Gravity-fed Water Distribution System for Magome Village

Design for Life: Water in Tanzania January 2020

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0.0 Executive Summary

The goal of this project is to provide accessible clean water to the village of Magome in Iringa, Tanzania. Magome is located in the Southern Highlands region of Tanzania that is known for its mountainous terrain. The village of Magome has a population of 1,147 people that live within four sub-villages. Most villagers live along the ridgelines and get their water from sources in the valleys. The primary sources used by the primary school, the dispensary, and the Lutheran church are all contaminated with E. Coli. The villagers know that boiling the water makes it safer to use, but some still consume the water without boiling it first. Accessing these sources requires strenuous hikes down and back up steep inclines. The proposed design would both provide water that is not contaminated with E. Coli and significantly reduce the amount of physical labor and time that is expended collecting water currently.

The design for Magome will be a two phased system. About 3km to the west of the village, there is a spring source at an elevation of about 1820m. This allows for an ideal setup for a gravity fed system. Phase 1 will consist of a gravity main bring the water 3km from the spring to two 10,000L tanks located in the village center at an elevation of about 1793m. At the spring, a large cement cistern will be built which will not only isolate the water from its surroundings, but also settle out any sediments which may be in the spring water. From the storage tanks, there will be three supply lines which will serve 3 of the 4 sub villages all the villages priorities. An 800m line will go to the sub village of Mtule and have two DPs, one of which will be able to serve the Lutheran church. An additional 700m line will run from the tanks to a converted 5000L storage tank located at the dispensary. Finally, a shorter 180m line will serve as the main supply for the school.

Phase 2 will consist of a pump at the 2 primary storage tanks which will pump water up to the school, located at an elevation of 1845m. This will allow for an onsite water supply for the school. In addition, two shorter supply lines will serve the Salem preaching point, as well as serve the last sub village of Magome. The pump will be connected to the grid since power is expected to reach the village within the next year.

The village of Magome has created a water committee to help coordinate with St. Paul Partners for the building and sustainment of a water distribution system. They have shown excitement and a desire to contribute to the construction of their water system. Phase 1 of the design will cost $32,500 with $9,500 being in-kind contribution from the village. This brings the total cost of Phase 1 to $23,000 and the cost per person served to $22.01. Phase 2 of the design will cost $11,900 with $2,800 being in-kind contribution from the village. This brings the total cost of Phase 2 to $9,100 and the cost per person served to $16.02.

Table of Contents

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Name	Role
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1.5 Magome Village Leaders

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*Indicates a member of the water committee

2.0 Project Profile

2.1 Project Title

Gravity-fed Water Distribution System for Magome Village

2.2 Project Location

Region:	Iringa, Tanzania
Village:	Magome
Sub-villages:	Mtule, Mlandege, Ilala, Magome

2.3 Project Implementation Organization

Organization:	St. Paul Partners
Function:	Funding and oversight
Email:	sppwater@gmail.com
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2.4 Project Beneficiaries

Community:	Magome Village
Population:	1,147
Community Areas Served:	Primary School, Dispensary, & Village Center
Current Water Sources:	Located in valleys and contaminated with E. Coli year-round
Proposed Water Source:	Muhanga Spring 3 km from village center and tested free of E. Coli

2.5 Project Budget

The budget for Phase I and Phase II of the proposed water distribution system are shown in the Table 2.1. These costs are further broken down in Section 8.

Table 2.1 | Total Costs for Phase 1 and Phase 2 of Proposed Design.

	Phase 1	Phase 2
Raw Materials	$14,600	$6,000
Transportation	$3,200	$1,100
Labor (in-kind)	$9,500	$2,800
15% Management Fee	$2,600	$1,000
15% Contingency	$2,600	$1,000
Total Cost to Donors	$23,000	$9,100

3.0 Background

The village of Magome is located 45 km southeast of the city of Iringa in the Southern Highlands of Tanzania. The coordinates for the village center (the market center) are 8.082015° south, 35.968943° east. The elevation of the village center was 1793 m. The village population as of January 2020 was 1,147 people. See Figure 3.1 and 3.2 below for the layout of the village. The village collects water from upwards of seven surface sources, and has no wells.

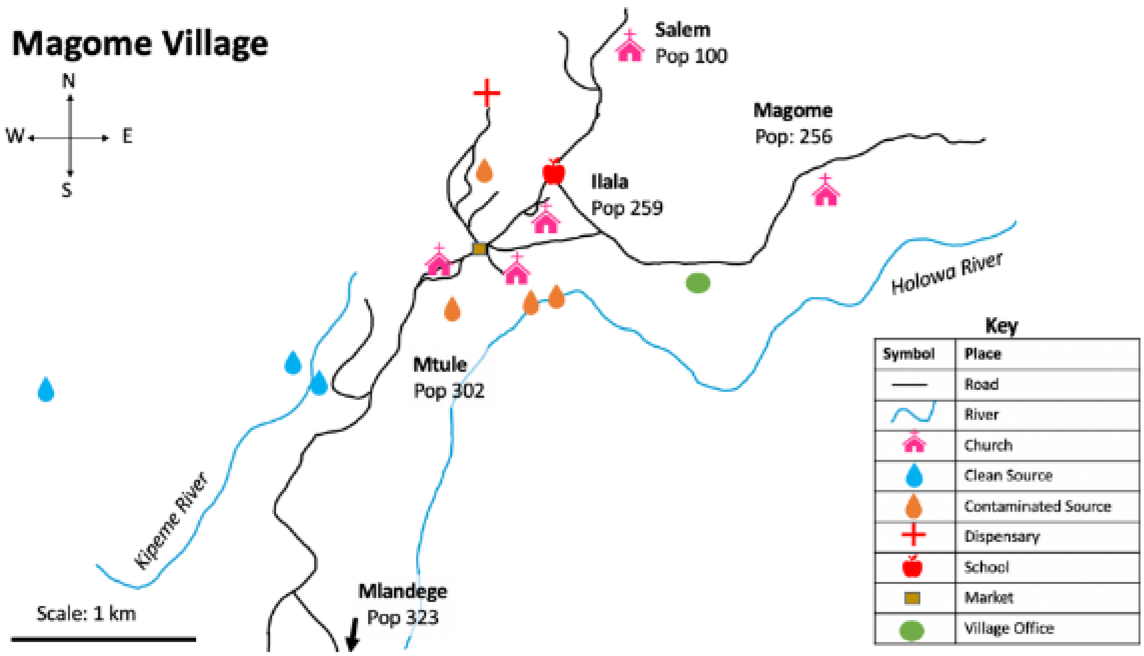


Figure 3.1 | Hand-Drawn Map of Magome.

Figure 3.2 | Google Earth View of Magome. The red pins are subvillages while the yellow pins are key locations.

3.1 Story of the Visit

The journey to Magome took three hours by land cruiser through deep valleys and up steep hills. During the final hour of travel, the road conditions worsened due to downpouring rain and increasingly steep inclines. Thankfully, our driver Michael was a professional, and managed to deliver us to the village without getting stuck in the mud or falling off any cliffs.

Figure 3.3 | Road to Magome.

Upon ascending the final hill to enter the village, the team was greeted by 30 villagers who were waiting in the rain, eager to welcome us. As the team exited the land cruiser, villagers sang and danced enthusiastically, and the students joined in. After dancing in the rain for several minutes, the villagers brought everyone into the church where the dancing continued.

Figure 3.4 | Lutheran Church.

When the dancing subsided, the pastor greeted us and introduced us to the present village leaders, and the team introduced themselves to the villagers in attendance. After the welcoming ceremony, the pastor brought us to the church office where we enjoyed a delicious meal with some of the leaders of the village. As we finished eating, the weather began to clear up and sun came out, making perfect weather to begin our tour of the village. We were told we would see the important landmarks and a few of the nearby water sources. Magome collects water primarily from surface sources and has no wells. When we got outside, we were amazed at the beautiful scenery surrounding us. The buildings of the village sat on a ridge, with lush green hills in every direction as far as we could see.

Figure 3.5 | View Overlooking Magome.

Our tour of Magome began by walking down the hill from the church and through the market center to the dispensary. Before entering the dispensary, we walked around the building, and noticed two 5,000 L tanks being used to collect rainwater from the gutter. The tanks were both filled with water and were functional but used wooden sticks as plugs to start and stop flow rather than a valve.

Figure 3.6 | Water Catchment System at Dispensary.

We entered the dispensary and interviewed the single clinical officer on duty. She informed us that typically there are two clinical officers present, but one was absent due to maternity leave. Bertha Mareaesi, the clinical officer, told us that the dispensary normally collects water from a nearby surface source. However, during the rainy season they primarily use the rainwater collected in the two tanks. In the dry season, there are approximately 50 patient visits per month. During the rainy season the number of cases increases to roughly 100-300 visits per month, but this number can reach up to 500 patients. This escalation in patient visits primarily due to increased runoff into surface water sources. Coughing, diarrhea, and stomach problems are the most common symptoms that warrant a visit to the dispensary according to the clinical officer.

After the interview, we hiked down to the source from which the dispensary collects water during the dry season. When we arrived, we were alarmed to see that the source was nothing more than a large puddle of brown water in the valley between the primary school and dispensary. Even more shocking was that the pastor told us the primary school collected water year-round from the source as well. We tested the water for bacteria using a 3M Petrifilm Count Plate and incubated it for 24 hours. The water was found to contain both coliform and E. coli (see Appendix A for Petrifilm Interpretation Guide). Not only was the risk for E. coli rated as “very high” according to the 3M test standards provided, Dr. Ken Smith, MIT alumni and 3M employee of 40 years who’s tested countless water supplies in Tanzania, said the result was the worst he’s ever seen. We informed the pastor of the results and recommended that other sources be used instead, or at the very least boil the water before drinking it.

Figures 3.7a & 3.7b | School & Dispensary Source (1) with Petrifilm Test Results.

We decided to head to the primary school next to meet with the headmaster and discuss the school's water situation. The hike from the source to the school was grueling, it typically takes students more than 30 minutes to climb. The trail (if you can even call it that) has a 30% grade and had poor footing the entire way. The elevation gain from the source to the school was over 100 m. As we hiked, it was difficult to imagine how anyone could carry water up the hill, let alone young children.

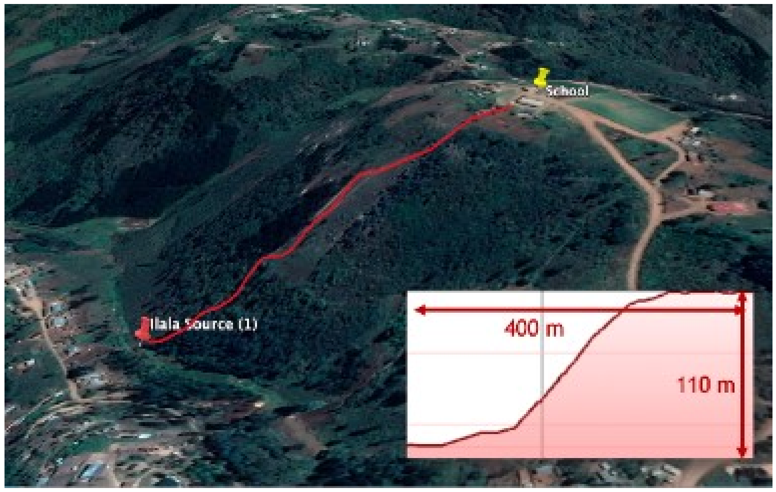


Figure 3.8 | Path from Source 1 to School.

Figure 3.9 | View from the Top of Climb to School.

We reached the school exhausted by the climb, but eager to learn more about the water situation. We met with the headmaster in his office to learn about the school. There were 332 students enrolled (162 girls and 170 boys) with 8 teachers (5 men and 3 women) that live at the school. Not all of the students live in Magome, and some students walk up to 7 km one-way. The headmaster confirmed that the school collects water from the same source as the dispensary, and uses water for cooking, cleaning, and drinking. Class is often postponed so that students can collect water from the bottom of the hill. Students from grades 3-7 (ages 8 to 13) hike down the hill with 20 L buckets and return with buckets full of water weighing up to 20 kgs. It takes 30 minutes or more for a student to collect one bucket. The children often get thirsty and drink straight from the bucket on the way back up to the school, without boiling the water. We were told that the water is only boiled before drinking about half the time due to the time required and the high demand. It was truly sobering to learn about the current state of water at the school; not only do children have to take time away from learning to climb down and up a steep hill to collect water, but also the water they are collecting is extremely unsafe for consumption.

Figure 3.10 | Buckets Used by Students for Water Collection.

We left the headmaster's office feeling saddened by the reality of their situation, but hopeful to find a feasible solution for the future. As we walked outside, dozens of smiling and waving students greeted us. The stark contrast from the somber conversation with the headmaster to the smiling faces outside was remarkable. Despite their circumstances, these were some of the happiest children we have ever seen. We returned to the church office for lunch with newfound motivation.

Figure 3.11 | Primary School Students.

After another tasty meal, the village leaders brought us to the other nearby water sources. We hiked through the valley behind the pastor's house to two river sources and to a standing water source that the pastor's family collects from. The source was approximately a 0.3 m deep with a diameter of around 1.5 m. The water was clear, but full of floating debris and scum. The three sources were tested, and after incubation, they were all determined to have high risk of E. coli. All three sources had "cleaner" water relative to the school and dispensary source but were still unsafe to consume and required difficult hiking up and down steep hills. We were hopeful the next day we could find a source free of E. coli that we could design a water distribution system around.

Figure 3.12 | River Sources (2 & 3) & Pastor's Source (4).

The next morning, we left at 7:00am to hike to the Muhanga source. The source reportedly had clean, safe water, but was not often used because of the long, difficult hike required to access it. For the first 2 km of the trail, we hiked through a valley with a low point of 1725 meters. The footing was rough, and often consisted of narrow planks across ditches and overgrown vegetation. A few times, some of us actually fell off the path and into the tall grass; thankfully, no one was injured.

Figure 3.13 | Hiking through Valley to Muhanga Spring (Source 5).

For the final 1 km of the hike, the path became steep, and elevation increased 100 meters to a final elevation of 1820 meters. When we arrived, the source appeared to be nothing more than a trickle of water emerging from the ground, but after a little digging, there was an area of about 0.5 m by 0.5 m of water. After several flowrate tests with a bottle and a stopwatch, the flowrate was estimated to be 1500 liters per hour. Since this flow rate was taken during January of 2020, during the rainy season, it may not represent the minimum yield of the spring during the dry season (October to November). The source was tested and found to have significantly fewer coliform counts, and no E. coli colonies. The presence of coliform is not a concern because coliform is commonly found in soil, on vegetation, and in surface water sources, and is not likely to cause illness [1]. We left Muhanga Spring happy to have found a source that was both free of E. coli and at an elevation greater than the village center.

Figure 3.14 | Flowrate Test and Petrifilm from Muhanga Spring (5).

On our way back to the village, we stopped at two river sources (sources 6 & 7) and tested them for bacteria. Both sources had lower coliform counts and no E. coli colonies. We noticed several women and children doing laundry in the river and collecting water, so thought it would be a good time to try and balance buckets of water on our heads. Unsurprisingly, none of us were able to balance a bucket for even a fraction of a second without spilling. One of the villagers had to show us how it's done, and casually put a nearly 20 kg bucket full of water on his head and posed for a picture. We were always amazed how easily men, women, and even children could balance full buckets on their heads while walking or doing other tasks.

Figure 3.15 | "Learning" how to Balance Water.

After returning to the village and eating lunch, we went to the village office to meet with the water committee. The water committee was founded in 2017 and is comprised of 8 elected members (4 men and 4 women), with members from each of the 4 sub villages. An encouraging sign was that the committee already has raised 2,150,000 Tanzanian Shillings ($943 USD). The ability to fundraise is crucial in maintaining water distribution systems. When asked about the village's priorities regarding water, the committee members without hesitation answered with the primary school and dispensary. Their top three priorities ranked in order of decreasing importance were: the primary school (1), dispensary (2), and the market/Lutheran church area (3). Magome is 80% Lutheran, and the church is a main area of congregation. We were all very impressed to see the unity that the committee showed, and that many members prioritized areas that would not directly benefit themselves. After discussing the village's needs, we shared our preliminary plan to deliver water to the village center using a gravity-fed system from a cistern at the Muhanga Spring. When we finished describing the design, the committee members asked us when and where to start digging trenches for the pipes. We reminded them that a design was not guaranteed, and that the proposal still needed to be funded. The villagers responded with optimism, saying "by God's will, we will have a water system" and thanked us countless times for willingness to help bring them a water distribution system.

Figure 3.16 | Water Committee.

At the conclusion of the meeting, we rode in the Land Cruiser and took some last GPS waypoints (village/sub-village boundaries, other churches, and Salem preaching point). We then returned to the church office for dinner. Before dinner was ready, dozens of children lined up outside in the rain and waited for us to come out and play with them. We showed them American football and they learned remarkably quickly and could throw perfect spirals in a matter of no time. When the rain subsided, we showed them how to take selfies with our phones. They absolutely loved Snapchat filters, especially the classic dogface filter. The children laughed and screamed for nearly an hour until we had to go in for dinner. Hearing their energetic laughter and seeing their beaming smiles while taking selfies was definitely a highlight of the trip.

Figure 3.17 | Children Posing for Selfies.

The following morning, we attended church service. The beautiful music and choir were moving, despite not understanding a majority. After an introduction from the pastor, we sang “Asante Sana Jesus” (Thank so much, Jesus). It was an unforgettable moment as the whole congregation joined us, singing and clapping in unison. When the service concluded, an auction was held outside the church. None of us knew what was going on as it seemed like three items were sold within seconds. Somehow, Peter ended up buying a couple passion fruits and plantains. After handing out most of the fruit to villagers, we said our goodbyes, boarded the Land Cruiser, and began the journey back to Iringa.

As we were leaving the village, we reflected on our short stay in Magome. It was amazing to spend time with and learn from such resilient people, especially the children. It was difficult for us to think about the fact that the water distribution system we would design may not ever be implemented. It was especially hard to think about the smiling children that we played with will likely continue to drink contaminated water. Despite having little access to clean water, the people of Magome were the happiest people we have ever met. They showed us that happiness comes from the people around you, and by appreciating what you have instead of focusing on what you don’t. We are thankful to have had the opportunity to spend time with such inspirational people, and hopeful that the system we design be implemented.

3.2 Key Information

The following sections summarize the key findings from the village visit.

3.2.1 Subvillages of Magome

Table 3.1 | Subvillage Populations and Locations. The four sub villages of Magome and their corresponding populations and coordinates are shown below.

Subvillage	Population	Coordinates
Ilala	259	8.082015° S, 35.968943° E
Mtule	302	8.083850° S, 35.966221° E
Mlandege	327	8.090370° S, 35.962288° E
Magome	259	8.082265° S, 35.975810° E

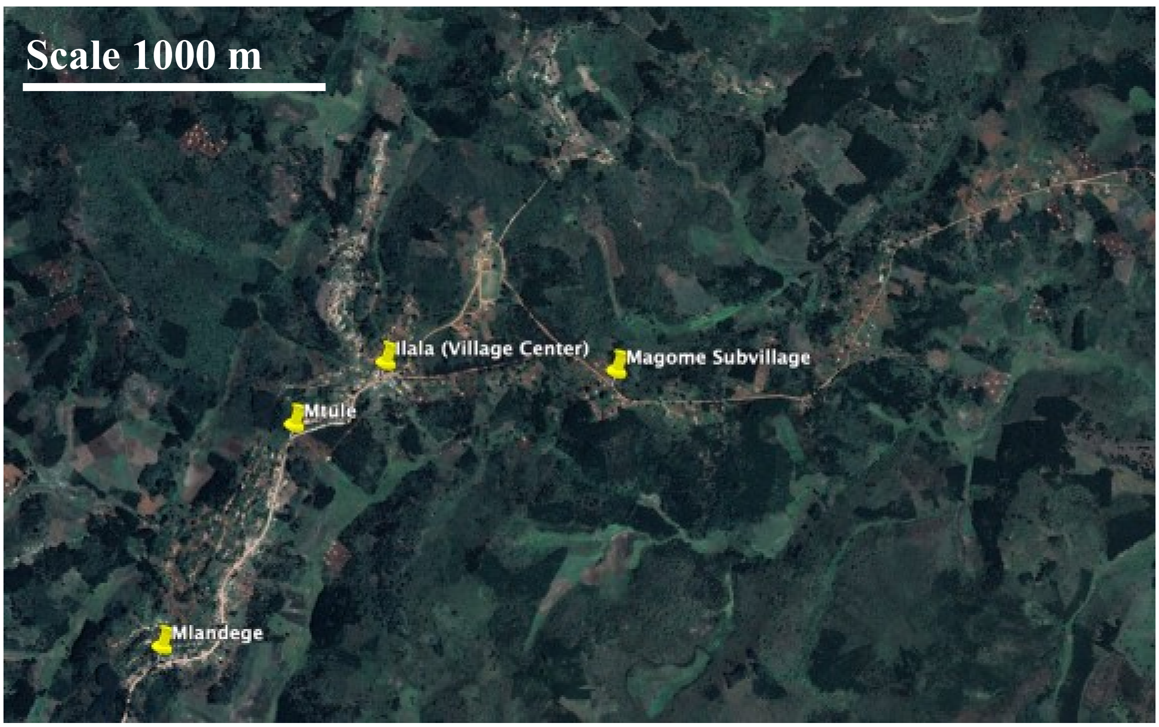


Figure 3.18 | Sub villages Map.

3.2.2 Village Priorities

Table 3.2 | Village Priorities and Locations. The water committee ranked their top three priorities, and the table below contains their elevation and coordinates. Because of the relatively close proximity, the Lutheran church and market center were grouped into a single priority.

Ranking	Location	Elevation (m)	Coordinates
1	Primary School	1845	8.078606° S, 35.971950° E
2	Dispensary	1745	8.075673° S, 35.968896° E
3	Market Center	1798	8.082030° S, 35.968867° E
3	Lutheran Church	1814	8.083197° S, 35.966947° E

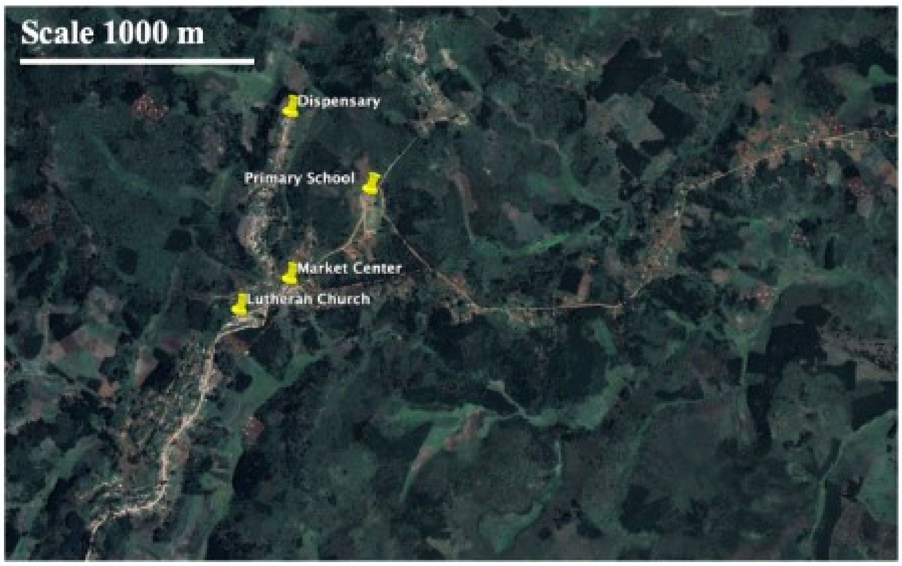


Figure 3.19 | Village Priorities Map.

3.2.3 Water Sources

Figure 3.20 | Water Sources Map.

Table 3.3 | Water Sources and Locations. The locations of each water source with the corresponding results of the Petrifilm test and other notes for each source is shown.

Source	Elevation	Coordinates	E. coli Risk	Notes
1	1727 m	8.077706° S, 35.968870° E	Very High	Supplies school & dispensary
2	1732 m	8.083815° S, 35.972122° E	High	Supplies most of Magome & Ilala
3	1732 m	8.083863° S, 35.971442° E	High	Same stream as Source 2
4	1738 m	8.084585° E, 35.967602° E	High	Pastor's house & church
5	1819 m	8.089547° S, 35.949440° E	None	Muhanga Spring
6	1721 m	8.086182° S, 35.950611° E	None	Same stream as source 5
7	1727 m	8.086380° S, 35.962258° E	None	Different stream from 5 & 6

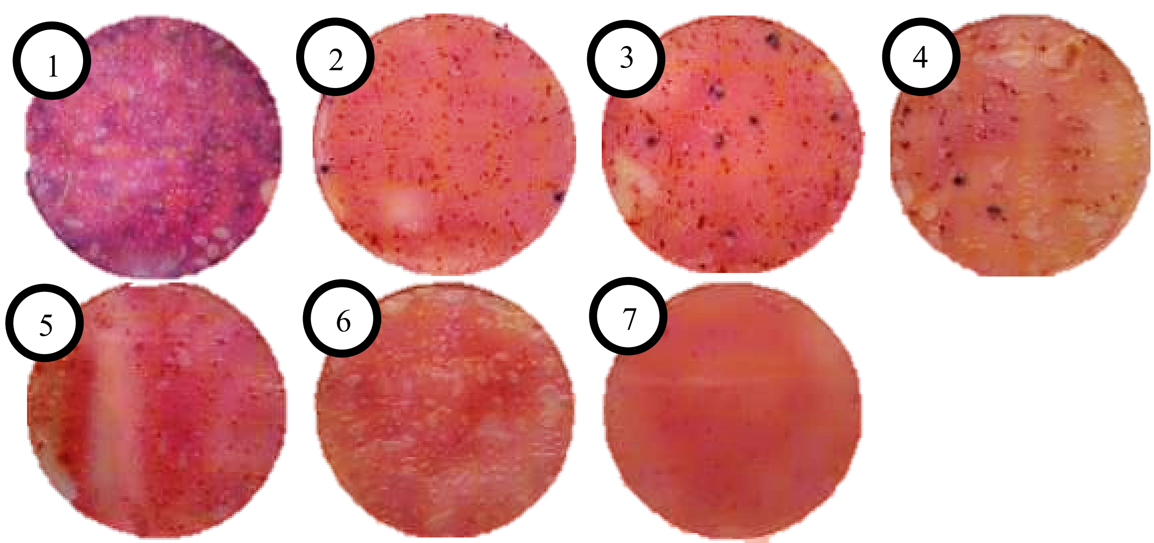


Figure 3.21 | Petrifilm Test Results for Sources 1 through 7.

4.0 Design Criteria

The design of the Magome water distribution system was primarily dictated by the village's priorities, as well as the Tanzanian Design Guidelines. Water demand, system capacity, and loss considerations are all factors covered within these general guidelines for a water system. For a more detailed overview of these design guidelines, reference Appendix B.

4.1 Tanzanian Water Code

A critical aspect outlined in the Tanzanian Design Guidelines is the water demand based on population. One consideration that was accounted for was the design period. The water system designed must be able to accommodate the village's population 10 years from implementation assuming a 1.5% growth in population per year. To satisfy this requirement, a 16% total growth was added to the current population of Magome to account for this future inflation.

The water demand per person was also an important design criterion. It was noted that 25 liters per person per day are required, as well as 10 liters per student per day. Table 4.1 contains the current and projected population of Magome and shows the water demand based as outlined by the Tanzanian Water Code.

Table 4.1 | Water Demand. Current and projected populations of Magome.

Location	Location Breakdown	Demand Per Capita (L/person/day)	2020		2030 (estimate 16% ten year increase)	
			Population Served	Total Demand (L/day)	Population Served	Total Demand (L/day)
Ilala		25	259	6,475	301	7,525
Salem		25	100	2,500	116	2,900
Mtule		25	302	7,550	351	8,775
Mlandege		25	127	3,175	148	3,700
Magome		25	140	3,500	163	4,075
Primary School	**Students**	10	332	3,320	386	3,860
	Teachers	25	8	200	10	250
Dispensary	**Patients**	10	30	300	35	350
	Staff	25	2	50	3	75
Phase I			1,060	21,070	1,234	24,535
Phase II			240	6,000	279	11,085*
Total			1,300	27,070	1,503	31,510

*The total demand for Phase 2 includes the 4,110 L/day required for the students at the primary school and the teachers. This value needs to be accounted for in the Phase 2 demand for the pumping specifications and system design. However, this demand was accounted for in Phase 1, and is not added again to the total demand per day for Phase 1 and 2.

The Tanzanian Water Code also outlines that the system should be designed to account 20-25% of water loss due to leaks and valves left open. This was not accounted for in Table 4.1. For the total demand per day in 2030, after accounting for losses on the higher end, the total demand per day is 39,388 L/day. This is equivalent to an average demand of 3,282 L/hour and a peak demand of 8,206 L/hour. Thus, the system should be designed for 2.19 L/s based on the peak demand.

An additional requirement met by the Magome system design is that individuals served by the water system will not travel more than 400 meters to reach their respective distribution point. All distribution points (DPs) will serve a maximum of 250 people and be capable of supplying the peak demand required by the population. More information about water demand can be found in Appendix D.

5.0 Proposed Design

5.1 Phase 1

Phase 1 is designed with a goal to bring clean water from the Muhanga Spring source to the village's top priorities. The system will be able to satisfy the village's water demand of 31,720 liters/day with the spring supplying an estimated minimum of 36000 liters/day (1500liters/hour). Before implementation, an additional flow rate test should be performed at Muhanga Spring to estimate the output during the dry season (October to November). This will provide a value for the dry weather flow which will be the minimum flow rate value. It is recommended that observation of the spring's yield should be monitored during the wet and the dry seasons for at least 2 years to ensure validity and consistency of results. A recommended method of measuring the flow rate is by installing a V notch weir to calculate the output. This is especially useful in the dry season to get a more accurate representation of the minimum flow during the dry season. Also note that the final spring output will be measured after the source is fully developed. Since this system will be gravity fed, there will be no need for power or a pump to supply the water. With 5 DPs and approximately 4500m of HDPE pipe, a total of 1045 people will be served clean water in 3 of the 4 sub villages. The DPs will be placed on the ridges of the mountains near the population centers so the people will not have to walk down into the valleys for water. This will significantly reduce the labor required to collect water.

To accomplish this task, a water collection system will be built at the Muhanga Spring at an elevation of 1820 meters. At this site, there will be a large cement cistern which will serve to clean and isolate the spring water. The cistern will be elaborated on more in Section 5.3. This system will divert water from the current stream to two 10,000-liter tanks at the village center. From the cistern, a 3-kilometer gravity main consisting of 50 mm diameter pipe will deliver water from the spring to the storage tanks. At the lowest point the pipe will be at 1725 meters which results in approximately 94 meters of elevation change. Figure 5.1 shows the Google Earth view of the gravity main path from the cistern to the storage tanks.

Figure 5.1 | Google earth view of the system. The cistern will be located at 8.089547 S, 35.94944 E and the proposed tank will be located at 8.082247 E, 35.968561 E

As seen in Figure 5.2, this large elevation change results in a maximum pressure of 9.4 atm at the lowest point of the gravity main. Therefore, pipe ranging from PN6 to PN12 will be used. The gravity main will be hand dug a meter underground along the edges of farm fields and ridges, to the storage tanks. There is a 27 m elevation change from the cistern to the tank site. The height of the 10,000 L SIM tank is roughly 3 m, which leaves 24 m of available head for transporting the water. It was ensured that the gravity main has the capacity to supply up to 2436 liters/hour, which is a high-end flow rate estimation for the Muhanga Spring. Because water is constantly running from the spring, it is not necessary to have any higher flow rates for supply reasons.

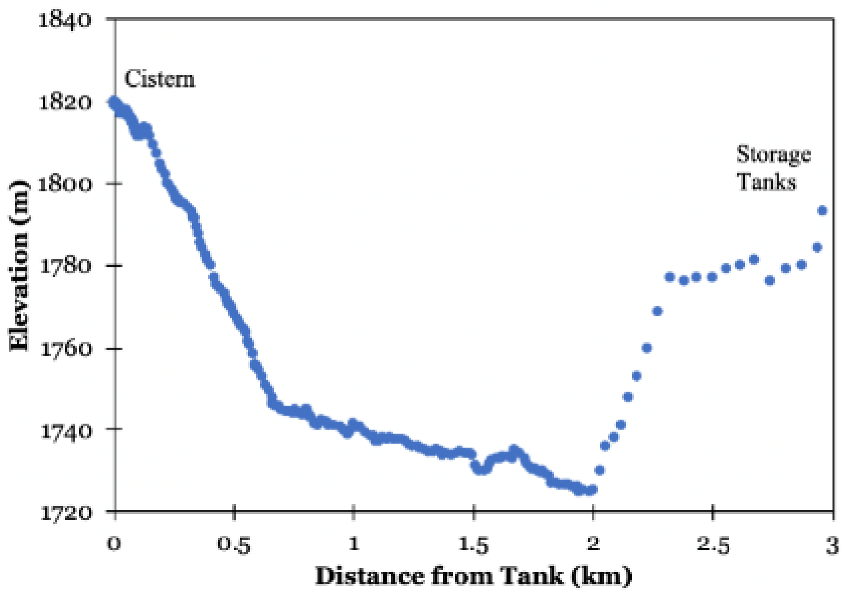


Figure 5.2 | Elevation profile of the Gravity Main from the Cistern to the Tanks.

At the low point of the gravity main, a cleanout will be placed, which will allow for the main to be emptied in case any issues would arise within the line. In addition, it is advised that 2 more cleanouts be placed in the line, one in between the cistern and the low point, and one located near the village between the storage tanks and the low point in the line.

Air release valves are recommended at local high points in the line which occur about 1.7 km and 2.7 km from the cistern. In addition, a water shutoff valve will be put at the cistern, which will allow for the water to be shutoff if a leak or other issue were to occur.

Once the water reaches the tanks, it will be distributed to 3 separate branches which will contain the DPs. The storage tank will be connected to the branch lines using shutoff valves, which will allow for maintenance to be performed on the branches if necessary.

The first branch will be the Mtule line, serving the entire population of Mtule as well as parts of Mlandege. This line will be approximately 852 m long consisting of 40 mm pipe.

As shown in Appendix G.2, the maximum elevation change in this line is 15 m, allowing the line will consist entirely of PN6 pipe. For 726 m, this line will be in the same trench as the gravity main. This will reduce the total labor required by the village and provide an advantageous elevation profile for the line. The rest of the line will be in an independent trench dug along ridge and through the sub village. The recommended DP locations are shown in Figure 5.3 with the coordinates in Table 5.1.

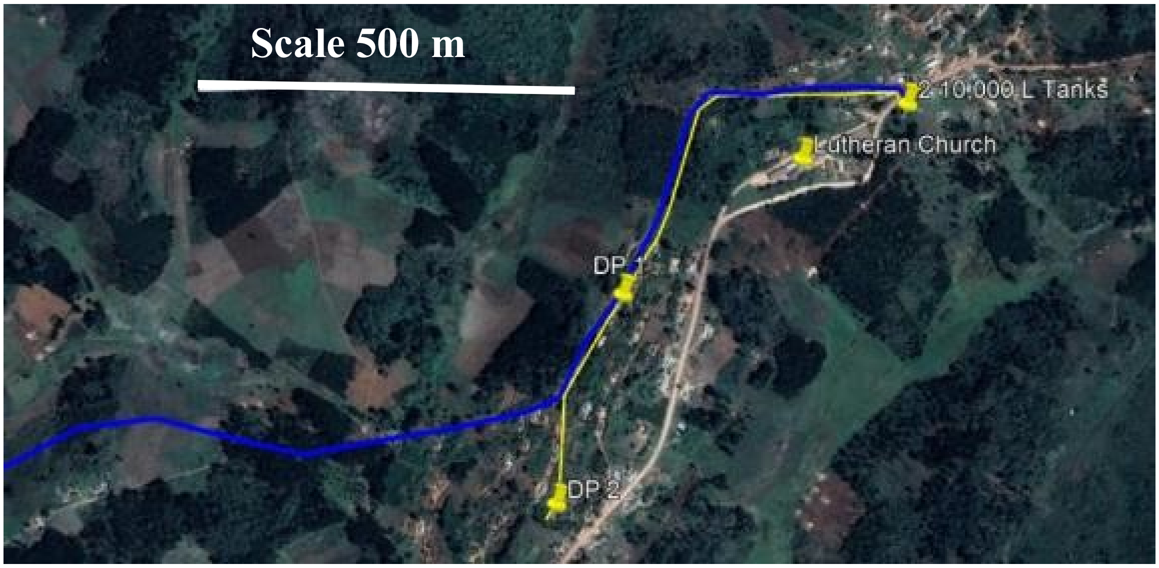


Figure 5.3 | Google Earth View of the Mtule branch. Note the gravity main is shown in the thick blue line. The yellow line represents the Mtule line.

Table 5.1 | GPS locations and Elevations. Proposed DP Locations on the Mtule Line.

DP Number	Coordinates	Elevation
1	8.084474° S, 35.965144° E	1776
2	8.086836° S, 35.964068° E	1773

Serving a total population of 429 people, this branch requires the capacity to supply a peak demand of 2592 liters/hour. All demand calculations can be found in Appendix D.1.1. The 40 mm diameter pipe will have the capacity to deliver 3289 liters/hour, shown in Appendix C.4. In addition, the first DP labeled DP 1, is the DP which the Lutheran church and its large kitchen will use for water. The branch also has the capacity to add another DP at the end of the line if needed. Since the design guidelines specify that 2 DPs can only supply 2400 liters/hour, there may be a need for a future DP. This alternative is elaborated more in Section 6.0.

The second branch, leading to the dispensary, will run from the 2 storage tanks to the northwestern area of the village. It will supply the dispensary, as well as part of Ilala with clean water. This line will be 762 m long and will have an elevation change of 53 m as see by Appendix E.1. Therefore, this line will have both PN6 and PN8 32 mm pipe. The branch will contain 2 DPs, with the coordinates in Table 5.2. Figure 5.4 shows the overview of dispensary branch with the locations of the branch's features.

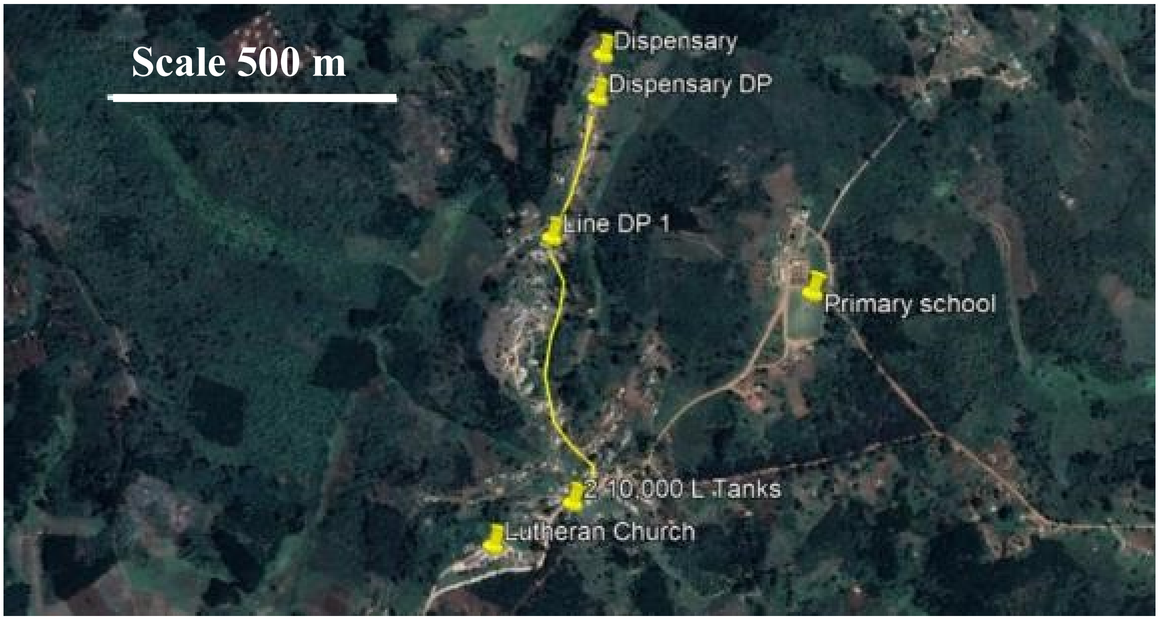


Figure 5.4 | Google Earth View of Ilala Branch. Major village landmarks are also on the map.

Table 5.2 | GPS locations and Elevations. Proposed DP Locations on the Ilala Line.

DP Number	Coordinates	Elevation
1	8.079444° S, 35.968017° E	1767
2 (Dispensary)	8.075673° S, 35.968896° E	1744

This branch will in total be serving approximately 220 people; 76 being at the dispensary and 144 being at the Ilala DP. Referencing Appendix D the line requires a peak flow rate of 1329 liters/hour. Using the EES code in Appendix C.4, the branch can supply 3145 liters/hour which is almost triple the demand. This, as well as the dispensary already having a working water catchment system, will ensure that even in times of high demand the line will be sufficient. The dispensary currently has two 5,000 L tanks that are being used for a water catchment system. This provides the dispensary with water during the wet season when rainfall is common. With the implementation of Phase 1, one of the 5,000 L tanks will be attached to the dispensary line. This tank will run into the dispensary and provide an indoor source of water for the dispensary. The remaining 5,000 L tank will remain as a functional water catchment system to provide additional water for cleaning and cooking purposes, as well as a backup source of water in case a temporary error was to occur with the main line.

The third branch, which is the school branch, is the shortest line in the system. However, it is very important because it serves 2 of the villages top 3 priorities. The branch will run from the storage tanks 201 m northeast where the DP will be located. The total elevation change is 16 m from the tanks to the DP. This allows for 32 mm PN6 pipe to be used in this line. Figure 5.5 contains the overview of this line as well as the recommended location of the DP.

The school and Ilala line will supply about 64 people with water. However, all 332 children from the school will be using this DP which, when projected to the year 2030, results in a peak demand of 1189 liters/hour. Appendix C.3 shows that's that both the DP and the line can distribute 1406 liters/hour. When the children are in class and the School DP is not in use, it would be available to other residents of the village.

Figure 5.5 | Google Earth View of the School Branch. Note the actual location of the DP was calculated at 8.080763S, 35.969076E.

For all three DP branches, it is recommended that cleanouts be placed at the local low points and air release valves at the local high points. Due to the nature of the elevation profile for both the school line and the dispensary line, cleanouts at just the low points in the line would most likely be satisfactory. However, due to the hilly terrain the Mtule branch is on, multiple cleanouts and release valves could be very beneficial in case of future issues. As a general note for all distribution points on branches with more than on DP, flow limiters should be applied. For Phase 1, both the Mtule and Dispensary line have more than one DP, which indicates the requirement of flow limiters. When DPs are contained on the same branch, the flow provided to each DP is impacted by the valve setting of the other DPs on the same branch. To avoid unequal water distribution within each branch, implementing flow limiters will ensure that a constant, pre-determined flow rate will be maintained despite the operational status of other DPs on the same line.

With the gravity main, as well as the three distribution branches, the system will sufficiently meet the demand of all the people coming for clean water. A general system elevation profile, as well as an overhead view of the proposed system is shown in Figures 5.6 and 5.7. As noted by these figures, the energy grade lines for all 4 gravity branches are above the elevation profile. This ensures that cavitation will not be an issue for the system even if all 5 taps would be open at the same time.

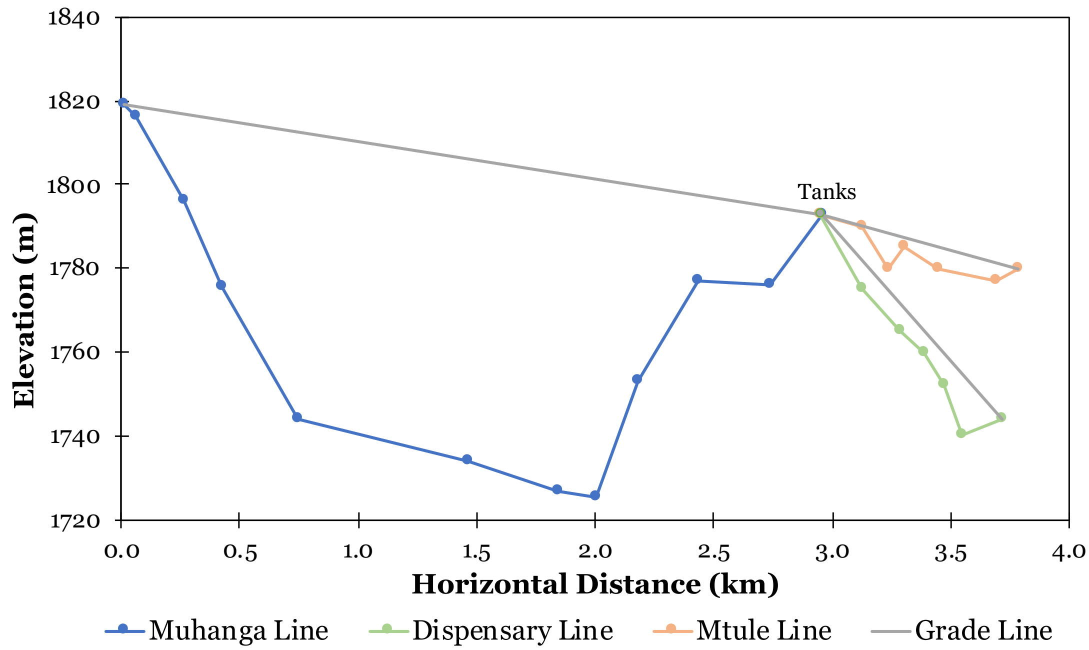


Figure 5.6 | Elevation Profile of the System. The School and Ilala line is not shown due to the minimal elevation change and the short distance which the line travels.

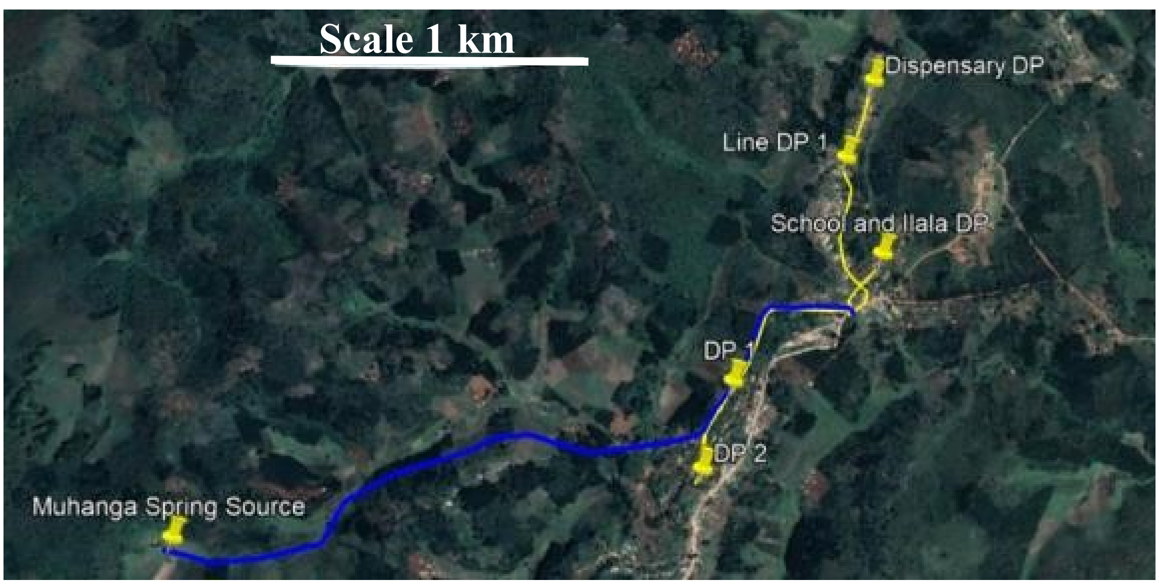


Figure 5.7 | Overhead View of the Proposed Phase I System. Note that the blue line represents the gravity main, whereas the yellow lines are supply lines to DPs.

As shown by the Tanzanian Design Guidelines in Appendix B, only people that reside within 400 m of any given DP should be served by the system. Careful DP displacement and branch routing allowed for this guideline to be met for most of the village. This can be seen below in Figure 5.8. In most cases the longest walks are much shorter, but because of the difficult terrain it was difficult to cover certain portions of the village. Even though a number of circles severely overlap, this is due to the requirement that any single DP can only serve a maximum of 250 people.

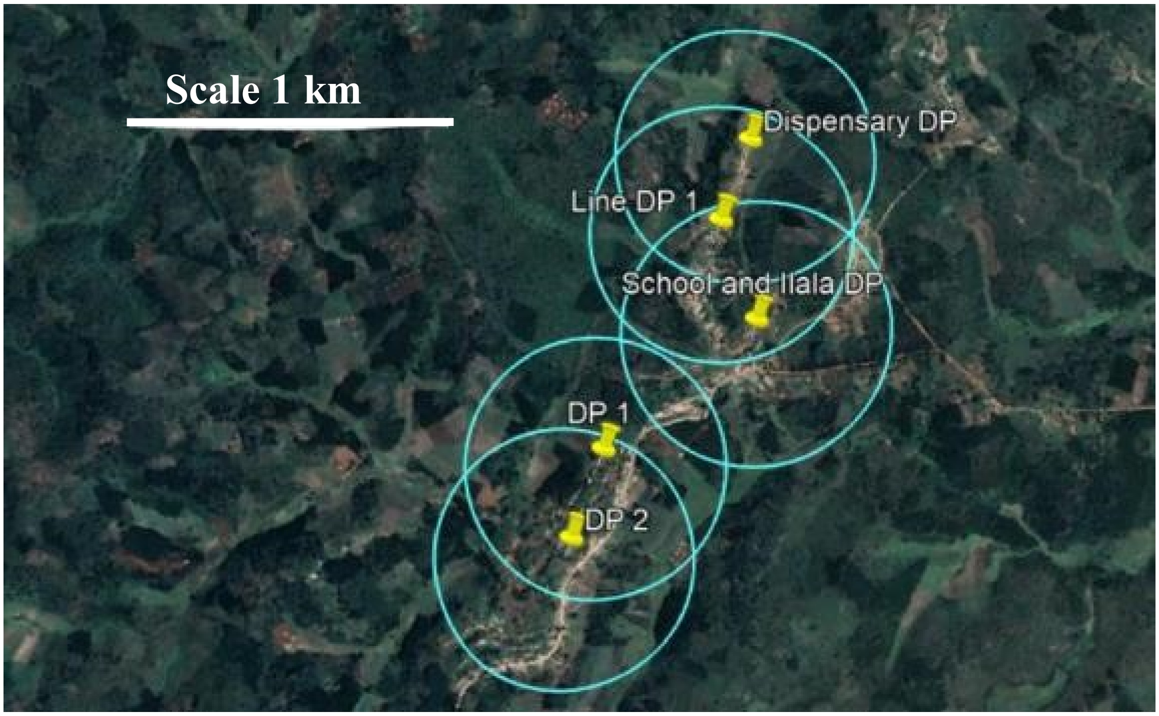


Figure 5.8 | Overview of the Magome DPs. 400m radius circles around each DP

5.2 Cistern

A cistern will be built at the Muhanga spring source. In the effort of conserving elevation, the cistern will be built at the highest possible point in which the water will still flow from the Muhanga spring into the tank. A cistern is a large concrete tank with a cover on it which will isolate the water from the outside environment. It serves as the entrance point to the water distribution system. The cistern will collect water from the spring and trap all suspended particles at the bottom of the tank.

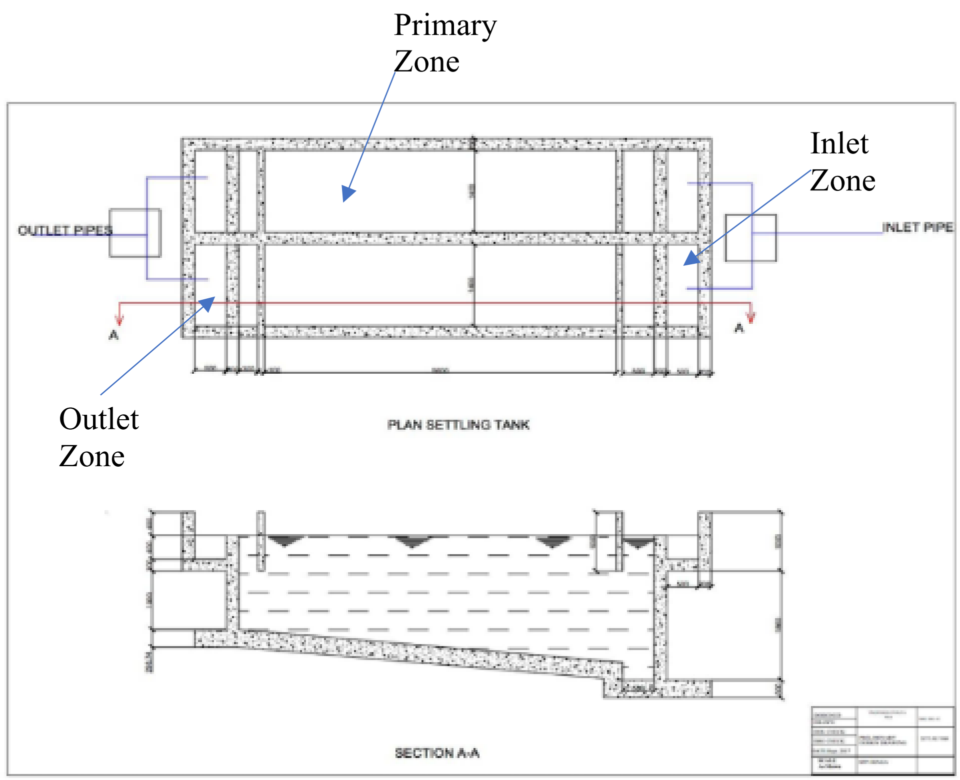


Figure 5.9 | Plan view as well as overhead view of the proposed cistern.

The cistern for this system is designed for a small sized silt particle. At the inlet, raw water will enter the tank and reside in the tank for a period of time, called the residence time. Figure 5.9 shows the different parts of the proposed cistern. The inlet pipe will likely be a short pipe connection from the spring which will direct the water into the tank.

As seen from Figure 5.9, the tank will comprise of three primary regions. The inlet zone is connected to the inlet pipe and is where the water will enter the tank. This zone will serve to reduce the turbulence in the water as it enters the tank, ensuring the assumption that the flow is laminar is met. The inlet zone will be separated from the primary zone by a large baffle weir. This weir will serve with a purpose to trap all floating particles as well as larger particles that may make it into the tank. The primary settling zone will be where the majority of particles settle. The tank was designed for a smallest particle of 0.03mm and a density of 1500 kg/m^3. Any particles larger or heavier than this particle will settle out. A final weir will separate the primary zone from the outlet zone. It is recommended that this weir be either a solid plate or a very fine screen so that all the particles are contained in the primary zone. In addition, to ensure water can reach the outlet zone, it is recommended that the screen be about 70% of the total cistern height. A weir height of such will allow for clean water to flow into the outlet zone efficiently. The outlet zone will serve to keep all settled particles in the primary settling zone and will be connected to the outlet pipe.

The overall inner dimensions for the cistern will be 4x1x1m. The plan area dimensions of 4x1m ensure that that the smallest design particle can settle out of the water as seen in

Appendix H. Since the number of particles settled out of the water are independent of the tank height, the height of the tank was chosen to be 1m. Using the overall cistern dimensions of 4x1x1m and assuming a high-end incoming flow rate of 2000LPH, it was calculated and verified that all target particles and those bigger would settle out. Since pathogens in fresh water tend to be attached to particles of this size, the outgoing water will be safe and free of any harmful bacteria.

5.2 Phase 2

Phase 2 of the Magome water distribution system is designed around the assumption that the village will gain access to grid power. As of the last visit, January 2020, the village of Magome did not have access to grid power. The power lines and poles were put up around the village but without power. Magome expects grid power before the start of 2021.

Phase 2 is also an optional addition based on the revenue available for the project as well as the community's needs. The goal of Phase 2 is to bring water on-site to the primary school, which is the highest location within the village of Magome. During Phase 1, a distribution point for the school to use was put in within the 400 m radius as outlined by the Tanzanian Design Guidelines. The DP could not be put on-site due to the high elevation of the school and the limitations of the gravity fed system. Phase 2 is an addition that will provide Magome primary school with an additional convenience of a shorter walking distance to the nearest DP. It will also provide water at an elevation suitable for providing water to previously unserved areas in Magome.

A 2-horsepower surface pump will be added to the tanks located at the market. See Appendix E for more information on the pump size calculation. This choice of pump would be connected to the bottom of a SIM tank via a pipe, which would then pump water to the tanks located at the school. A 650-meter-long line that climbs 52 meters in elevation will be dug in order to bring water from the tanks at the market to the school. Note that the pumping line shown in Figure 5.9 is not connected to the School and Ilala DP line in Phase 1. The line implemented in Phase 1 cannot withstand the pressure and flow rate required of the pumping line. For this reason, the School and Ilala DP line will remain separate from the pumping line to the school. The line will be connected to a 10,000 L tank on-site at the school. The pipe will have an outer diameter of 40 mm and be rated at PN10 near the market area and decrease to PN6 after gaining elevation.

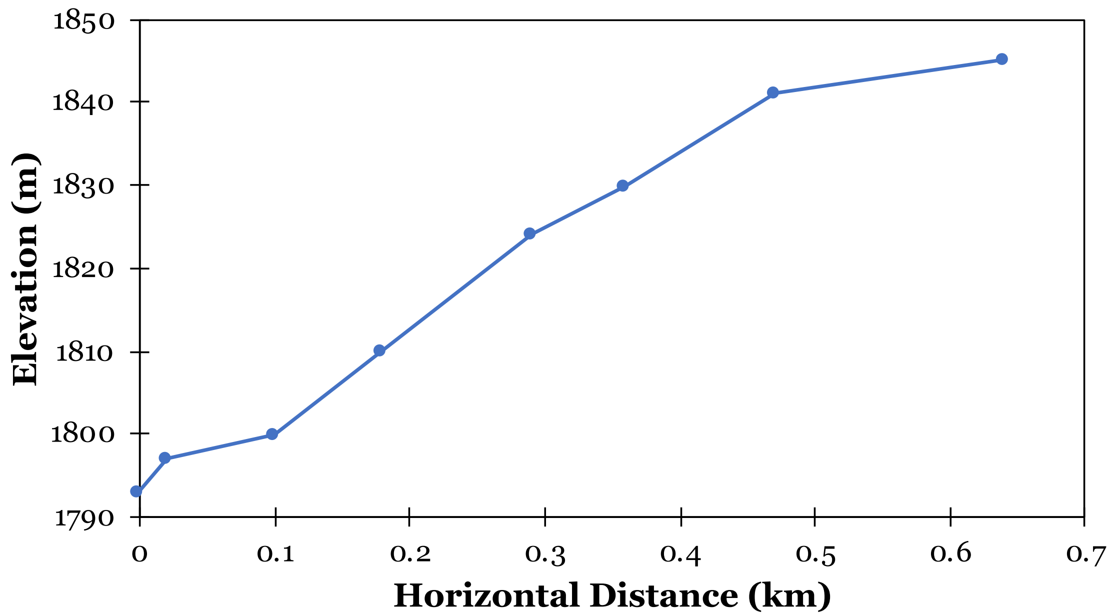


Figure 5.9 | Elevation Profile of Pumping Line. From the tanks located at the market to the tank located at the primary school.

Figure 5.10 | Google Earth View of Pumping Line. Location of the market and primary school (yellow), the tanks located in the market and at the school (purple), as well as the pumping line connecting the two tanks (red).

A distribution point will be put in near the tanks at the school to serve the students there. Due to very little elevation change and a short-traversed distance, the pipe used will be rated PN6 and will have an outer diameter of 25 mm. The DP will be serving 332 students along with 8 staff members. The projected peak demand for the school DP is 851 liters/hour. Based on the pipe size, the school DP has the capacity to supply 1707 liters/hour, which exceeds the requirements based on the projected water demand.

An additional line will run to Salem preaching point, which is just north of the school. The line to Salem will be approximately 450 meters long and decreases in elevation by 35 meters. This will require pipe with a 25 mm diameter and rating of PN6. The Salem line will serve a projected population of 116 people, which equates to a peak demand of 604 liters/hr. Based on the pipe size, the line can supply 987 liters/hour, which exceeds the required capacity for the line.

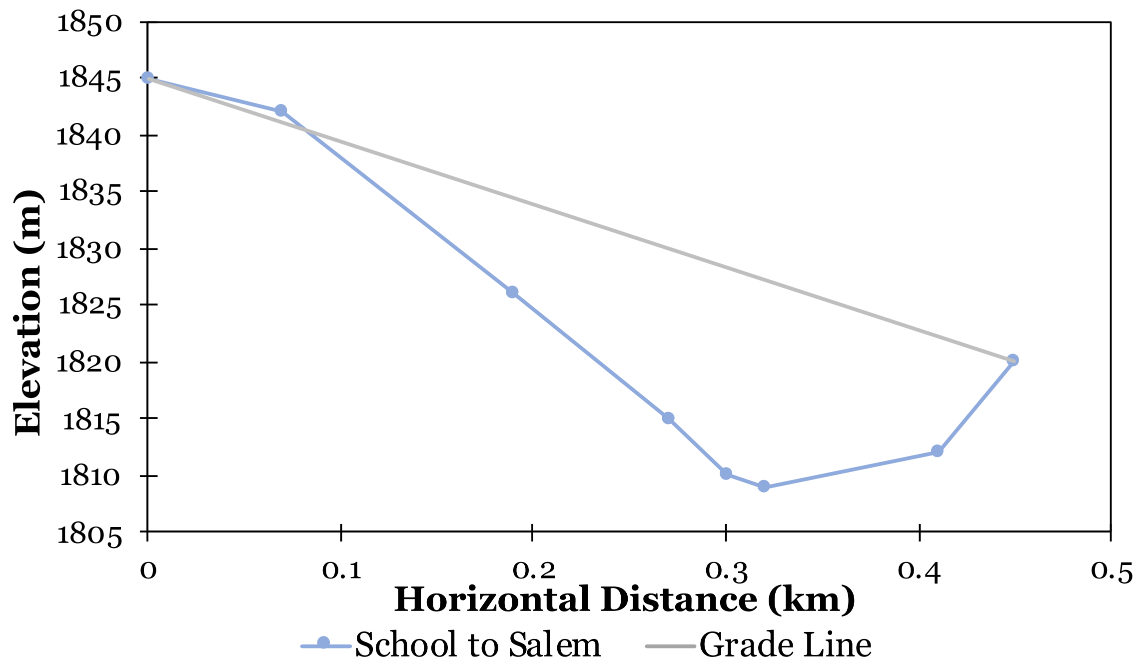


Figure 5.11 | Elevation Profile of Salem Line. From the tank located at the primary school to the distribution point located at Salem preaching point.

Figure 5.12 | Google Earth View of Salem Line. Location of the primary school (yellow), the location of the 10,000 tank (purple), the line running to the DP (red), and the Salem DP (blue).

From the tanks at the school, a line will be laid to the sub village of Magome. The line will be 550 meters long and decrease 75 meters in elevation. This will require a line with 25 mm in outer diameter and a rating of PN10. Due to the pipe diameter chosen, the line has the ability to supply 1191 liters/hour. Since the Magome line is projected to serve 162 people in 2030, equating to a peak demand of 846 liter/hour, the pipe chosen will be sufficient.

Figure 5.13 | Google Earth View of Magome Line. Location of the primary school (yellow), the location of the 10,000 tank (purple), the line running to the DP (red), and the Magome DP (blue).

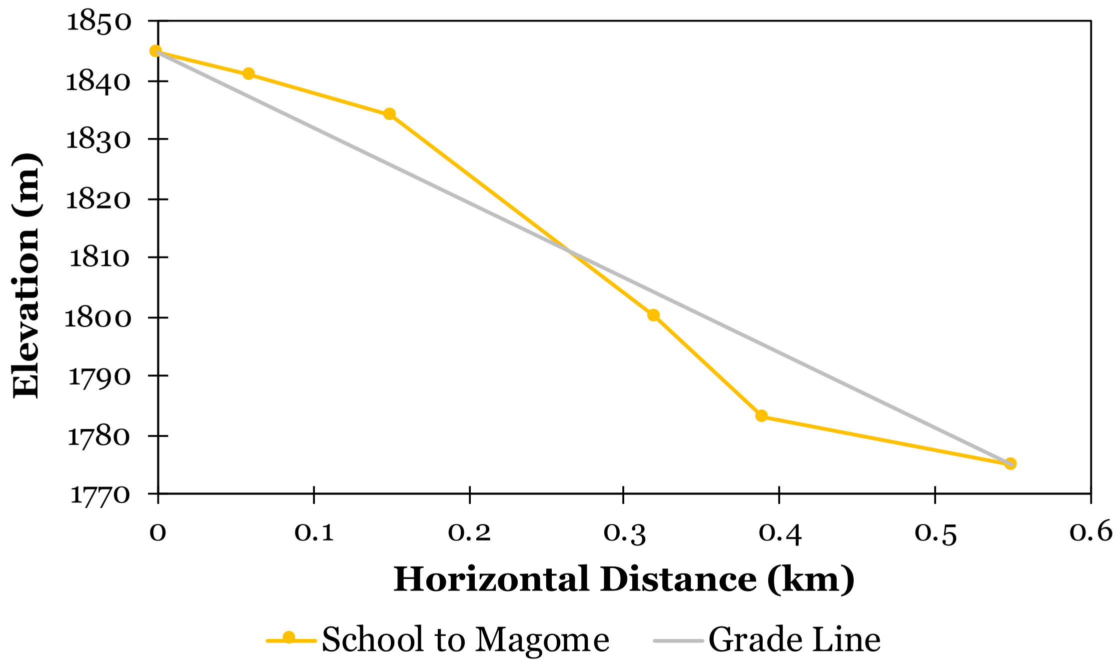


Figure 5.14 | Elevation Profile of Magome Line. From the tank located at the primary school to the distribution point in Magome sub village.

A summary of the elevations and GPS coordinates of the relevant features of the Phase 2 design is provided in Table 5.2.

Table 5.2. Location and Elevation of Phase 2 System Components.

Tank/DP	Coordinate	Elevation (m)
2 10,000 L Tanks in the market	8.082247° S, 35.968561° E	1793
10,000 L Tank	8.078919° S, 35.972591° E	1845
School DP	8.078556° S, 35.972534° E	1841
Salem DP	8.075131° S, 35.974379° E	1820
Magome DP	8.082405° S, 35.976026° E	1775

For more information regarding the pipe specifications including flow rate capacity and diameter, reference Appendix C.5-C.7 for Phase 2. See Appendix D for more on water demand. A cistern will be built at the Muhanga Spring source. In the effort of conserving elevation, the cistern will be built at the highest possible point in which the water will still flow from the Muhanga Spring into the tank. A cistern is a large concrete tank with a cover on it which will isolate the water from the outside environment. It serves as the entrance point to the water distribution system. The cistern will collect water from the spring and trap all suspended particles at the bottom of the tank.

6.0 Alternative Design

6.1 Locations of Distribution points, tanks, and pipelines

The location of each of the distribution point and the pipeline subject to change based on village visits and surveying as well as village desires. If Magome chooses to move a distribution point based on preference of the villagers or ease of accessibility, as long as the design implications have been studied and noted, the distribution point can be moved if the system functionality allows it.

The pressure distribution and length of the gravity main have been designed at a "worst case scenario". The current design for the gravity main allows the pipeline to go from Muhanga Spring and though the valley, which is the lowest point. Based on the design, the pressure in the pipes in the valley will not exceed burst pressure. However, if the design allows it, the pipeline can be dug along the ridgeline near the valley to prevent the pipes from going to such low elevations.

The water committee of Magome expressed a desire to locate the storage tanks at a higher elevation near the church. From a design point, the tanks had to be located at a lower elevation closer to the village market due to the amount of head needed in order to allow the water to flow from Muhanga to the storage tanks. The water tanks can be moved to other locations within the village market, so long as the elevation is less than the elevation of the current tank location (1793 m). If the location of the storage tanks are moved, further investigation and modeling should be performed in order to ensure a favorable hydraulic grade line for each of the lines extending to the distribution points around the village.

Figure 6.1 | Google Earth View of Potential Tank Locations.

Table 6.1 | Potential Tank Locations.

Tank	Coordinates	Elevation (m)
1	8.082604° S, 35.968041°E	1798
2	8.082478° S, 35.968029° E	1796
3*	8.082247° S, 35.968561° E	1793
4	8.081769° S, 35.968957° E	1793
5	8.081466°, S 35.968750° E	1788

*Tank 3 is the current proposed tank location.

6.2 Phase 2 Alternative Power Design

Although a surface pump was elected for this design, it could be replaced with a submergible pump. This choice of pump would sit within the SIM tank at the bottom and pump water up to through the pipe to the tank located at the school. Submergible pumps are typically used in boreholes and tend to be a more expensive design. This type of pump requires a certain form factor and requires a sleeve in order to ensure the pump is properly cooled. Further cost assessment and sizing analysis must be performed prior to selection of this design. The most cost-effective grid powered pump should be selected to satisfy the pumping requirement for Phase 2.

If the village of Magome does not have access to grid power by the time of the desired implementation of Phase 2, a solar powered pump is also an option. The pump would require a 1 kW array of solar panels in order to provide enough power for the pump to run. The calculation of this estimate is provided in Appendix E and should be verified before implementation. An inverter would also be required to convert the DC power to AC. The pump would only run during the day with sufficient sunlight due to the nature of solar power. This would mean that the pump would not be able to bring water to the school overnight, creating potential issues of supply on-site at the school.

Solar panels have a high up-front cost but require little revenue to maintain and provide energy. Therefore, the life cycle cost of solar powered pumping systems is typically lower than that of grid powered systems. The upfront cost of the solar panels, wiring, pump, and control panel for this system would need to be assessed.

A discussion with the water committee must be conducted in regard to the mounting of the location of the solar panels. A secure spot must be established in order to maintain the integrity and security of the system. The location will also need to be close to the tank locations in order to run the electrical line. The pastor's house and buildings in the market are in the vicinity of the proposed tank locations. These are some options that could be explored.

6.3 Water Treatment Option

An alternative option to a full system implementation would be the treatment of surface water. Conventional treatment of surface water sources could be implemented, and treated water could be pumped to storage tanks located at the primary school. Since a pump is already required, pumping directly to the tanks located at the primary school would best address the village's priorities. Depending on the flow rate obtained from the treated water and the pump, water could be distributed to the proposed locations outlined in Phase 1 and Phase 2. Water would be gravity fed to all of the DP locations since the school is at the highest elevation. The routes of the system branches and exact DP locations should be revisited and studied. Implementation of system branches is dependent on available water dictated by the flow rate. After bringing water to the school, it is recommended to lay branches reaching the market and dispensary. After implementation of these branches, if available water supply remains, additional lines may be constructed.

This alternative solution was not as heavily considered due to the ongoing operational costs and maintenance required. Financial resources would be required to pay for the pump electricity bill and to cover ongoing water treatment. These costs would be added to the existing cost of the physical system (piping, fittings, tanks, DPs, and other system features). It would also likely serve a smaller population of Magome. Implementation of the Muhanga Spring fed system is believed to have more capacity to serve the people and provide a broader system. However, the use of potable water treatment kits for locations such as the primary school, dispensary, and church could be funded as an interim solution. This would provide temporary access to clean water at key locations within the village.

7.0 Design Impact

7.1 Community Health and Safety

By providing clean, accessible water to the community of Magome, major health improvements are expected. The community currently drinks from sources that range from High to Very High risk for both E. coli as well as coliform bacteria. During the wet season, water quality is especially poor due the amount of run off that settles in the village's water sources. Since Magome is such a hilly community dense with agricultural land and some livestock, the wet season poses a higher risk for water borne illnesses. It was reported that in the wet season, the dispensary can treat from 200 to 500 individuals per month. From these numbers it is evident that water quality has a severe impact on the health of the community and impacts the overall productiveness of the people who live there. By gaining access to cleaner water, conditions such as dysentery, cholera, and diarrhea are less of a risk. It is also important to note that Magome's most contaminated source is serving the populations which are most vulnerable to disease. Source 1, the source that provides water to both the primary school and the dispensary, is populated with E. coli too numerous to count as well as a high concentration of coliform. The mortality rate of water borne illnesses such as cholera and dysentery are much higher in the young and elders, which are the populations served by Source 1.

Aside from water borne illnesses, another health impact that indirectly results from contaminated water are burns and increased smoke inhalation. When women in the village boil the water to reduce the risk of disease from drinking the water, they are at risk for other negative health risks. Burns are a major cause of disability, prolonged hospital stays, and mortality in Tanzania [2].

7.2 Economic Impact

In the village of Magome, water collection is a time intensive task. On average, villagers collect water three to four times daily with each trip taking about 45 minutes round-trip. Children at the primary school between the ages of 8 and 15 years old are required to fetch water during the school day. These children fetch water three to four times daily and miss classes while performing this task. This means that water collection takes about two to three hours each day for community members and school children. This does not include the time required to boil the water, which is critical in a community with such contaminated water.

Not only is water collection time intensive, but it is also labor intensive. The surface sources in Magome are located in valleys near the village, which makes water collection a downhill and uphill hike. The hike to a typical source in Magome consists of about a 40 to 100-meter elevation gain for about 0.4 kilometers. The terrain of Magome is very mountainous and lush, with overgrown vegetation and muddy trails. These features make navigating the land even more difficult, especially while carrying 20 liters of water weighing about 20 kg.

7.3 Operating Cost

The proposed Phase 1 design for the water distribution system for Magome village is a purely gravity fed system. Water will flow from Muhanga Spring to the tanks located in the village center and be distributed to the population by gravity fed lines to distribution points. The operating cost of this subsystem will be very low and require little maintenance.

A foreseeable issue that would require maintenance would likely be a struck pipe by a farmer hoe. Since the village of Magome consists of many agricultural plots, and the pipe runs long distances through the community, a pipe could be at risk of being damaged and cause a leak. However, if trenches are dug to a depth of 1 meter, the pipe should be deep enough to avoid damage.

Additional maintenance that the system would require is cleaning of the storage tanks as well as the cement cistern located at the spring source. These facilities would require cleaning in order to maintain a high caliber of water quality and avoid bacterial and algae growth. The frequency of cleaning will be conveyed to the community and responsibility would be distributed to selected individuals.

The water committee will be responsible for collecting funds, maintaining a savings account, and distributing the responsibilities of maintaining the system. A method of fund collection will be implemented to ensure that the community has a monetary reserve to fund repair to the system as well as general upkeep.

With the addition of Phase 2, the system complexity will be increased. Additional storage tanks will be added, as well as more distribution points. The main addition will be the pump and transformer that are responsible for transporting the water to the school. This pump will require maintenance to ensure functionality and will need to be replaced after 10 or more years, once the lifetime has been exceeded. The pump will also require electrical input, which will be supplied by grid power. The power from the grid will require financial contributions from the community to pay the power bill. These funds will be collected by the water committee and consist of annual payments for all manpower producers in the community.

7.4 Environmental Impact

The main environmental impact of the construction of Magome's proposed water distribution system is that the increased use of water from the selected spring will impact communities and vegetation downstream. It is recommended that 10% of Muhanga Spring's flow be left untouched for environmental purposes. It should also be noted that near Muhanga Spring exists two other major rivers that will remain untouched.

8.0 Implementation Budget

8.1 Phase I and Phase II Budget

The budgets have been determined according to the Tanzanian design guidelines and using costs from local Tanzanian supply companies. An exchange rate of 2280 Tanzanian Shillings (TSH) for every 1 US Dollar (USD) was assumed. An itemized budget for Phase 1 is shown in Table 8.1 and an itemized budget for Phase 2 is shown in Table 8.2.

Table 8.1 | Phase 1 Costs.

Material	Unit	Quantity	Unit Cost (USD)	Total Cost (USD)
Raw Materials				
10000 L tank	1 tank	2	$ 1,140.35	$ 2,281
Concrete for tank foundation	1 bag	100	$ 10.00	$ 1,000
5000 L tank	1 tank	1	$ 434.21	$ 434
Concrete for dispensary tank foundation	1 bag	50	$ 10.00	$ 500
Taps	1 tap	5	$ 50.00	$ 250
Tank pipe fittings	1 fitting	3	$ 60.00	$ 180
Pipe fittings	10% of pipe costs	See Appendix F for Pipe Costs		$ 658
Piping for gravity main	1.5 inch pipe	See Appendix F for Pipe Costs		$ 5,273
Piping for DPs	1 inch pipe	See Appendix F for Pipe Costs		$ 1,302
Cistern reinforcement	Per piece	102	$ 8.00	$ 816
Cistern fittings, weir, & boarding	Lump sum	1	$ 1,331.00	$ 1,331
Concrete for cistern	1 bag	50	$ 10.00	$ 500
			Raw Materials Subtotal	*$ 14,525*
Transportation				
Pipe	Truck & tractor	12	$ 176.00	$ 2,112
Tanks	Truck & tractor	3	$ 176.00	$ 528
Concrete	Truck & tractor	3	$ 176.00	$ 528
			Transportation Subtotal	*$ 3,168*
Labor				
DPs	$2 per person per day	6	$ 2.00	$ 12
Digging	$2 per meter	4728	$ 2.00	$ 9,456
Cistern	$2 per person per day	9	$ 2.00	$ 18
			Labor Subtotal	*$ 9,486*
			Raw Materials + Transportation Costs	$ 17,693
			15% St. Paul Partners Management Fee	$ 2,654
			15% Contingency	$ 2,654
			Total Labor Cost	$ 9,486
			In-kind Contribution	$ (9,486)
			Total Cost to Donors	$ 23,000
			Population served	1045
			Price per person	$ 22.01

Table 8.2 | Phase 2 Costs.

Material	Description	Unit	Unit Cost (USD)	Total Cost (USD)
Raw Materials				
10000 L tank	1 tank	1	$ 1,140.35	$ 1,140
Concrete for tank foundation	1 bag	50	$ 10.00	$ 500
Pump	1 unit	1	$ 2,000.00	$ 2,000
Transformer	1 unit	1	$ 1,000.00	$ 1,000
Piping for line to school	1 inch pipe	See Appendix F for Pipe Costs		$ 689
Piping to DPs	1 inch pipe	See Appendix F for Pipe Costs		$ 296
Pipe fittings	10% of pipe costs	See Appendix F for Pipe Costs		$ 99
Tank pipe fittings	1 fitting	2	$ 60.00	$ 120
Taps	1 tap	3	$ 50.00	$ 150
			Raw Materials Subtotal	*$ 5,994*
Transportation				
Pipe	Truck & tractor	4	$ 176.00	$ 704
Tank	Truck & tractor	1	$ 176.00	$ 176
Concrete	Truck & tractor	1	$ 176.00	$ 176
			Transportation Subtotal	*$ 1,056*
Labor				
DPs	$2 per person per day	4	$ 2.00	$ 8
Digging	$2 per meter	1393	$ 2.00	$ 2,786
			Labor Subtotal	*$ 2,794*
			Raw Materials + Transportation Costs	$ 7,050
			15% St. Paul Partners Management Fee	$ 1,057
			15% Contingency	$ 1,057
			Total Labor Costs	$ 2,794
			In-kind Contribution	$ (2,794)
			Total Cost to Donors	$ 9,165
			Population Served	572
			Cost Per Person Served	$ 16.02

An important aspect of the budget for both Phase 1 and Phase 2 are the significant labor costs that will be in-kind contributions from the village. The cost to donors is calculated as the sum of the raw materials and transportation with a 15% management fee paid to St. Paul Partners and a 15% contingency.

Another thing to note is that Phase 1 is not dependent on Phase 2, so if funding for Phase 1 is achieved the phase may be implemented without knowledge of whether or not Phase 2 will be implemented. It is also true that Phase 2 is dependent on Phase 1, so Phase 1 must be implemented in order for Phase 2 to be implemented.

9.0 References

(1) Environmental Health Fact Sheet (2006). Coliform Bacteria and Drinking Water. *Cedar County, Iowa Office of Environmental Health and Zoning.* Retrieved from https://www.cedarcounty.org/offices/environmentalhealth/forms/factsheet.pdf

(2) Outwater, A. H., Ismail, H., Mgalilwa, L., Temu, M. J., & Mbembati, N. A. (2013). Burns in Tanzania: morbidity and mortality, causes and risk factors: a review. *US National Library of Medicine National Institutes of Health*. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3560491/

(3) 3M Petrifilm™ (2017). Interpretation Guide. E. coli/Coliform Count Plate. *3M Food Safety.* Retrieved from https://multimedia.3m.com/mws/media/236246O/petrifilm-ecoli-coliform-interpretation-guide.pdf

(4) World Health Organization (1997). Guidelines for Drinking Water Quality. 2nd Edition. Volume III Surveillance and Control of Community Water Supplies. WHO. Geneva.

(5) Metcalf, Robert (2006). The Portable Microbiology Revolutionizing Point Water Source Testing in Africa. PowerPoint presentation. California State University, Sacramento, CA.

Appendix A: Petrifilm Interpretation Guide

The following describes the differences between coliform and E. coli:

What are Coliform Bacteria?
Coliform bacteria are commonly found in soil, on vegetation, and in surface water. They also live in the intestines of warmblooded animals and humans. Some coliform bacteria strains can survive in soil and water for long periods of time. Coliform bacteria will not likely cause illness. However, because coliform bacteria are most commonly associated with sewage or surface waters, the presence of coliform bacteria in drinking water indicates that other disease-causing organisms (pathogens) may be present in the water system. There are three different groups of coliform bacteria; each has a different level of risk.

Total coliform, fecal coliform and E. coli – what's the difference?
Total coliform, fecal coliform and E. coli are all indicators of drinking water quality. The total coliform group is a large collection of different kinds of bacteria. The fecal coliform group is a sub-group of total coliform and has fewer kinds of bacteria. E. coli is a sub-group of fecal coliform.

Total coliform bacteria are commonly found in the environment (e.g. soil or vegetation) and are generally harmless. If only total coliform bacteria are detected in drinking water, the source is probably environmental, and fecal contamination is not likely. However, if environmental contamination can enter the system, there may be a way for other pathogens to enter the system. Therefore, it is important to determine the source and resolve the problem.

Fecal coliform bacteria are a sub-group of the total coliform group. They appear in great quantities in the intestines and feces of people and animals. The presence of fecal coliform in a drinking water sample often indicates recent fecal contamination – meaning that there is a greater risk that pathogens are present than if only total coliform bacteria are detected.

E. coli is a subgroup of the fecal coliform group. Most E. coli are harmless and are found in great quantities in the intestines of people and warm-blooded animals. Some strains, however, may cause illness. The presence of E. coli in a drinking water sample almost always indicates recent fecal contamination – meaning that there is a greater risk that pathogens are present. E. coli outbreaks receive much media coverage. Most outbreaks have been related to food contamination, caused by a specific strain of E. coli known as E. coli 0157:H7, which can cause serious illness and death. When a drinking water sample is reported as "E. coli present", it does not mean that this specific strain is present. However, it does indicate recent fecal contamination. Treating contaminated drinking water with a disinfectant, or boiling the water, destroys all E. coli, including 0157:H7.

- Coliform Bacteria and Drinking Water[1]

The following briefly describes the appearance of E.coli and other coliform colonies on a 3M Petrifilm Count Plate:

> The United States Food and Drug Administration (FDA) Bacteriological Analytical Manual (BAM) define coliforms as Gram negative rods, which produce acid and gas from lactose fermentation.
>
> Most E. coli (about 97%) produce betaglucuronidase which produces a blue precipitate associated with the colony indicated by the blue to red-blue colonies. The top film traps gas produced by the lactose fermenting coliforms and E. coli. About 95% of E. coli produce gas, as indicated by colonies associated with entrapped gas (within approximately one colony diameter). Blue colonies without gas are not counted as E. coli. * Other coliform colonies are red and closely associated with entrapped gas. The total coliform count consists of both the red and blue colonies associated with gas.
>
> Most E. coli O157 strains are atypical, for example they are glucuronidase negative; they will not produce a blue color, and will not be detected on 3M Petrifilm E. coli/Coliform Count Plates.

- 3M Petrifilm Interpretation Guide [3]

Table A1 | Example Petrifilm Results. Results provided in 3M Petrifilm Interpretation Guide [3].

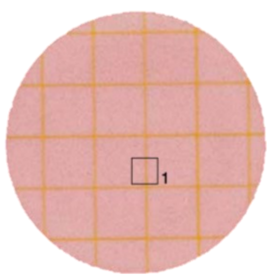
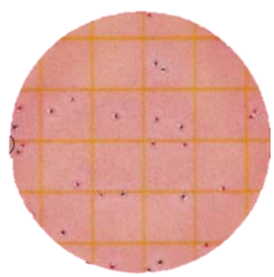
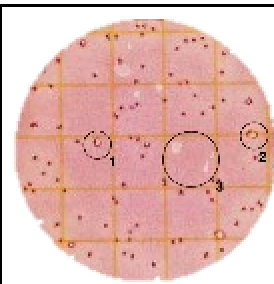
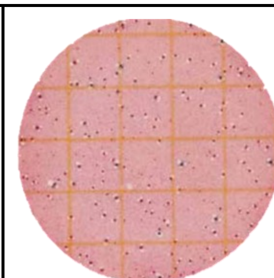
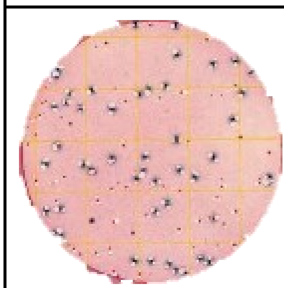
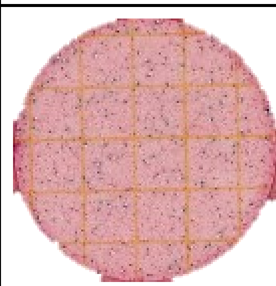
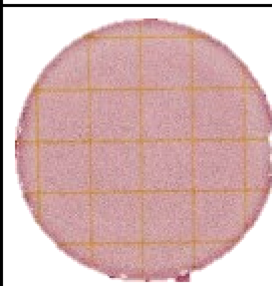
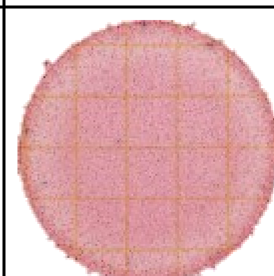
 No growth = 0	 E. coli count = 13 (blue colonies with gas) Total coliform count = 28 (red and blue colonies with gas)	 Estimated total coliform count = 150	 Estimated E. coli = 17 (blue colonies with gas) Estimated total coliform count = 150
 E. coli count = 49 (blue colonies with gas) Total coliform count = 87 (red and blue colonies with gas)	 Total coliform count = Too Numerous to Count (TNTC)	 Total coliform count = Too Numerous to Count (TNTC)	 Total coliform count = Too Numerous to Count (TNTC)

Table A2 | Risk Levels vs Petrifilm E.coli Count.

Risk Level [4]	Petrifilm E.coli [5]
Conformity	0
Low	0
Intermediate	0
High	1-10 (blue with gas bubbles count)
Very High	> 10 (blue with gas bubbles count)

Appendix B: Tanzanian 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 distribution point (DP) 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. The relative roughness (ε/d) is roughness divided by the internal pipe diameter.

The maximum working pressure for a pipe should be approximately 80% of rating. For example: a HDPE pipe is rated at PN 8. PN 8 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 serves a minimum 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/s. Slower than 0.5 m/s usually means the pipe is too large. Higher than 1.5 m/s may lead to water hammer.

Lines should be buried at 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 costs.

Appendix C: Engineering Equation Solver Code for Lines

The flow simulations and calculations were performed in Engineering Equation Solver (EES) software. The code that was entered is provided for each section and is specific to each line in regard to elevation and line length. EES was used to determine the flow rate in each line as well as ensure that the flow rate through each line is sufficient to supply the village with its water needs. It was also used to study pressure distributions along each line and was referenced when choosing pipe wall thickness.

Table C1 provides a summary of the variables used in the EES code and what they represent.

Note: The variables Kv2_var, Kv3_var, d12_var, d23_var, z_var, L_var, K2var, etc were used as variables for creating a parametric table. These correspond to the input variables that were varied in the parametric table.

Table C1 | Variables used in EES Code.

Variable	Unit	Description
g	m/s^2	Gravity constant
rho	kg/m^3	Density of water
f	null	Friction factor estimate
nu	m^2/s	Kinematic viscosity of water
pi	null	Equivalent to $\pi = 3.14159$ ...
z1	m	Elevation of start
z2	m	Elevation of end/intermediate point of the line depending on how many distribution points
z3	m	Elevation of the end of the line
L12	m	Length from point 1 to point 2 of the line
L23	m	Length from point 2 to point 3 of the line
L_DP	m	Length of the line to the distribution point from the main line
d12	m	Diameter of the line going from point 1 to point 2
d23	m	Diameter of the line going from point 2 to point 3
d_DP	m	Diameter of the distribution point
p2	Pa	Pressure at point 2
p3	Pa	Pressure at point 3
p2bar	Pa	Pressure at point 2 in bar
p3bar	Pa	Pressure at point 3 in bar
Q12	m^3/s	Volumetric flow rate in the pipe spanning from point 1 to point 2
Q213	m^3/s	Volumetric flow rate in the pipe spanning from point 2 to point 3
Q12LPH	m^3/s	Volumetric flow rate in the pipe spanning from point 1 to point 2 in liters per hour
Q23LPH	m^3/s	Volumetric flow rate in the pipe spanning from point 2 to point 3 in liters per hour
QDP2LPH	m^3/s	Volumetric flow rate exiting from the first distribution point of a line in liters per hour
QDP3LPH	m^3/s	Volumetric flow rate exiting from the second distribution point of a line in liters per hour
Kv2	null	Valve coefficient for the first distribution point in a line (ranges from 10 [is fully open] to 1e9 [is closed])
Kv3	null	Valve coefficient for the second distribution point in a line
V12	m/s	Velocity of the water in the pipe from point 1 to point 2
V23	m/s	Velocity of the water in the pipe from point 2 to point 3
V2DP2	m/s	Velocity of the water exiting from the first distribution point
V3DP3	m/s	Velocity of the water exiting from the second distribution point

C.1 Phase 1: Muhanga Spring to Tank Gravity Main Line EES Calculations Code to Find Water Velocity

The code provided below was used to determine the velocity and flow rate through the gravity main.

```
Start code{
{Physical properties}
g=9.81 [m/s^2]
rho=1000 [kg/m^3]
f=0.025
nu=1.12e-06

{DP pipe info}
z1= 1820 [m]
z2=1793 [m]
L12=3103 [m]

{guess diameters}
d12=40.6/1000 [m]

{Equations}
p2=0
p2/(rho*g)+z2-z1+V12^2/(2*g)*1.05*f*L12/d12=0
Q12=V12*0.25*d12^2

{3600000 converts from m^3/s to LPH}
Q12LPH=3600000*pi*d12^2/4*V12

{converts Pascals to bar}
p2bar=p2/100000

}End Code
```

Table C2 | EES Constants and Outputs.

Variable	Value
d12 (m)	40.6/1000
L12 (m)	3000
p2 (Pa)	0
p2bar (bar)	0
Q12 (m^3/s)	0.0002154
Q12LPH (liters per hour)	2436
V12 (m/s)	0.5226
z1 (m)	1820
z2 (m)	1793

C.2 Phase 1: Muhanga Spring to Tank Gravity Main Line EES Calculations Code to Find Pressure Distribution

Using the velocity calculated using the code from C.1, the pressure distribution of the gravity main was calculated. A parametric table was created with the distance from the spring source and the elevation of each point as inputs. The result is displayed graphically in Figure C1.

```
Start Code{

{Create parametric table with distance from source and elevation as inputs}
{Physical properties}
g=9.81 [m/s^2]
rho=1000 [kg/m^3]
f=0.025
nu=1.12e-06

{DP pipe info}
z1= 1820 [m]
z2=zvar
L12=Lvar

{guess diameters}
d12=40.6/1000 [m]

{Equations}
V12= 0.5226
p2/(rho*g)+z2-z1+V12^2/(2*g)*1.05*f*L12/d12=0
Q12=V12*0.25*d12^2

{3600000 converts from m^3/s to LPH}
Q12LPH=3600000*pi*d12^2/4*V12

{converts Pascals to bar}
p2bar=p2/100000

}End Code
```

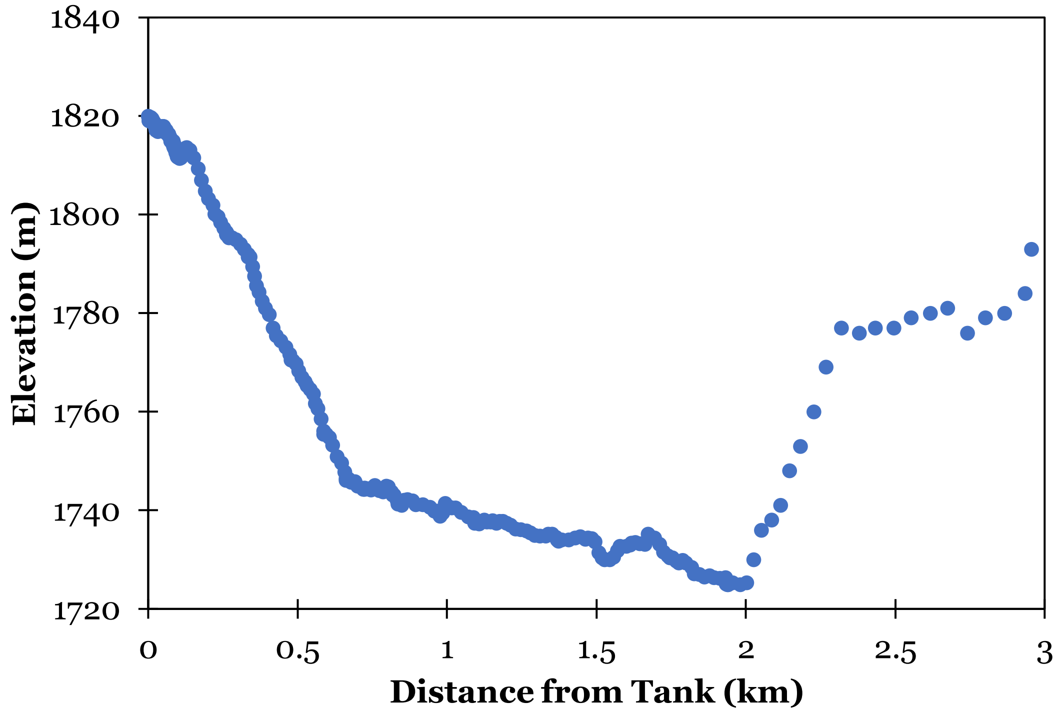


Figure C1 | Input to EES Code Displayed Graphically. Elevation Profile of Gravity Main.

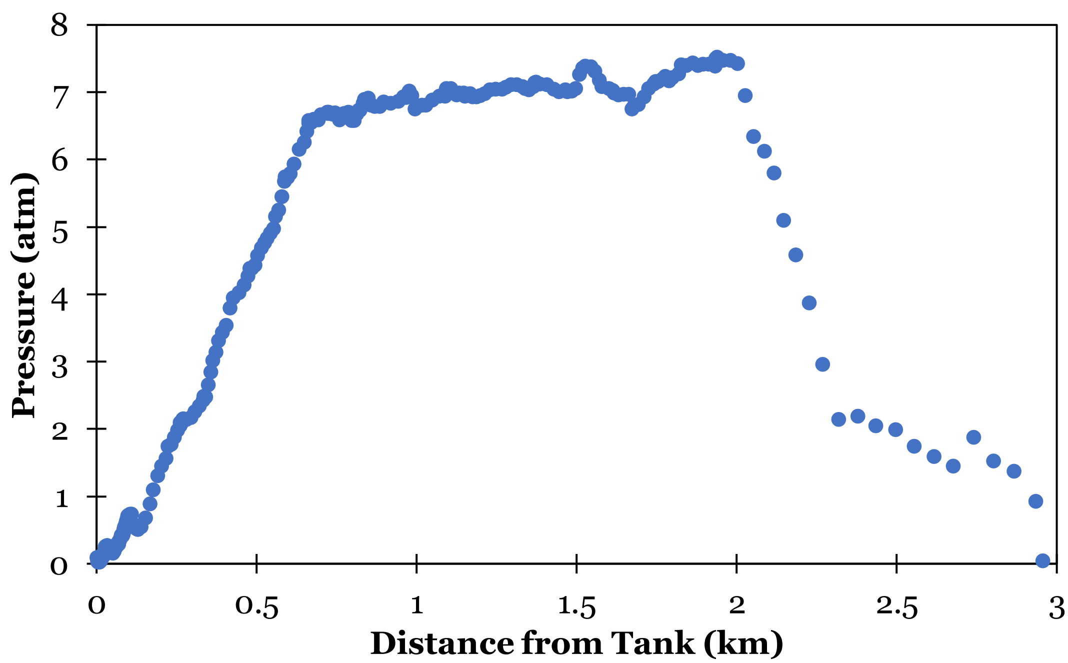


Figure C2 | Output of EES Code Displayed Graphically. Pressure Distribution of Gravity Main.

C.3 Phase 1: Tank to Dispensary Line EES Calculations Code

The line to the dispensary contains two distribution points located at point 2 and point 3. Various combinations of diameters and valve coefficients were used. The best formulation was selected from the pool of options and is displayed in Table C.2.1.

Start Code{

```
{create parametric table with d12, d23, Kv2, Kv3, L12, L23, and d_DP as inputs}
{Physical properties}
g=9.81 [m/s^2]
rho=1000 [kg/m^3]
f=0.025
nu=1.12e-06

{DP pipe info}
d_DP=d_DP_var
L_DP=20 [m]
z1=1793 [m]
z2=1767 [m]
z3=1744 [m]
L12=310 [m]
L23=760 [m]

{guess diameters and valve settings}
{10 is max flow and 10^9 is closed}
d12=d12_var
d23=d23_var
Kv2=Kv2_var
Kv3=Kv3_var

{Equations}
p2/(rho*g)+z2-z1+V12^2/(2*g)*1.05*f*L12/d12=0
(p3-p2)/(rho*g)+z3-z2+V23^2/(2*g)*1.05*f*L23/d23=0
-p2/(rho*g)+V2DP2^2/(2*g)*(1.05*f*L_DP/d_DP+Kv2)=0
-p3/(rho*g)+V3DP3^2/(2*g)*(1.05*f*L_DP/d_DP+Kv3)=0
V12*d12^2=V23*d23^2+V2DP2*d_DP^2
V23*d23^2=V3DP3*d_DP^2

{3600000 converts from m^3/s to LPH}
Q12LPH=3600000*pi*d12^2/4*V12
Q23LPH=3600000*pi*d23^2/4*V23
QDP2LPH=3600000*pi*d_DP^2/4*V2DP2
QDP3LPH=3600000*pi*d_DP^2/4*V3DP3

{converts Pascals to bar}
p2bar=p2/100000
```

p3bar=p3/100000

}End Code

Table C3 | Input and Output for the EES Code for the Selected Formulation.

Input	**1**	**2**	**3**	**4**	**5**	**6**
d12 (m)	0.02896	0.02896	0.02896	0.02896	0.02896	0.02896
d23 (m)	0.027072	0.027072	0.027072	0.027072	0.027072	0.027072
d_DP (m)	0.027072	0.027072	0.027072	0.027072	0.027072	0.027072
Kv2	10	1000	10000	1000000000	0	1000000000
Kv3	10	10000	1000	0	1000000000	1000000000
Output						
p2bar (bar)	0.07977	1.757	1.752	1.487	0.2112	2.551
p3bar(bar)	0.0896	3.738	2.327	0.09599	2.468	4.807
Q12LPH (liters/hr)	3145	1783	1788	2063	3060	3.512
QDP2LPH (liters/hr)	1527	1217	387.5	1.13	3058	1.48
Q23LPH (liters/hr)	1618	566	1400	2062	1.456	2.032
V12 (m/s)	1.326	0.7517	0.7538	0.8699	1.29	0.001481
V2DP2 (m/s)	0.7367	0.5871	0.187	0.0005454	1.476	0.0007142
V23 (m/s)	0.7808	0.2732	0.6756	0.995	0.0007025	0.0009805

C.4 Phase 1: Tank to School Distribution Point EES Calculations Code

The tank to the school line consists of a single distribution point. Various combinations of diameters and valve coefficients were tried and are displayed in Table C4. The best formulation is highlighted in green.

Start Code{

```
{Create parametric table with d_DP, Kv2 as inputs}
{Physical properties}
g=9.81 [m/s^2]
rho=1000 [kg/m^3]
f=0.025
nu=1.12e-06

{DP pipe info}
d_DP=d_DP_var
L_DP=20 [m]
z1=1793 [m]
```

```
z2=1786 [m]
L12=190 [m]

{guess diameters and valve settings}
{10 is max flow and 10^9 is closed}
d12=dvar
Kv2=K2var

{Equations}
p2/(rho*g)+z2-z1+V12^2/(2*g)*1.05*f*L12/d12=0
-p2/(rho*g)+V12^2/(2*g)*(1.05*f*L_DP/d_DP+Kv2)=0

{3600000 converts from m^3/s to LPH}
Q12LPH=3600000*pi*d12^2/4*V12

{converts Pascals to bar}
p2bar=p2/100000

}End Code
```

Table C4 | Input and Outputs of EES Code. Selected Formulation Highlighted.

Input		**Output**		
d12 (m)	Kv2	p2bar (bar)	QDP2LPH (liter/hr)	V2DP2 (m/s)
0.02896	10	0.3521	1406	0.5929
0.02896	1000	0.592	747.9	0.3154
0.02896	10000	0.6741	272.8	0.115
0.02896	1000000000	0.6867	0.8788	0.0003706
0.0362	10	0.3543	2448	0.6608
0.0362	1000	0.6065	1202	0.3245
0.0362	10000	0.6766	427.8	0.1154
0.0362	1000000000	0.6867	1.373	0.0003706
0.022625	10	0.3503	760.6	0.5255
0.022625	1000	0.5742	439.8	0.3039
0.022625	10000	0.6707	165.6	0.1144
0.022625	1000000000	0.6867	0.5364	0.0003706

C.5 Phase 1: Tank to Mtule Line EES Calculations Code

The line to Mtule sub village contains two distribution points located at point 2 and point 3. Various combinations of diameters and valve coefficients were used. The best formulation was selected from the pool of options and is displayed in Table C5.

```
Start Code{

{create parametric table with d12, d23, Kv2, Kv3, L12, L23, d_DP as inputs}
```

```
{Physical properties}
g=9.81 [m/s^2]
rho=1000 [kg/m^3]
f=0.025
nu=1.12e-06

{DP pipe info}
d_DP=d_DP_var
L_DP=20 [m]
z1=1793 [m]
z2=1776 [m]
z3=1773 [m]
L12=570 [m]
L23=860 [m]

{guess diameters and valve settings}
{10 is max flow and 10^9 is closed}
d12=d12_var
d23=d23_var
Kv2=Kv2_var
Kv3=Kv3_var

{Equations}
p2/(rho*g)+z2-z1+V12^2/(2*g)*1.05*f*L12/d12=0
(p3-p2)/(rho*g)+z3-z2+V23^2/(2*g)*1.05*f*L23/d23=0
-p2/(rho*g)+V2DP2^2/(2*g)*(1.05*f*L_DP/d_DP+Kv2)=0
-p3/(rho*g)+V3DP3^2/(2*g)*(1.05*f*L_DP/d_DP+Kv3)=0
V12*d12^2=V23*d23^2+V2DP2*d_DP^2
V23*d23^2=V3DP3*d_DP^2

{3600000 converts from m^3/s to LPH}
Q12LPH=3600000*pi*d12^2/4*V12
Q23LPH=3600000*pi*d23^2/4*V23
QDP2LPH=3600000*pi*d_DP^2/4*V2DP2
QDP3LPH=3600000*pi*d_DP^2/4*V3DP3

{converts Pascals to bar}
p2bar=p2/100000
p3bar=p3/100000

}End Code
```

Table C5 | Input and Output for the EES Code for the Selected Formulation.

Input	1	2	3	4	5	6
d12 (m)	0.02896	0.02896	0.02896	0.02896	0.02896	0.02896
d23 (m)	0.02896	0.02896	0.02896	0.02896	0.02896	0.02896
d_DP (m)	0.02896	0.02896	0.02896	0.02896	0.02896	0.02896
Kv2	10	1000	10000	1000000000	0	1000000000
Kv3	10	10000	1000	0	1000000000	1000000000
Output						
p2bar (bar)	0.03637	0.863	0.9792	0.8957	0.0565	1.668
p3bar(bar)	0.01152	1.074	0.7213	0.02705	0.3508	1.962
Q12LPH (liters/hr)	1884	1324	1224	1296	1873	2.855
QDP2LPH (liters/hr)	1206	976.3	331.6	1.004	1872	1.37
Q23LPH (liters/hr)	678.6	347.2	892.6	1295	0.6281	1.485
V12 (m/s)	0.7947	0.5581	0.5162	0.5467	0.7897	0.001204
V2DP2 (m/s)	0.5085	0.4117	0.1398	0.0004233	0.7895	0.0005775
V23 (m/s)	0.2862	0.1464	0.3764	0.5462	0.0002649	0.0006264

C.6 Phase 2: School Tank to Magome Distribution Point EES Calculations Code

The school tank to the Magome sub village line consists of a single distribution point. Various combinations of diameters and valve coefficients were tried and are displayed in Table C6. The best formulation is highlighted in green.

```
Start Code{

{create parametric table with d12, Kv2 as inputs}
{Physical properties}
g=9.81 [m/s^2]
rho=1000 [kg/m^3]
f=0.025
nu=1.12e-06

{DP pipe info}
z1=1845 [m]
z2=1775 [m]
L12=620 [m]

d12=d12_var
Kv2=K2var

{Equations}
```

```
p2/(rho*g)+z2-z1+V12^2/(2*g)*1.05*f*L12/d12=0
-p2/(rho*g)+V12^2/(2*g)*(1.05*f*L12/d12+Kv2)=0

{3600000 converts from m^3/s to LPH}
Q12LPH=3600000*pi*d12^2/4*V12

{converts Pascals to bar}
p2bar=p2/100000

}End Code
```

Table C6 | Input and Output to EES Code. Selected Formulation Highlighted.

Input		Output		
d12 (m)	Kv2	p2bar (bar)	Q12LPH (liters/hr)	V12 (m/s)
0.027072	10	3.462	2206	1.064
0.027072	1000	4.993	1636	0.7897
0.027072	10000	6.498	725.6	0.3501
0.027072	1000000000	6.867	2.428	0.001172
0.03384	10	3.469	3849	1.189
0.03384	1000	5.184	2709	0.8367
0.03384	10000	6.566	1146	0.354
0.03384	1000000000	6.867	3.794	0.001172
0.02115	10	3.456	1191	0.9416
0.02115	1000	4.786	930.2	0.7355
0.02115	10000	6.409	436.3	0.345
0.02115	1000000000	6.867	1.482	0.001172

C.7 Phase 2: School Tank to Salem Distribution Point EES Calculations Code

The school tank to the Salem preaching point line consists of a single distribution point. Various combinations of diameters and valve coefficients were tried and are displayed in Table C7. The best formulation is highlighted in green.

```
Start Code{

{create parametric table with d12, Kv2 as inputs}
{Physical properties}
g=9.81 [m/s^2]
rho=1000 [kg/m^3]
f=0.025
nu=1.12e-06

{DP pipe info}
z1=1845 [m]
```

```
z2=1820 [m]
L12=450 [m]

d12=d12_var
Kv2=K2var

{Equations}
p2/(rho*g)+z2-z1+V12^2/(2*g)*1.05*f*L12/d12=0
-p2/(rho*g)+V12^2/(2*g)*(1.05*f*L12/d12+Kv2)=0

{3600000 converts from m^3/s to LPH}
Q12LPH=3600000*pi*d12^2/4*V12

{converts Pascals to bar}
p2bar=p2/100000

}End Code
```

Table C7 | Input and Output of EES Code. Selected Formulation Highlighted.

Input		**Output**		
d12 (m)	Kv2	p2bar (bar)	Q12LPH (liters/hr)	V12 (m/s)
0.02896	10	1.241	1828	0.7707
0.02896	1000	1.902	1232	0.5197
0.02896	10000	2.36	505	0.213
0.02896	1000000000	2.452	1.661	0.0007004
0.0362	10	1.245	3188	0.8604
0.0362	1000	1.968	2019	0.5448
0.0362	10000	2.377	795.1	0.2146
0.0362	1000000000	2.452	2.595	0.0007004
0.022625	10	1.238	987.3	0.6821
0.022625	1000	1.826	709	0.4898
0.022625	10000	2.337	305	0.2107
0.022625	1000000000	2.452	1.014	0.0007004

C.8 Phase 2: School Tank to School Distribution Point EES Calculations Code

The school tank to the school line consists of a single distribution point. Various combinations of diameters and valve coefficients were tried and are displayed in Table C.3.1. The best formulation is highlighted in green. It is important to note that the school DP in Phase 2 is located on-site, along with the tanks. This means that the DP at the school is very close to the tank, and is fed through a very short line with the elevation difference consisting just the height of the tank.

```
Start Code{

{create parametric table with d12, Kv2 as inputs}
{Physical properties}
g=9.81 [m/s^2]
rho=1000 [kg/m^3]
f=0.025
nu=1.12e-06

{DP pipe info}
z1=1845 [m]
z2=1841 [m]
L12=20 [m]

d12=d12_var
Kv2=K2var

{Equations}
p2/(rho*g)+z2-z1+V12^2/(2*g)*1.05*f*L12/d12=0
-p2/(rho*g)+V12^2/(2*g)*(1.05*f*L12/d12+Kv2)=0

{3600000 converts from m^3/s to LPH}
Q12LPH=3600000*pi*d12^2/4*V12

{converts Pascals to bar}
p2bar=p2/100000

}End Code
```

Table C8 | Input and Output of EES Code. Selected Formulation Highlighted.

Input		Output		
d12 (m)	Kv2	p2bar (bar)	Q12LPH (liters/hr)	V12 (m/s)
0.02896	10	0.2386	3089	1.303
0.02896	1000	0.3855	652.6	0.2752
0.02896	10000	0.3917	209.7	0.08843
0.02896	1000000000	0.3924	0.6643	0.0002801
0.0362	10	0.2465	5256	1.418
0.0362	1000	0.3869	1023	0.2762
0.0362	10000	0.3918	327.8	0.08846
0.0362	1000000000	0.3924	1.038	0.0002801
0.022625	10	0.231	1707	1.18
0.022625	1000	0.3837	396.4	0.2739
0.022625	10000	0.3915	127.9	0.08838
0.022625	1000000000	0.3924	0.4055	0.0002801

Appendix D: Water Demand

D.0 Average and Peak Demand Sample Calculations

Referencing Table 4.1, Phase 1 and Phase 2 combined will be supplying water to 1,110 individuals and 386 students. The daily water demand for each person and each student is defined by the Tanzanian Water Code, which is outlined in greater detail in Appendix B.

$$1{,}110\ people\ (25L/person/day) + 386\ students(10L/student/day) = 31{,}610\ L/day$$

$$Average\ demand = \frac{Demand}{Daylight\ Hours} = \frac{31{,}610\ L}{12\ hours} = 2{,}634\ L/hr$$

$$Peak\ Demand = Average\ demand * (2.5) = (2{,}634\ L/hr)(2.5) = 6{,}585\ L/hr$$

The total, average, and peak demand for each distribution line is outlined in Table D1. The peak demand was then used to determine the diameter of the pipe for each line. The pressure rating for each line was determined by studying the elevation profile the line will traverse. The water demand was compared to the supply the line is capable of in order to ensure the system has enough capacity to handle the peak demand of the village. These results are recorded in Table D2.

D.1 Water Demand Per Distribution Line

Table D1 does not account for 20-25% losses. This is done in Table D2.

Table D1| Water Demand Per Distribution Line.

	Population Served	Total Demand (L/day)	Average Demand (L/hr)	Peak Demand (L/hr)
Phase 1				
School Ilala Line	75 people 386 students	5,735	478	1,195
Dispensary Line	255 people	6,375	531	1,328
Mtule Line	497 people	12,425	1,035	2,589
Phase 2				
School Line	10 teachers 386 students	4,060*	338	846
Magome Line	162 people	4,050	338	844
Salem Line	116 people	2,900	242	604
Total Flow Rate Demand		31,685	2,640	6,601

*The water demand for the students at the primary school was accounted for in the Phase 1 water demand calculation. It should not be included when calculating the total water demand for the village but should be considered when designing the flow rate the system must accommodate.

D.2 Peak Demand For Each Line

The peak demand outlined in Table D1 was multiplied by 1.25 to account for an assumed 25% losses due to leaks and open valves. The result was inserted into the Water Demand column of Table D2.

Table D2 | Supply Line Length and Diameter and Maximum Supply.

	Supply Line Length (m)	**Pipe Size Outer Diameter(mm)**	**Water Demand (L/hr)**	**Supply Capable by Line Based on Pipe Size and PN Rating (L/hr)**
Phase 1				
Gravity Main	2955	50	N/A*	2436
School Ilala Line	190	32	1,493	3,145
Dispensary Line	761	32	1,660	3,145
Mtule Line	827	40	3,107	3,289
Phase 2				
Pumping to School Line	649	40	2,867**	3,289
School Line	20	25	1,057	1,707
Magome Line	550	25	1,055	1,191
Salem Line	450	25	755	987

*Controlled by the capability of Muganga Spring to supply the water. This value changes based on whether just Phase 1 or both Phase 1 and 2 are implemented.

**The water pumped to the school will supply the School Line, Magome Line, and Salem Line.

Appendix E: Pump Calculations

E.1 Pump calculations

The following equation was used to determine the pumping power of the fluid ($\dot{W}_{fluid}$). In this equation, the power associated with changing the pressure of a fluid goes to zero because the pressure at both ends are equal to gauge pressure. The values of each of the variables are listed in Table E1.

The value of the volumetric flow rate was taken from Table D2 in Appendix D. The pumping system was designed around the peak demand of Phase 2 and accounts for 25% losses.

$$\dot{W} = \dot{m}\frac{(P_2 - P_1)}{\rho} + \dot{m}g(z_2 - z_1) + \frac{\dot{m}V_{pipe}^2}{2}\left(1.05\frac{fL}{d} + K_v\right)$$

total pump power required | power associated with changing the pressure of a fluid | power associated with changing the elevation of the fluid | power needed to overcome frictional losses (wall friction, elbows, fittings, valves, etc.)

Table E1 | Supply Line Length and Diameter and Maximum Supply

Variable	Value
$\dot{V}$	$2867\ LPH = 8.0 \times 10^{-4}\ \mathrm{m}/s^2$
$\dot{m}$	$0.8\ kg/s$
$Vpipe$	$1.05\ m/s$
L	$649\ m$
d	$27.1\ mm$
f	0.025
ρ	$1000\ kg/m^3$
g	$9.81\ m/s^2$
$z1$	$1793\ m$
$z2$	$1845\ m$
$\dot{W}_{fluid}$	$685.33\ W$

The pumping power of the fluid was calculated, and the total power of the pump needed was calculated by considering losses and efficiency. The efficiency of the electricity usage and the efficiency of the pump (η_{pump}).

$$\dot{W}_{pump,\,electric} = \frac{\dot{W}_{fluid}}{\eta_{elec} \cdot \eta_{pump}} = \frac{685.33\ W}{(0.9)(0.6)} = 1269.13\ W = 1.70\ HP$$

Due to the calculations, a pump of 2 horsepower is required.

E.2 Solar Panel Estimates

The solar panel array estimates were calculated based on a volumetric flow rate of $918\ L/hr$. This result is provided in average demand of the Phase 2 system outlined in Table D1. After accounting for 25% losses, this results in a volumetric flow rate of $1{,}147.5\ L/hr$. This results in a required mass flow rate of $0.32\ kg/s$. The amount of water pumped to the school per day in kilograms is calculated below. Note that 12 hours is considered as a day since the water demand occurs during daylight hours.

$$\frac{0.32\ kg}{s}\ \frac{60\ s}{1\ min}\ \frac{60\ min}{1\ hr}\ \frac{12\ hr}{1\ day} = 13{,}824\ kg\ per\ day$$

The water is pumped 52 m to the primary school. This results in the following potential energy.

$$PE = mgh = (13{,}824\ kg)(9.81\ m/s^2)(52\ m) = 7051899\ J$$

$$3.6\ MJ\ = 1\ kWh$$
$$7051899\ J\ = 1.96\ kWh$$

The kWh required was multiplied by 2 to account for a rough estimate of frictional losses and inefficiencies of the pump and electrical system. This value was then divided by 7 hours to account for the available sunlight during a calendar day. This results in a solar panels system that provides just under 1 kW.

Appendix F: Pipe Cost Calculations

F.1 Pipe Cost Calculations for Phase 1

Gravity Main				
Pipe	meters of 50mm pipe	Number of 2in Rolls Needed	Actual # of 1.5in Rolls to Order	Total Cost (USD)
PN 6	1160	7.733333333	8	1371.929825
PN 10	665	4.433333333	5	1322.368421
PN 12	1130	7.533333333	8	2578.947368
				5273.245614

Mtule Line				
Pipe	meters of 40mm pipe	Number 1.25in Rolls needed	Actual # of 1in Rolls to order	Total Cost (USD)
PN 6	832	5.546666667	6	736.8421053
PN 10	0	0	0	0
PN 12	0	0	0	0
				736.8421053

Dispensary line				
Pipe	meters of 32mm pipe	Number of 1in rolls needed	Actual # of 1in Rolls to Order	Total Cost (USD)
PN 6	565	3.766666667	4	275.4385965
PN 10	0	0	2	221.0526316
PN 12	0	0	0	0
				496.4912281

Tanks to School DP				
Pipe	meters of 32mm pipe	Number of 1in Rolls Needed	Actual # of 1in Rolls to Order	Total Cost (USD)
PN 6	180	1.2	1	68.85964912
PN 10	0	0	0	0
PN 12	0	0	0	0
				68.85964912
			Phase 1 Pipe Cost	6575.438596

F.2 Pipe Cost Calculations for Phase 2

Pumping from the tanks to the school				
Pipe	meters 40mm pipe	Number of 1.25in Rolls Needed	Actual # of 1.25in Rolls to Order	Total Cost (USD)
PN 6	540	3.6	4	491.2280702
PN 10	0	0	1	198.6842105
PN 12	0	0	0	0
				689.9122807

School to Magome Sub village				
Pipe	meters of 25mm pipe	Number of 1in Rolls Needed	Actual # of 1in Rolls to Order	Total Cost (USD)
PN 6	404	2.693333333	3	138.1578947
PN 10	0	0	1	65.78947368
PN 12	0	0	0	0
				203.9473684

School to Salem				
Pipe	meters of 25mm pipe	Number of 1in Rolls Needed	Actual # of 1in Rolls to Order	Total Cost (USD)
PN 6	449	2.993333333	3	138.1578947
PN 10	0	0	0	0
PN 12	0	0	0	0
				138.1578947
			Phase 2 Pipe Cost	1032.017544

Appendix G: Elevation Profiles for the Supply Lines

G.1 Line from the Tanks at the Market to the Ilala Branch

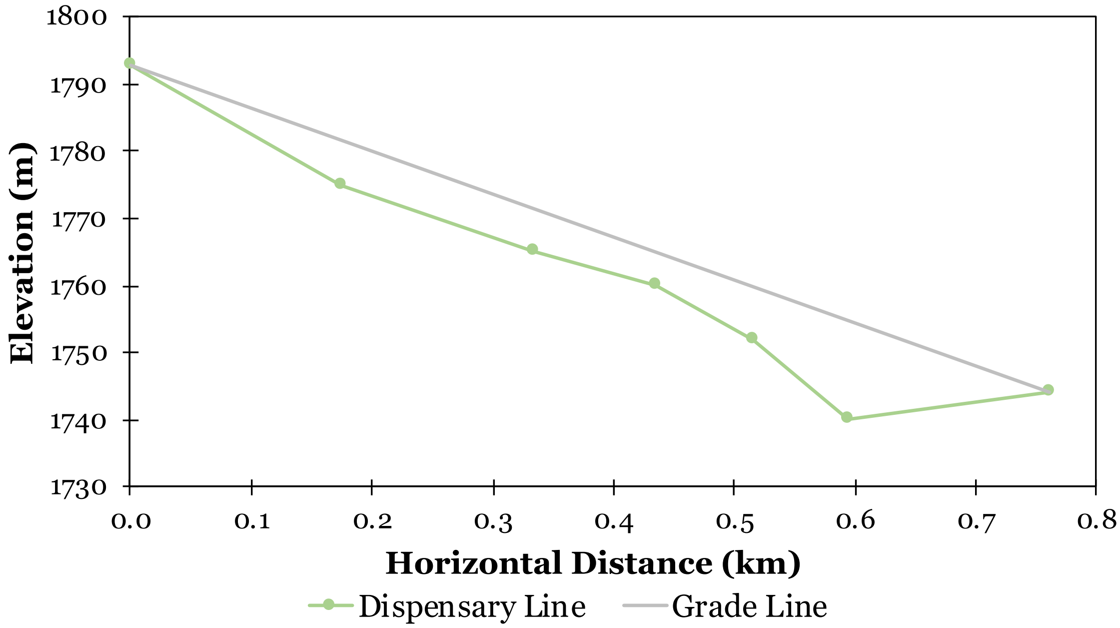


Figure G1 | Elevation Profile of Ilala Line. From tanks located at the market to the dispensary. G.2 Line from the Tanks at the Market to the Mtule Branch

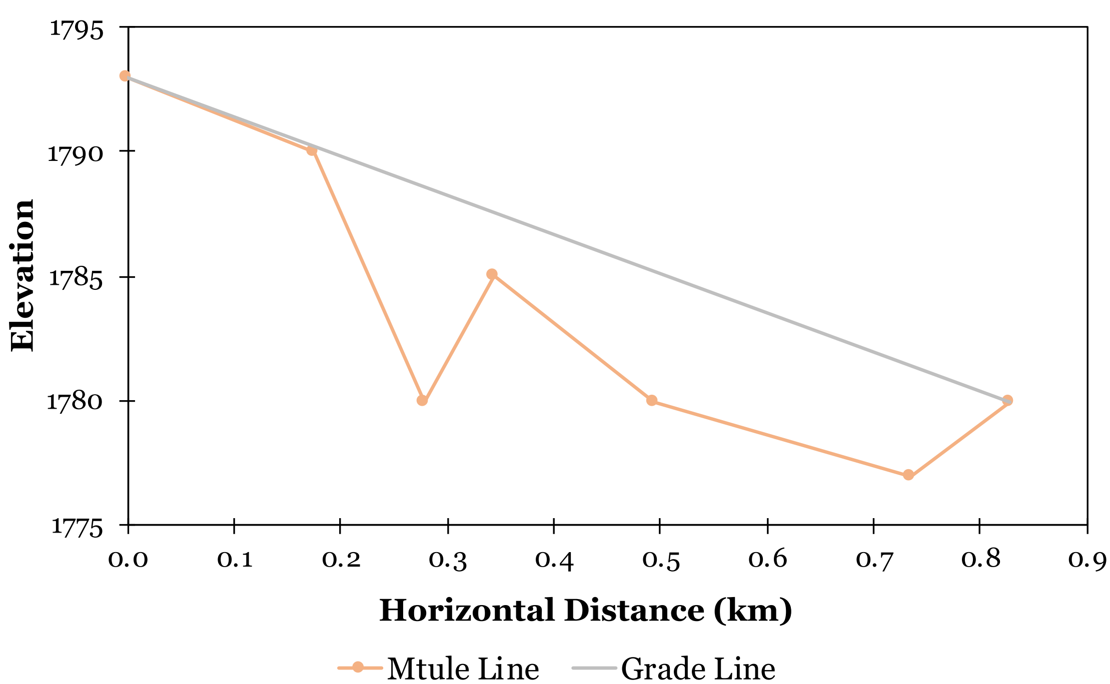


Figure G2 | Elevation Profile of Mtule Line. From tanks located at the market to Mtule sub village.

G.3 Line from the Tanks at the Market to the School Branch

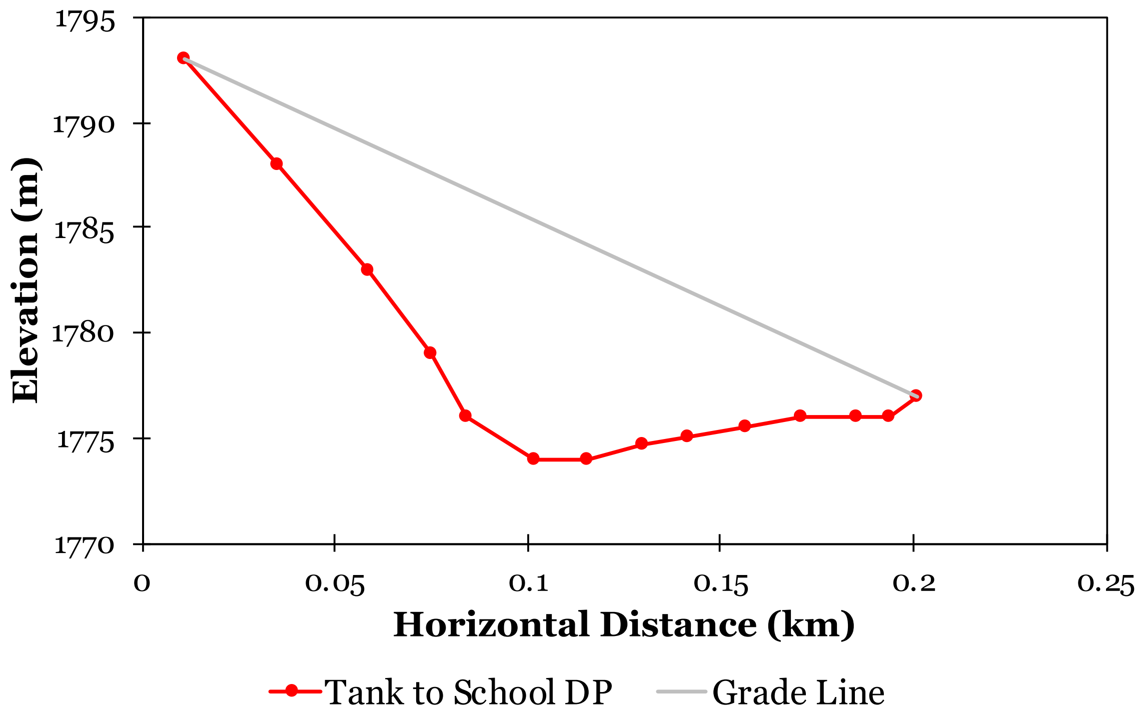


Figure G3 | Elevation Profile of School Line. From tanks located at the market to the DP near the school.

G.4 Pumping Line from the Tanks at the Market to the Tanks at the School

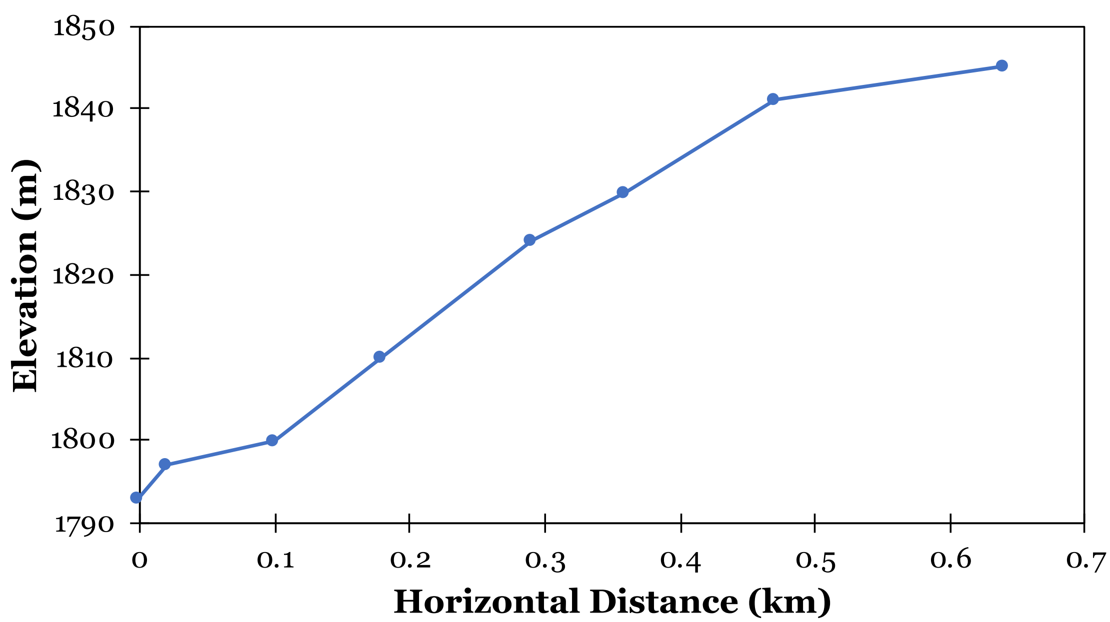


Figure G4 | Elevation Profile of Pumping Line. From tanks located at the market to the tanks located at the primary school.

G.5 Line from the Tanks at the Primary School to the Salem Branch

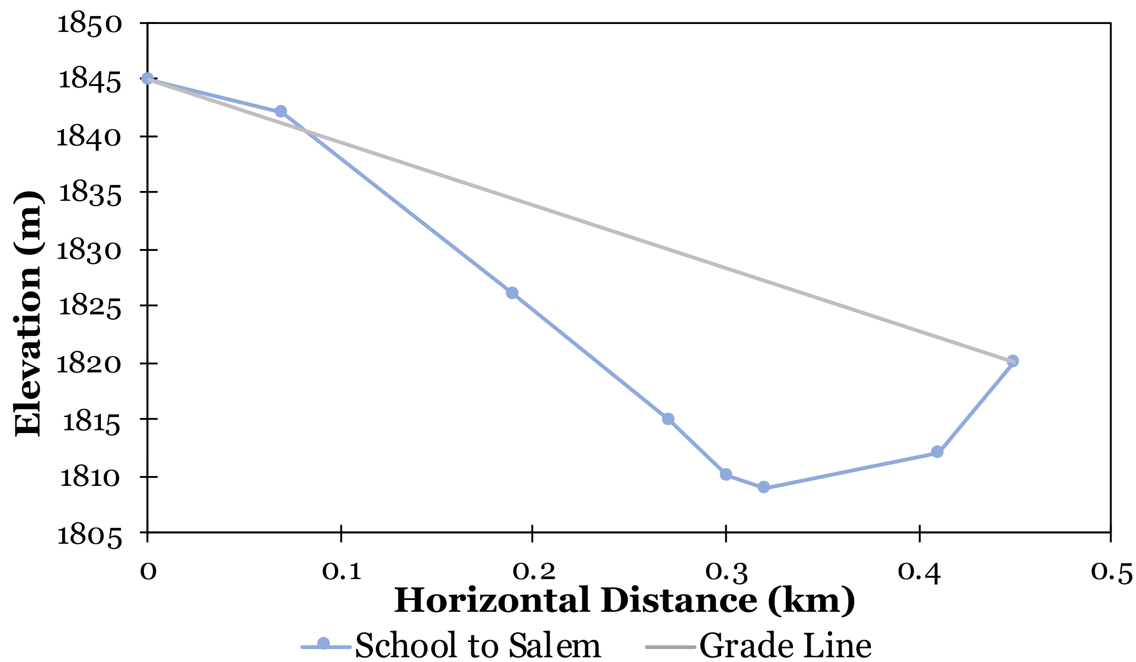


Figure G5 | Elevation Profile of Salem Line. From tanks located at the primary school to Salem DP.

G.6 Line from the Tanks at the Primary School to the Magome Branch

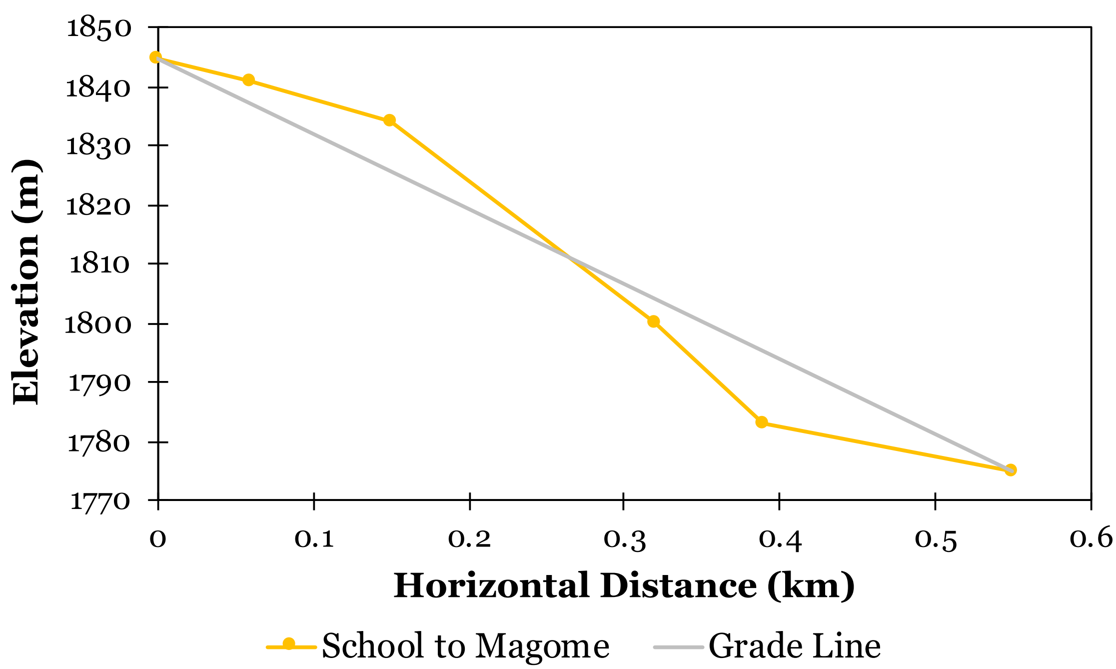


Figure G6 | Elevation Profile of Salem Line. From tanks located at the primary school to Salem DP.

Appendix H: Cistern Sizing

Settling Velocity= $u = \frac{g*d^2*(p_p - p_f)}{18*v} = 2.41 m/s$
Where:
d= diameter of the particle (0.00003m^2)
p_p, p_f =respective density of the particle and fluid (1500, 1000 kg/m^3)
v =viscosity of the fluid at 15 degrees Celsius

Area of Cistern

$$A_{plan} = \frac{Q}{u} = \frac{0.000556 m^3/s}{2.41 m/s} = 2.417 m\text{^}2$$

Since the general guideline asks for a 4x1 sizing ratio, the area was chosen to be 4x1m which has an area of 4 m^2