four hours, the samples were photographed, and the initial photographs were compared to the final results. Each test tube transitioned to a darker yellow color, which is evident of coliform. The test tubes were placed under a UV light, and most of them fluoresced, which is evident of E.Coli. Figure 3.9 shows the third water sample that did not fluoresce, so it tested negative for E.Coli. The sample was collected from the River 1 source. This source was located in an area that was exposed to relatively less runoff contamination than the other sources. The test tubes that fluoresce blue tested positive for E. Coli. Additional water sample results can be found in **Appendix C.**

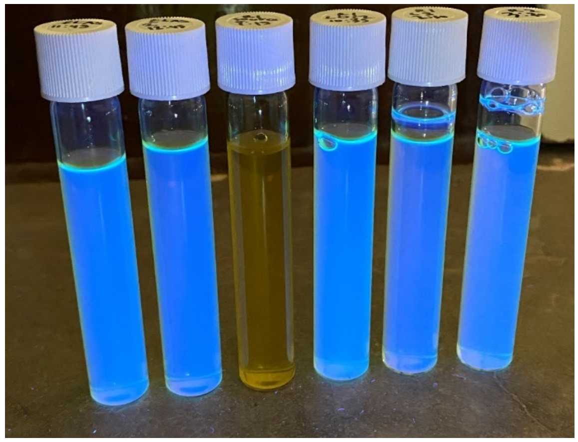

Figure 3.9. Water Quality Test Results Under UV light

The Primary School has an existing borehole. The hand pump produced water that turns brown while pumping one bucket shown in Figure 3.10. The hand pump is not known to be contaminated with E. Coli, and the brown color is attributed to clay and other minerals. The primary school has a water system, but it requires further development to achieve safe, clean water. A 12 liter bucket could be consistently filled while pumping at maximum capacity for about 23 seconds.

Figure 3.10: Water from the Primary School Borehole

Figure 3.11: Village Discussion

After attempting to use each well, testing a few of the wells for water quality, and gaining insight on each of the identified wells in the village through speaking with the villagers, it was concluded that two of the seventeen identified wells were viable for use year round by the villagers with a low risk of contaminants. This is due to the quality of the 13 new wells implemented in November of 2019 (10 of which were located) and the availability of water during the dry season in two of the borehole hand pumps. With that being said although Mibikimitali has an abundance of hand pumps, 14 of which the villagers readily have access to, the quality, sustainability, and safety of these pumps simply is not sufficient for the 1284 occupants of Mibikimitali. Thus, discussions with the village water committee lead to the agreement that a sustainable, accessible, and safe water source is direly needed in Mibikimitali.

3.3 Demand and Priorities

The village water committee was established in 2016, and they provided information about the dynamics of Mibikimitali, including the priorities of the village. The water committee does not currently require payment by its citizens to use the hand pumps, and they hire a fundi--Swahili for mechanic--from a neighboring village for any repairs or installations of new hand dug wells. There is an increasing demand for a sustainable solution for water safety and cleanliness within all three villages. The water committee detailed the priorities of the village during a meeting with the village chairperson and representatives from each sub village and school. They agreed that the main priority is Masimike. The dispensary and the primary school are the two main priorities within this sub village. Mibikimitali would be the next priority, with a demand for clean water near the Lutheran Church, which is near a densely populated area. There are about 300 residents in close proximity to the Lutheran Church.

St. Theresa's Secondary School has a current attendance of 302 students with 30 additional staff. The secondary school has two wells; one well is 55m deep and the other is 25m deep. These systems have pumps that are powered by solar panels, and the water source is often depleted when the sun sets. Once the water source is depleted, the students will walk to the village center and fetch water from that source. At this time, the main priorities of the village do not include St. Theresa's Secondary School. It is important to recognize the presence of its water sources for the possibility of future improvements or additions.

The people of the village were eager to begin contributing to a new sustainable water system. They were ready to start digging trenches to lay pipe and work with each other to contribute to the system. The women and children have been continuously taking time out of their day to pump water, see Figures 3.12 and 3.13. The need for a sustainable water system in Mibikimitali is evident as was the village's commitment to its installation and propagation.

Figure 3.12 and 3.13: Women and Children Pumping Water

4.0 Design Criteria

4.1 Tanzanian Water Code

The water distribution system developed for this village adheres to a list of Tanzanian design requirements that were used to determine the village's daily water demand. As dictated by these requirements, the village was assessed based on its population in the year 2030 assuming a 16% population increase. Design requirements also mandate that each person must have a minimum of 25 liters of water per day, and students attending the primary school must have 10 liters of water per day. Using this knowledge, the total daily volumetric flow rate for each sub-village can be calculated and distributed amongst the appropriate number of distribution points. This data informs decisions regarding pipe sizing, distribution point location in reference to the storage tanks, and water kinematics.

The data for each sub-village was compiled into the following three tables. The average daily demand for water (ADD) was determined based on the population numbers provided in the previous paragraph. The peak rate metric is another important Tanzanian design requirement that is determined by taking 2.5 times the average hourly rate to account for the bimodal trends (meaning that most people go to get water once in the morning and again in the evening) that have been observed in similar communities in Tanzania. A complete list of Tanzanian design requirements can be found in Appendix A.

Table 4.1: Water demand and pipe sizing data for Masimike sub-village .

Metrics	Data
Current Population [people]	490
10 Year Population [people]	568
Current Students [people]	365
10 Year Student Population [people]	423
ADD [L/day]	18400
Peak Rate [L/hour]	3840
Storage Capacity [L]	9220
Number of DPs Required	3
Adjusted Storage Capacity [L]	11500

Table 4.2: Water demand and pipe sizing data for Mibikimitali sub-village.

Metrics	Data
Current Population [people]	429
10 Year Population [people]	498
ADD [L/day]	12500
Peak Rate [L/hours]	2594
Storage Capacity [L]	6225
Number of DPs Required	2
Adjusted Storage Capacity [L]	7780

Table 4.3: Water demand and pipe sizing data for Ulangala sub-village.

Metrics	Data
Current Population [people]	365
10 Year Population [people]	423
ADD [L/day]	10600
Peak Rate [L/hours]	2200
Storage Capacity [L]	5300
# of DPs	2
Adjusted Storage Capacity [L]	6630

5.0 Proposed Design

5.1 Masimike and Mibikimitali

After receiving the priorities of the village from the water committee and understanding the geographic layout of Mibikimitali a water distribution is proposed. This system is designed to maximize access to clean water for as many people as possible who do not already live near a clean source and minimize unnecessary costs. It was determined that an air hammer borehole should be drilled at a central location in Masimike and employ the use of a pump to fill two 10,000 liter storage tanks that gravity feeds water to the sub-villages of Masimike and Mibikimitali. This will be done via roughly 2.4 km of buried HDPE (high density polyethylene) piping that leads to 3 distribution points in Masimike and 2 in Mibikimitali for a total of 5 distribution points (DPs) serving approximately 1,066 people.

An air hammer borehole was deemed necessary as opposed to mud rotary drilling due to the failures of wells shallower than 50 meters throughout the village. Additionally, it is believed that the chosen location in Masimike will be a viable drilling site because it is not especially low-lying. In fact, the proposed location is a local high point, but Masimike has little elevation change in this area, and a successful air hammer borehole is currently in use at the primary school roughly 900 meters from the drilling site. When it comes to powering the borehole's pump, Mibikimitali was observed to be completely on the electrical grid, which means that the use of stepped down power is likely an easy option to pump water from the borehole to the nearby storage tanks. The selection of two 10,000 liter tanks was based on the specifications shown in Tables 4.1 and 4.2. The GPS coordinates of the pump and storage tank locations as well as those of all 5 distribution points can be found in Table 5.1

For the Masimike sub-village, the HDPE piping starts at the storage tanks using the 75mm PN6 variety and travels 237 meters to the village center where the first distribution point is located. From here, the pipe has two branches for the remaining distribution points: one goes a short 50 meters to the dispensary, and the other travels 668 meters to the primary school. Both of these branches consist of 50 mm PN6 piping. The justification for having the dispensary distribution point even though it is quite close to the village center is that it is desirable for there to be water exclusively for the people being taken care of at the dispensary. This line is shown in blue on the map of the northern half of the village (Figure 5.2).

The second line that runs from the storage tanks is a 63 mm PN6 pipe that serves the Mibikimitali sub-village. The pipe travels 1190 meters to the first distribution point along this line at an area of high population density nicknamed "Dinkytown." From here, the line extends an additional 400 meters to an area that is easily accessible to those who live near the Lutheran church, but also still provides the proper elevation gradient for an effective gravity-fed system. This pipeline is shown in red in Figure 5.2.

For the pipes that run to either sub-village, there was very little elevation change between the storage tanks and DPs, so the pressure exerted on the insides of the pipes (head) was never significant enough to warrant anything stronger than PN 6. Selecting pipe diameters was an iterative process involving the EES code in Appendix B and the results in Table 5.2. The goal of this process was to obtain the smallest diameter pipes (and therefore the lowest cost) while still meeting the water demands of each sub-village.

Table 5.1: GPS coordinates of the borehole site, storage tanks, and distribution points.

Location	Latitude	Longitude
Storage Tanks and Pump	8°7'17.3424"S	35°32'26.5308"E
Primary School	8°6'54.6408"S	35°32'28.5216"E
Dispensary	8°7'10.812"S	35°32'32.19"E
Village Center	8°7'13.08"S	35°32'31.3152"E
Dinkytown	8°7'26.7492"S	35°32'56.544"E
Lutheran Center	8°7'24.2364"S	35°33'4.6872"E

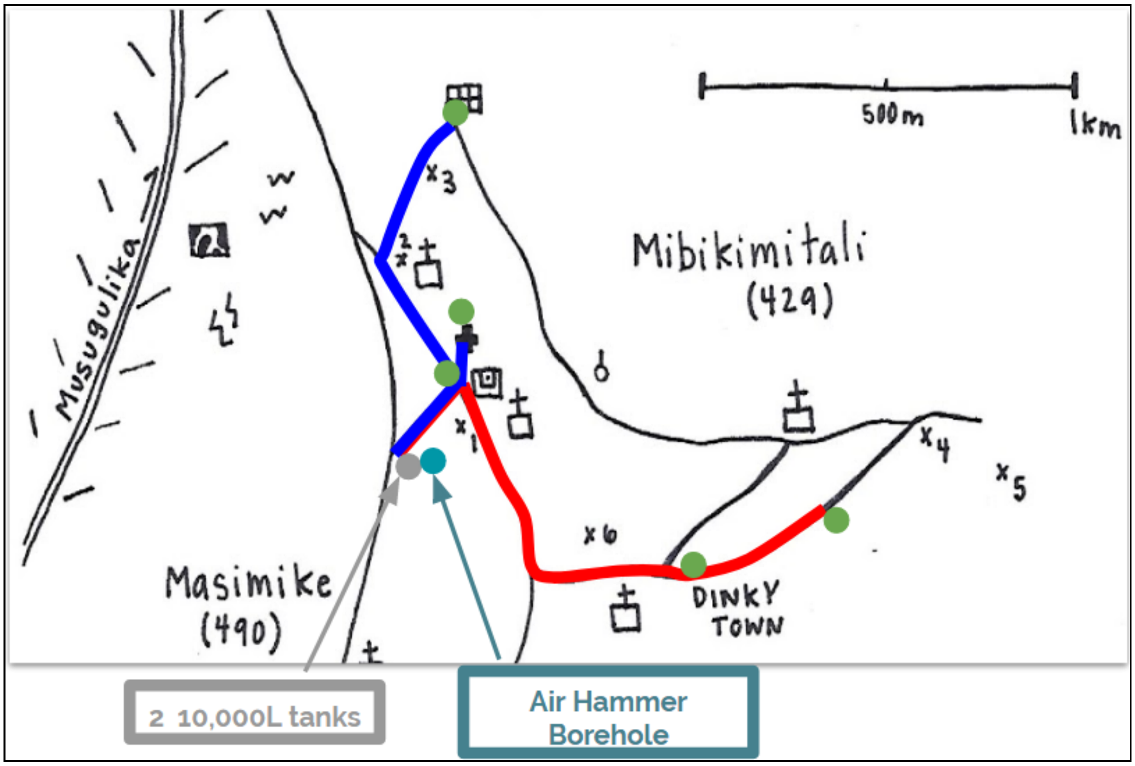

Figure 5.2: A map of the proposed design pipelines.

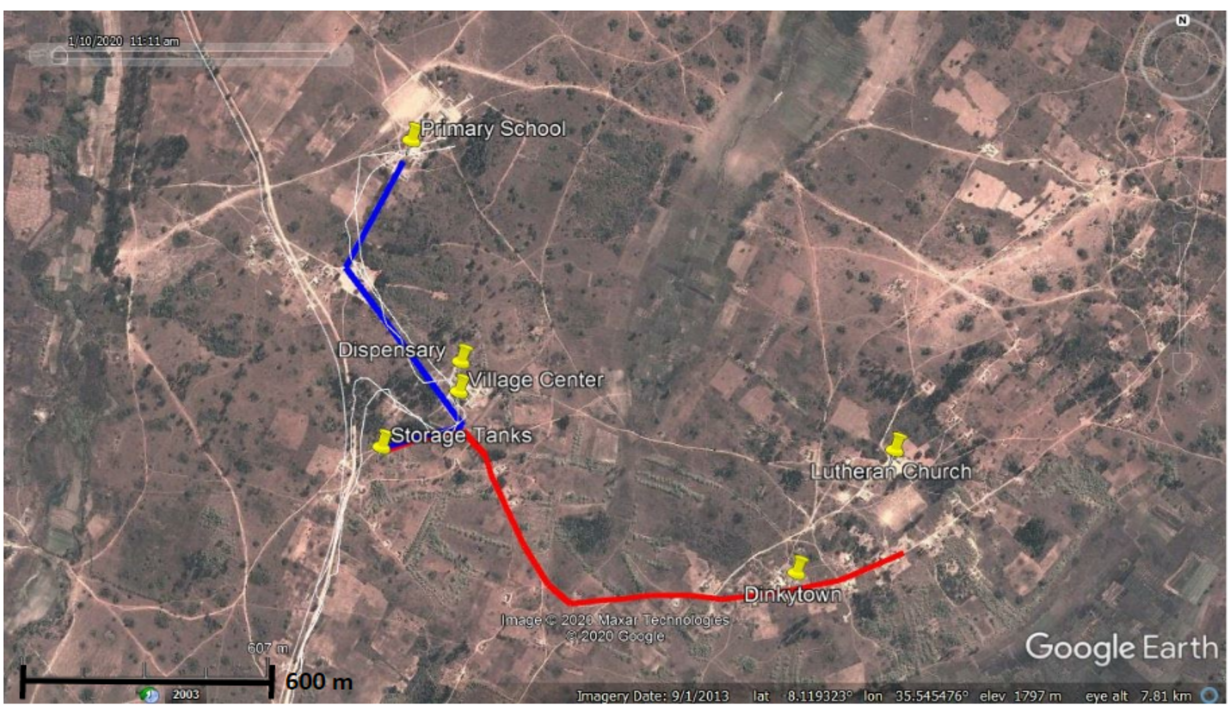

Figure 5.3: A Google Earth image of the proposed design pipelines.

In order to ensure that the proposed design meets, or exceeds, the designed demand it was necessary to perform fluid mechanic calculations. Each distribution point was analyzed in order to confirm that the proper hourly flow rate could be achieved under all feasible system conditions (one DP open and another closed, both open, etc.) for the designed pipe diameter. The results of this analysis can be seen in Tables 5.2 and 5.3. Similarly, each distribution point should have an acceptable velocity of water through it, and these results can be seen in Table 5.4 and 5.5. It is in the best interest of the project cost to select the smallest pipe diameter that still delivers the proper flow rate, and these properties were optimized through iteration of various hypothetical solutions in EES. The final results of these calculations are shown in the following tables and complete EES code is provided in Appendix B.

Table 5.2: Results of EES flowrate calculations for the Masimike pipeline.

DP 2 Status	DP 3 Status	DP 4 Status	DP 2 Flowrate [LPH]	DP 3 Flowrate [LPH]	DP 4 Flowrate [LPH]
Open	Open	Open	2560	2781	1190
Open	Closed	Closed	3076	-	-
Closed	Open	Closed		3308	-
Closed	Closed	Open	-	2-	1609
Open	Open	Closed	2820	2949	1-
Open	Closed	Open	3001	-	1432
Closed	Open	Open	-	3148	1420
Closed	Closed	Closed	-	-	-

Table 5.3: Results of EES flowrate calculations for the Mibikimitali pipeline.

DP 2 Status	DP 3 Status	DP 2 Flowrate [LPH]	DP 3 Flowrate [LPH]
Open	Open	1720	1262
Open	Closed	2492	16.11
Closed	Open	18.08	2241
Closed	Closed	25.79	25.78

Table 5.4: Results of EES velocity calculations for the Masimike pipeline.

DP 2 Status	DP 3 Status	DP 4 Status	DP 2 Velocity [m/s]	DP 3 Velocity [m/s]	DP 4 Velocity [m/s]
Open	Open	Open	1.12	1.15	0.50
Open	Closed	Closed	1.3	-	-
Closed	Open	Closed	-	1.4	-
Closed	Closed	Open	-	-	0.68
Open	Open	Closed	1.19	1.24	-
Open	Closed	Open	1.26	-	0.60
Closed	Open	Open	-	1.32	0.60
Closed	Closed	Closed	-	-	-

Table 5.5: Results of EES velocity calculations for the Mibikimitali pipeline.

DP 2 Status	DP 3 Status	DP 2 Velocity [m/s]	DP 3 Velocity [m/s]
Open	Open	0.72	0.53
Open	Closed	1.05	-
Closed	Open	-	0.94
Closed	Closed	-	-

6.0 Alternative Solution

Another possible design is exactly the same as the proposed solution, however no new borehole would be required and that would save the air hammer drilling cost. Since the primary school is only 900m away from the location of the two storage tanks, we proposed repurposing the existing 150m borehole at the school and pumping its water to the tanks for distribution. Initially, this was considered the ideal design as it would save a significant amount of money, specifically, reducing the total cost of the project down to about $16,300 or $10.87 per person.

However, after some extensive discussion amongst the group and our advisors it was decided that we would instead move ahead with drilling a new borehole. This was chosen based on some expressed concerns over using one of the village's only clean and reliable water sources. It was brought to light that a situation could arise in which the pump could break down and potentially not be fixed for up to several weeks. After considering this, we decided that digging a 100m borehole with an air hammer and using the existing 150m borehole by the primary school as somewhat of an emergency/ extra source of water for the community was the best course of action.

7.0 Conclusion

Mibikimitali is a rural village in the southern part of the Iringa region of Tanzania and consists of three sub villages, Masimike, Mibikimitali and Ulangala. The village sustains itself through traditional agricultural means, however its citizens see most of their income by raising large amounts of livestock, mainly cattle. Mibikimitali is in dire need of a water distribution system as the vast majority of their wells run dry and do not yield clean drinking water which results in over 200 visits to the dispensary per month due to the consumption of unsanitary water. Our team decided that in order to provide clean water to the areas of priority in Mibikimitali, as stated by the water committee, a 100 meter borehole be dug, via air hammer, to pump water to two storage tanks located near the village center. To make this water easily accessible to the largest number of people, we designed our system to have water distribution points at population dense areas of the Masimike and Mibikimitali sub villages. Specifically, we are suggesting that distribution points be placed at the primary school, dispensary, village center, “Dinkytown”, and Lutheran Church. The proposed design is capable of serving the projected population of 1500 for Masimike and Mbikimitali and will cost an estimated $24,750 to implement and breaks down to just $16.50 per person served.

Appendix A: Tanzanian Design Requirements

The following guidelines were followed when designing the water system:

- 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 accommodate a population 16% higher in 2027 than today.
- 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 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. If I understand the design guidelines, each so-called DP (distribution point) should be designed with a T having 2 spigots, so each DP should be able to provide 20 liters/min.
- 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.)
- Maximum working pressure for a pipe should be approximately 80% of rating.
- 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.
- Minor losses should be modeled at 5% of major losses.
  - Add 15% to pipe costs for fittings.
  - Add 20% to pipe costs for freight charges.

Appendix B: EES Code

Masimike Code:

```
g = 9.81 [m/s^2]
rho = 1000 [kg/m^3]
nu = 1.12e-06
mu = 1e-03

d_DP = 29/1000 [m]
L_DP = 20 [m]

{length and elevation settings}
z1 = 1819 [m]
z2 = 1814 [m]
z3 = 1813 [m]
z4 = 1814 [m]
L12 = 237 [m]
L23 = 50 [m]
L24 = 668 [m]

{diameter and valve settings}

d12 = 67.9/1000 [m]
d23 = 45.3/1000 [m]
d24 = 45.3/1000 [m]
Kv2 = 10 {wide open valve}
Kv3 = 10 {wide open valve}
Kv4 = 1000000
{complete equations}

p2/(rho*g) + z2 - z1 + V12^2/(2*g)*1.05*f12*L12/d12 = 0

(p3-p2)/(rho*g) + z3 - z2 + V23^2/(2*g)*1.05*f23*L23/d23 = 0
(p4-p2)/(rho*g) + z4 - z2 + V24^2/(2*g)*1.05*f24*L24/d24 = 0

-p2/(rho*g) + 1 + V2DP2^2/(2*g)*(1.05*f12*L_DP/d_dP + Kv2) = 0
-p3/(rho*g) + 1 +  V3DP3^2/(2*g)*(1.05*f23*L_DP/d_dP + Kv3) = 0
-p4/(rho*g) + 1 +  V4DP4^2/(2*g)*(1.05*f24*L_DP/d_dP + Kv4) = 0

V12*d12^2 = V23*d23^2 + V2DP2*d_DP^2 + V24*d24^2
```

V24*d24^2 = V4DP4*d_DP^2
V23*d23^2 = V3DP3*d_DP^2

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

Q23 = 3600000*pi*d23^2/4*V23
Q24 = 3600000*pi*d24^2/4*V24

QDP2 = 3600000*pi*d_dP^2/4*V2DP2

p2bar = p2/100000

p3bar = p3/100000

Re12 = (V12*d12)/nu

Re23 = (V23*d23)/nu
Re24 = (V24*d24)/nu
10^(-1/(2*sqrt(f12))) = 2.51/(Re12*f12)

10^(-1/(2*sqrt(f23))) = 2.51/(Re23*f23)
10^(-1/(2*sqrt(f24))) = 2.51/(Re24*f24)

<u>Mibikimitali</u>

g = 9.81 [m/s^2]

rho = 1000 [kg/m^3]

nu = 1.12e-06

mu = 1e-03

d_DP = 29/1000 [m]

L_DP = 20 [m]

{length and elevation settings}

```
z1 = 1819 [m]

z2 = 1812 [m]

z3 = 1812 [m]

L12 = 1190 [m]

L23 = 400 [m]


{diameter and valve settings}


d12 = 57/1000 [m]

d23 = 57/1000 [m]

Kv2 = 1000

Kv3 = 10 {wide open valve}


{complete equations}


p2/(rho*g) + z2 - z1 + V12^2/(2*g)*1.05*f12*L12/d12 = 0


(p3-p2)/(rho*g) + z3 - z2 + V23^2/(2*g)*1.05*f23*L23/d23 = 0


-p2/(rho*g) + 1 + V2DP2^2/(2*g)*(1.05*f12*L_DP/d_dP + Kv2) = 0


-p3/(rho*g) + 1 +  V3DP3^2/(2*g)*(1.05*f23*L_DP/d_dP + Kv3) = 0


V12*d12^2 = V23*d23^2 + V2DP2*d_DP^2
```

V23*d23^2 = V3DP3*d_DP^2

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

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

QDP2 = 3600000*pi*d_dP^2/4*V2DP2

p2bar = p2/100000

p3bar = p3/100000

Re12 = (V12*d12)/nu

Re23 = (V23*d23)/nu

10^(-1/(2***sqrt**(f12))) = 2.51/(Re12*f12)

10^(-1/(2***sqrt**(f23))) = 2.51/(Re23*f23)

Appendix C: Water Quality Test Results

	Colilert Test Tube		3M Petri Film		
Water Source	Total Coliforms	E.Coli	E.Coli Count	Coliform Count	Total Coliform
River 1 Source	P	N	0	8	8
River 1 Location 2	P	P	0	44	44
River 1 Location 3	P	P	0	75	75
River 2	P	P	2	74	76
ELAS Source	P	P	0	1000000	1000000
ELAS Location 2	P	P	2	1000000	1000002
Pump 5	P	P	0	96	96
Pump 3	P	N	0	10000	10000

*P - Positive, N - Negative

Appendix D: Cost Analysis

*Items in purple are in-kind contributions

	Product	Description	Quantity	Per Unit Cost	Total Cost
Raw Materials	Air hammer borehole	100m deep borehole	100	$80	$8,000
	Storage SIM Tank	10000 L	2	$1,126	$2,251
	Piping to Primary School	PN 6 class B 45.3mm	5	$122	$608
	Piping to Village Center	PN 6 class B 67.9mm	2	$274	$548
	Piping to Mibikimitali	PN 6 class B 57mm	10	$186	$1,861
	Cement, reinforcement	Tank Foundation	2	$200	$400
	Sand and stone	Tank Foundation	2	$250	$500
	Tap Fittings	5 DP = 10 taps	5	$110	$550
	Tank Fittings, Galv steel	Connection for tank and pipe	2	$150	$300
	Pipe Fittings (15% of HDPE pipe cost)	Connection for pipe sections	$3,017.75	15%	$453

Transportation	**Pipe (4 rolls per trip)**	**Truck &/or Tractor**	**5**	**$200**	**$1,000**
	Storage Tank (1 tank per trip)	**Truck &/or Tractor**	**2**	**$200**	**$400**
	Concrete	**Truck &/or Tractor**	**1**	**$200**	**$200**
Labor	**Dist.Points**	**$10 per DP**	**5**	**$10**	**$50**
	Digging	**$2/meter, 2500 m**	**2500**	**$2**	**$5,000**
	Local Plumber (all plumbing including piping, borehole and DP's)	**Sum**			**$1,500**
	Design and supervision support by SPP Engineer	**Per day**			**NC**
	Training of scheme attendant and provision of basic tools (pipe wrench, screw drivers and spanners)	each			**NC**
	Health and Hygiene sanitation training	each			**NC**
	Preliminary Total				**$25,221**
	Contingency 10%				**$2,522**
	SPP charges 15% (project direction and oversight)				**$4,162**

	Total	**$31,905**
	In Kind Contribution (Labor Costs)	**$5,550**
	Required Funds (Total Cost - In Kind Contribution)	**$26,355**

	Product	Description	Quantity	Per Unit Cost	Total Cost
Pumping system if required	Pumping system (submersible pump, wire and accessories, supplier quote require)	Set	1	$200	$200
	Electrification work: construction of power line by TANESCO	meter	100	$5	$500
	Construction of hut for control panels. Electric power meter	Sum	1	$1,000	$1,000
	Electrical contractor (Installation of submersible pump including testing)	Sum		$700	$700
	Miscellaneous materials for wiring the control house, supply of earth wire and light post	Sum		$200	$200
	Construction of well head chamber	Sum		$200	$200

	Total Cost	**$2,800**
	In Kind Contribution (Labor Costs)	**$1,200**
	Required Funds (Total Cost - In Kind Contribution)	**$1,600**