Water System Design for Ugesa Village

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Executive Summary

The goal of this project was to design a water distribution system capable of serving at least half of the population in the village of Ugesa in Tanzania, with priority given to schools, the dispensary, and churches. Ugesa has a population of approximately 4,800 people, or 775 households, distributed among six sub-villages. The village is spread out over about 5 kilometers and is made up of rolling hills. A high point exists at an elevation of 10 meters above the planned distribution points, making a gravity distribution system viable.

The existing water system in Ugesa consists of six surface water sources found at low elevations, three rope pumps located at schools, and seventeen privately owned rope pumps dispersed throughout the village. All existing rope pumps, as well as two dry hand pumps, were hand-dug. Rainwater is also collected as a drinking water source during the rainy season. It was reported at each surface source that the water never runs dry but at certain sources the water level lowers during the dry season. Based on field water tests, all of the surface water sources around the village are contaminated with coliform and must be boiled to be used as drinking water. In short, although the surface sources provide enough water for the entire village year round, they are laborious to reach and unsafe to consume.

To help Ugesa obtain clean water, a two-phase plan was developed. Phase one of the plan includes drilling a borehole, placing nine distribution points, and constructing a concrete foundation for the storage of three water tanks. A control building will be constructed near the borehole to house necessary power elements such as a transformer connecting the water system to the adjacent power line. The borehole will either be drilled with an air hammer or mud-rotary drill, depending on the results of future soil analyses. Two water storage tanks will be located at a local high point on a large rock and will provide water through a gravity main system to four of Ugesa's six sub-villages. Another water tank will be placed at a separate local high point in the southern part of the system to serve a fifth sub-village. Depending on the output of the borehole, this system has the potential to serve more than half of Ugesa's 4,800 residents with the recommended 25 liters of clean water per person per day. Phase two of the plan is to provide water to Ugesa's secondary school. This was not included in the first phase because the school is 10 kilometers away and requires its own system.

In preparation for the possibility of implementing a water system, the Water Committee of Ugesa has developed a plan for construction and maintenance of the system. This plan includes opening a previously closed water bank account, collecting 6,000 TSH per household per year from all villagers, and providing in-kind labor for construction. The total cost of phase one of the project is estimated to be $38,040 USD on top of an expected $9,020 in-kind contribution. Phase two is estimated to cost much less than phase one due to the small geographic area it will cover. A design best tailored to Ugesa's needs will be finalized with the help of St. Paul Partners and their continued connection with the village of Ugesa.

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Background

Ugesa is a village located approximately 60 km south of Iringa Town, where Bega Kwa Bega and the Lutheran Center are located with their associated resources. Bega Kwa Bega is involved in communications with villages in Tanzania and has provided the Ugesa design team with critical information for implementing a new water distribution project.

The trek to Ugesa began on a paved road, then transitioned to a clay/gravel road through a terrain of rolling hills. The vertical elevation gain is approximately 300 meters. The road is wide enough and in reasonable condition to accommodate large vehicles, even during the rainy season; notably, large coach buses were observed passing through the village during the site visit, which occurred in the rainy season.

Ugesa is approximately 5 km long and spans 3 km across with elevation generally declining as distance away from the road increases. There are three high points in the village that are at nearly the same elevation. Ugesa is made up of six sub-villages that have a combined population of 4,800 people according to data collected in 2015 when the most recent census was taken. Ugesa has one dense population center with the rest of the village being less dense. Most of the people in Ugesa are subsistence farmers. Ugesa has two primary schools, a dispensary, four churches, several shops, and a secondary school that is located about 10 km from the village center.

Figure 1: The main road of the village exemplifying the rolling hills topography.

Immediately after arrival, the team was warmly welcomed by the villagers. The team met with the Water Committee and the prominent village members (approximately 25 people in total) to discuss their priorities and needs. It was obvious that the Water Committee had met previously to discuss their water priorities because when one person answered a given question the entire group agreed. The committee decided that their priority water areas were the schools, dispensary, and churches. The committee also decided that each household would contribute 6,000 Tsh per year to maintain the water system and that anyone could use the system. They believed that the entire community would support this charge because the children, the sick, and the churches would be served which would indirectly benefit all residents. The committee also said that they have six primary sources of water, all of which are surface sources such as dammed springs or stagnant puddles. During the rainy season, most people collect rainwater off their roofs. These sources are explained in detail in the 'Current Systems' section of this report.

Figure 2: The community members present at the meeting with the Water Committee.

Hand-Drawn Maps of the Village

The following maps were drawn while touring Ugesa village and collecting field data. They show the six sub-villages that make up Ugesa as well as the important landmarks and community priorities. The purpose of the hand-drawn maps is to familiarize the reader with the important locations that the water system will reach. The proposed gravity distribution system that was designed involves placing two storage tanks at a high point in the northeastern portion of the village near the proposed borehole. The water will then be channeled to the two primary schools, the dispensary, and several population centers. A third storage tank will be placed in the southwestern stretch of the distribution system near Ugesa Primary school to provide additional storage for water reaching the southern part of the village.

Figure 3 shows the sub-village boundaries (dotted lines), important landmarks such as churches, local population centers (housing clusters), local water sources, and rope pumps (SS = surface source, RP = rope pump), and the two potential high points (large rocks indicated with a mountain symbol).

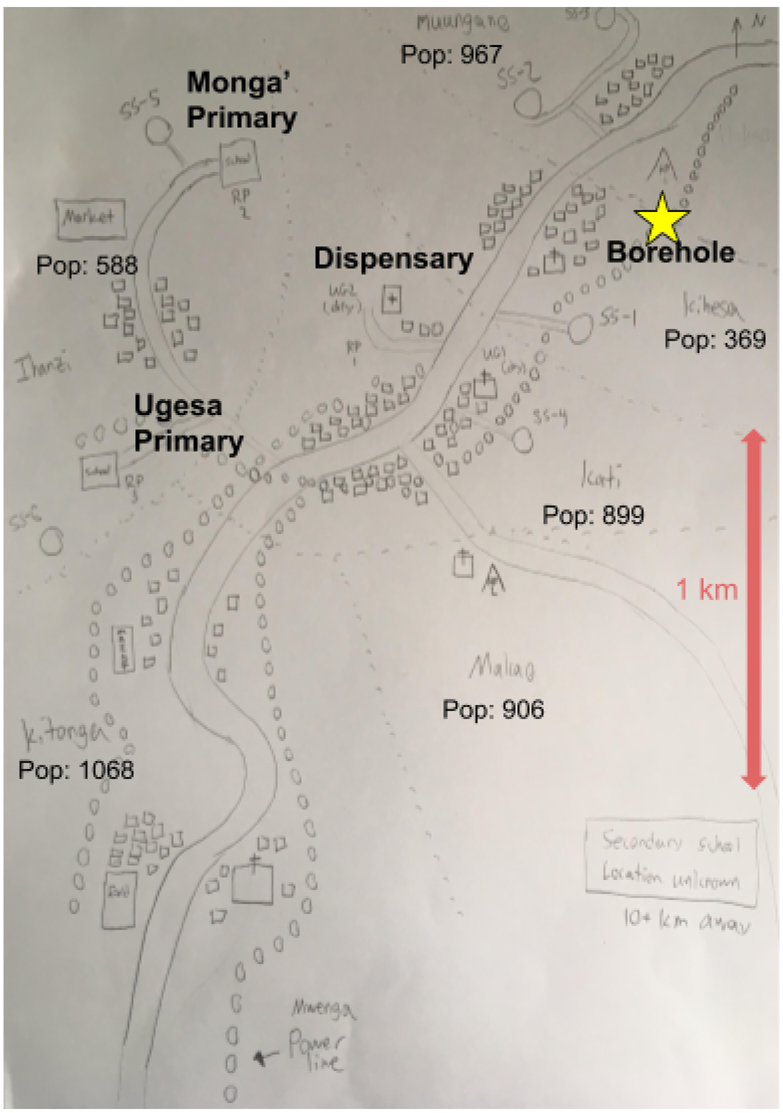

Figure 3: Hand-drawn map outlining sub-villages and noteworthy landmarks.

A simplistic view of the six sub-villages is shown in Figure 4. Important landmarks and meeting areas are highlighted in this figure and some elevation data is shown in order to demonstrate that the high points are above the village centers.

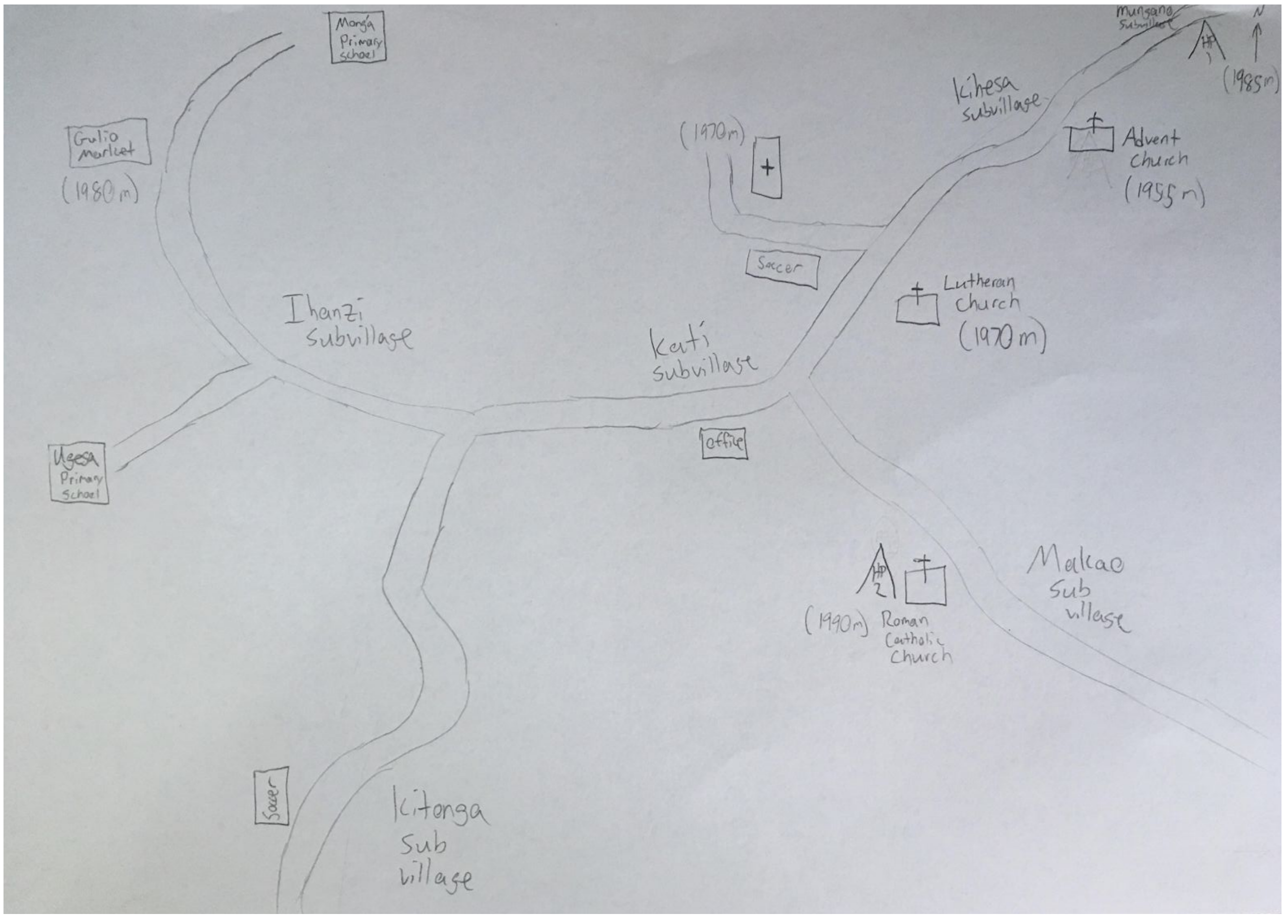

Figure 4: Hand-drawn map showing simplistic view of Ugesa.

Current Systems

Residents of the village of Ugesa currently have access to a total of two hand pumps, 20 rope pumps, and six surface sources. Both of the hand pumps have both been confirmed dry for a minimum of one year and 17 of the 20 rope pumps are privately owned. This leaves the majority of the community to draw water from the surface sources.

Hand Pumps

The two hand pumps are located centrally within the village. One hand pump is east of the main road adjacent to the Lutheran church and is pictured in Figure 5 and the other is directly west of the dispensary and is shown in Figure 6. Both pumps have been confirmed to be dry by Saint Paul Partners staff. In addition, the hand pump near the dispensary is partially broken and the village has decided not to make any repairs because of its dry status. Water samples were not taken from either location because there was no way of obtaining water from the pumps.

Figure 5: Hand pump adjacent to Lutheran church. Well depth is 24.4 m and the original water level was 10.7 m. Ran dry in 2016.

Figure 6: Hand pump near dispensary. Well depth is 36 m and the original water level was 12 m. Ran dry in February 2018.

Rope Pumps

Rope pumps use friction created by a rope and crank to bring water from underground to a spout above the ground where buckets can be filled. A total of 20 rope pumps are distributed throughout Ugesa. Each of the three schools -- Mong'a Primary, Ugesa Primary, and St. Ambrose Barlow Secondary -- have their own rope pump; however, the rope on the pump at Mong'a Primary, pictured in Figure 7, is unreliable and has been repaired multiple times and the rope on the pump at Ugesa Primary, pictured in Figure 8, is not present at all so no water can be drawn. Although two of the three accessible rope pumps were in working order, the water they provided was not enough to distribute to the full student body so the students also drew water from nearby surface sources. According to Mhumba Jamfi, the headmaster of St. Ambrose Barlow Secondary School, when the rope pump at the secondary school runs dry, the students must walk 20 minutes to fetch water from a nearby river, which is often used by roaming cattle that dirty the water. In addition to the lack of safety of the water sources, students attending the primary schools are faced with a long walk when the rope pumps run dry, which detracts significantly from time spent in class.

Water drawn from both the rope pump and the nearby surface source at Mong'a Primary tested positive for coliform, which increases the need for clean and plentiful water at school sites. The privately owned rope pump that provided water to the dispensary also tested positive for coliform. While these rope pumps are likely safer than the surface sources, the coliforms present indicate contamination. It is likely that the source of contamination to the rope pumps is that the open well and the ropes themselves carry bacteria. The 16 privately owned rope pumps that were not tested are shared only by close neighbors and therefore cannot be used as a water source for most villagers. Because all pumps were hand-dug and function the same way, it is assumed that they would all test positive for coliform.

Figure 7: Rope pump dug in 2015 and currently used by students at Mong'a primary school. Well depth is 9.1 m and original water level was 1.5 m. In the wet season this pump fills approximately 15 to 20 buckets at a time and requires 12 hours to refill while in the dry season the pump fills 1 to 2 buckets at a time and requires 24 hours to refill.

Figure 8: Rope pump used by students at Ugesa primary school. Well depth is 22.9 m and original water level was 4.3 m. Rope is currently missing from the pump so students are instead using a surface source.

Surface Sources

Villagers of Ugesa reported drawing water from a total of six spring surface sources. In addition, the students attending St. Ambrose Barlow Secondary School 10 km away used an additional surface source. Each surface source within the village of Ugesa was located approximately 20 to 40 m below the level of the main road and was only accessible by foot due to steep and often muddy and slippery paths. Collecting a 25 L bucket of water from these sources is a laborious task requiring both a hike along the road to the location of the path and a climb down/up the steep hills.

Water samples from each of the six sources were collected and tested for both coliform and E. coli. It was determined that all sources were contaminated with coliform bacteria, which indicated that other more harmful bacteria were likely present. One source was also contaminated with E. coli bacteria. As a result, it was concluded that the surface water sources currently in use are both strenuous to reach and unsafe to drink. Figure 9 shows three examples of surface sources used by villagers.

Figure 9: Three examples of surface sources where villagers fill buckets of water.

Rainwater

During the rainy season, water is collected from the rooftops into buckets, as shown in Figure 10. The villagers believed that their rainwater collection was safer than the surface water sources. However, during coliform testing, the rainwater was the first sample to appear visually contaminated. The dispensary's records indicated that more cases of typhoid and other waterborne illnesses appear during the rainy season. It is highly likely that the increase in waterborne illnesses is correlated with the increased consumption of contaminated water collected from the rooftops. The villagers were surprised to hear this news, as they have been using rainwater for ease of access and because they thought it was safer. They were advised by the team to boil all collected rainwater in order to avoid exposure to harmful bacteria.

Figure 10: Rainwater being collected by a green bucket to catch water diverted by the rooftop.

Water Sampling Results

During the village visit, two types of water tests were performed. Both tests involved placing water onto the test kit and incubating with body heat for 24 hours. The first test, shown in Figure 11, is a qualitative bacteria growth test. This test will change colors if coliform is present at a high enough concentration. In addition, each vial was placed under ultraviolet light. If the vial fluoresced then it also contained E. coli. None of the vials showed obvious fluorescence, so it was determined that the E. coli concentration in the water sources was not high. It can be seen in the leftmost vial in Figure 11 that the control vial, which was filled with water from a disposable bottle, did not change colors so the test was considered controlled.

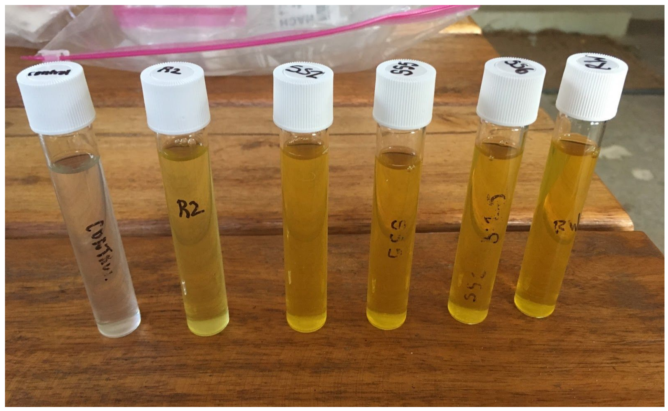

Figure 11: Vials filled from various water sources and arranged with the least contaminated are on the left.

The second water test, shown in Figure 12, was a quantitative test that involved counting the number of bacteria colonies that grew after 24 hours of incubation. It was possible to determine the relative level of contamination by counting the bacteria colonies that appeared. Coliforms and E. coli were differentiated by color and counted. Significantly less E. coli colonies were found than coliform. However, even small amounts of E. coli indicate a risk of dangerous pathogens. The results of both tests are shown in Table 1.

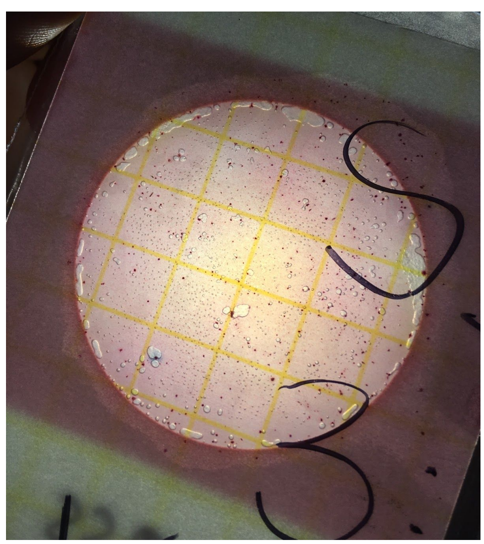

Figure 12: Sample from surface source 6. The blue colony in the lower left quarter of the circle is E. coli.

Table 1: Test results from the IDEXX test and 3M Petrifilm test. The color and fluorescing columns are data from the IDEXX test and the colonies columns are data from the 3M Petrifilm test.

			Colonies	
Source	**Color**	**Fluorescing**	**# Red (coliform)**	**# Blue (E. coli)**
1A	Yellow	No	180	2
1B	Yellow	No	160	1
SS1	Yellow	No	80	0
SS2	Yellow	No	100	0
SS3.1	Yellow	No	130	0
SS3.2	Yellow	No	115	0
SS4.1	Yellow	No	18	0
SS4.2	Yellow	No	23	1
SS5	Yellow	No	10	0
Rope 2	Light Yellow	No	7	0
SS6	Yellow	No	180	1
Rainwater	Yellow	No	400	0
Control	Clear	No	0	0

Village Needs

The main concern of the villagers was getting safe drinking water for the students and the sick. The whole village pledged money toward the water fund so the schools and dispensary could have access to safe, reliable water. The proposed system takes this into account; it is based on drilling a borehole to satisfy at least these three locations (two primary schools and the dispensary). Any surplus water will be used by the Ugesa villagers. It is not feasible to satisfy all of the villagers' needs with one system, so to distribute excess water the villagers chose to place distribution points at the local churches because they are used as meeting points and are typically surrounded by many houses. The water demand required by each village priority and the village as a whole is shown in Table 2.

Table 2: Expected population and water demand of Ugesa and its schools. Neither primary school is a boarding school. An additional 10 individuals was added for each school to account for the teachers.

Location	Current Population	Future Population	Water Demand
Mong'a School	309	450	4,500 L/day
Ugesa Primary School	274	400	4,000 L/day
Dispensary	N/A	N/A	550 L/day*
Ugesa Total	4,800	7,000	175,000 L/day

*The dispensary water demand requested by the doctor was 400 L/day. This value was adjusted for the future increase in patients.

Tanzania Design Guidelines

The Tanzanian Design Guidelines[1] were used to design a system to accommodate the needs expected 10 years into the future. The guidelines provide a list of best practices to use during design and were created from the input of many different engineers working in the region.

The guidelines used during the design are summarized as follows:

1. Population growth rate of 2.7% per year.
2. Water demand of 25 L per person per day.
3. Water demand at a school of 10 L per student per day.
4. Water demand at a medical center is 10 L per person and 50 L per bed per day.
5. Water velocity in pipes between is approximately 0.5 and 1.5 m/s.
6. Walking distance to a Distribution Point (DP) is less than 400 m.
7. Pump water to a high point and gravity feed it from the tanks to the DPs.
8. Each DP can serve a maximum of 250 people per day.
9. Put boreholes in terrain low points and near power lines to lower cost.
10. Minimum water storage capacity should account for 50% of the total daily demand.
11. Maintenance money must be collected as a % of the initial capital cost to account for future breakdowns. These amounts are collected yearly to ensure a sustainable implementation.
    a. Boreholes require 2% of the initial cost (20 year expected lifetime)
    b. Pumps require 5% of the initial cost (5-10 year expected lifetime)
    c. Tanks require 5% of the initial cost (10-15 year expected lifetime)
    d. Buildings require 1.5% of the initial cost (30 year expected lifetime)
    e. DPs require 5% of the initial cost (10 year expected lifetime)
    f. Other tools and equipment require 4% of the initial cost (10 year expected lifetime)

While these guidelines provide a baseline design, it is often difficult to meet all of the requirements due to limitations of the specific region/village. The proposed design was able to meet many of these guidelines, but fell short in the following areas. First, being able to provide 25 L/person/day was not feasible due to the large population of Ugesa village (project to be 7,000 villagers). After population forecasting, the required water demand would be over 170,000 L/day, which was believed unattainable based on previously drilled boreholes. Because of the limitation on what a borehole can provide (1500 L/hr or 36,000 L/day on average), the schools were given priority as well as the village centers closest to the water storage location. The distribution points are expected to serve more than 250 people per day in the current design, again due to the large population of Ugesa. With the proposed design, people may be walking greater than 400 m to a distribution point because not all people are able to be serviced with the design. However, this design can provide many people a minimum of 10 L per day, which is enough for drinking and cooking.

Lastly, if the borehole is able to produce more water than average, more distribution points may be added to accommodate more of the total Ugesa population. In this preliminary design, the community's priorities of bringing water to the schools and medical center have been met.

Proposed Water System Design

Overview

Several assumptions were made for the proposed design, which are outlined 'Tanzanian Design Guidelines' section on the previous page. Six surface water sources were visited. At each location it was made evident that these sources do not run dry in the rainy or dry season. From this information, it is assumed that the proposed system will have an output of 1,500 liters per hour (400 GPH). This is a baseline assumption that may or may not be accurate because the yield is unknown until a well is drilled.

Figure 13 shows the borehole location and the rising main to the storage tanks. These locations were chosen because the borehole is in a low-point near the road and powerlines. This will make drilling easier and the cost of power cable cheaper. The storage tanks will be built on top of a nearby rock which gives an additional 5 m of elevation. It is also worth noting that this rock has a gentle slope, making construction and maintenance easy.

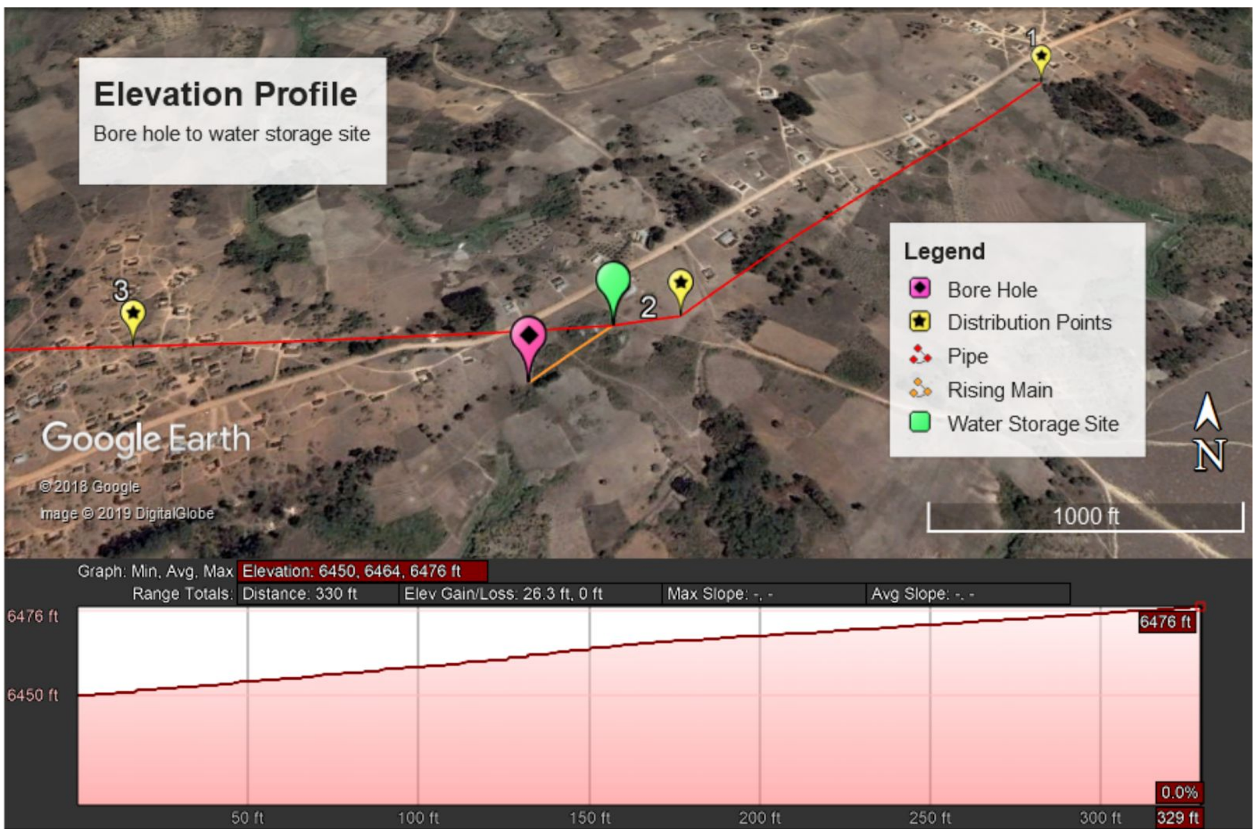

Figure 13: Borehole, rising main, and main storage site.

Figure 14 shows all proposed distribution points. The pink and green dots represent the borehole and storage tanks, respectively. The blue circles show the maximum recommended walking distance from the distribution points. Most houses in the village are within the desired distance to a DP. There will be an additional storage tank at DP7. Coordinates and elevations for each point of interest are in Appendix C. Table 3 contains estimates of the population served at each DP as well as the estimated demand. The total demand is not calculated in order to avoid counting students and dispensary patients multiple times.

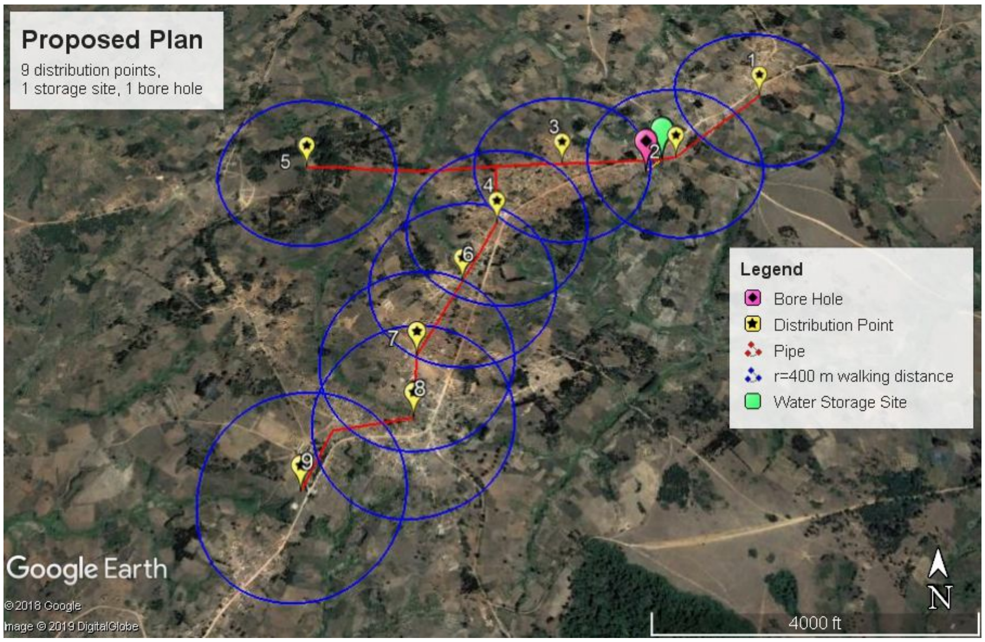

Figure 14: Proposed distribution points.

Table 3: Estimate population served and demand at each distribution point.

Distribution Point	Population Served (people)	Estimated Demand (people)
1. Muungano	250	1,400
2. Kihesa	250	540
3. Dispensary	50	50
4. Kati	250	655
5. Mong'a Primary School	450	450
6. Kati	250	655
7. Ugesa Primary School	400	400
8. Village Center/Makao	250	1,320
9. Kitonga	250	1,560
Total	2,500	N/A

Equipment Selection

The equipment used for this design must be sourced from local Tanzanian vendors so standard sizing was used for all pumps and pipes. The standard pipe selected for the preliminary design was 2-in High Density Poly-Ethylene (HDPE) pipe rated for 6 atmospheres of pressure, which was based on water flow and pressures in the pipes from calculations shown in Appendix A. It is important to note that HDPE pipe is sensitive to UV and must be buried underground. As the water travels through the pipeline it will be dispersed at the distribution points. If all taps are open, the amount of flow will decrease near the end of the system and therefore a smaller diameter pipe may be needed to maintain water velocity at the ends of the system. Above ground, galvanized metal pipe will be needed to connect the storage tanks to the underground HDPE pipe.

The pump size required for the design was determined to be 0.6 hp, which was rounded to a standard size of 1 hp. A 1 hp pump is expected to be capable of moving at least 1,500 L of water per hour up 110 m of rising main. A larger pump will be needed if it is possible to obtain more water from the borehole. The water will be pumped up to two 10,000 L storage tanks located on top of the high point rock. A third storage tank will be placed on the southern stretch of the pipeline in order to provide additional storage capacity and achieve higher flow rates at the end of the system.

Design Concerns

The main design concern for this system was the loss of gravitational energy as the water was moved further from the storage point. From the simulations it was noted that distribution point 7 (DP7) would drop to zero pressure if too many of the other distribution points were left open. This is because DP7 is on a local high spot and is far from the initial storage location, so frictional losses reduced the water pressure significantly (when all previous distribution points were open, DP7 was unable to achieve positive flow). This concern was addressed by placing a third water tank at DP7. Adding this tank means the downstream distribution points will receive water even if the upstream taps are open. However, the tank cannot fill when all the previous distribution points are in use. Thus, the system will fill the tank as long as the lowest two distribution points are not fully open, meaning the tank can fill with water in non peak times like the middle of the day and overnight.

Implementation Budget

Tables 4 and 5 show the cost breakdown of the proposed system. These costs include material and equipment purchases, transport, and labor for installation.

Table 4: Material costs.

Item	Quantity	Unit Cost (USD)	Shipping (+20%)	Total
Bore hole drilling	1	$ 10,000.00	$ -	$ 10,000.00
Pump (1 hp)	1	$ 2,000.00	$ 400.00	$ 2,400.00
Pump Controller	1	$ 500.00	$ 100.00	$ 600.00
PN-6 (50.8mm) 150m roll	28 rolls	$ 250.00	$ 1,403.33	$ 8,420.00
Tank	3	$ 1,100.00	$ 660.00	$ 3,960.00
Level Controller	1	$ 200.00	$ 40.00	$ 240.00
Distribution points	9	$ 175.00	$ 315.00	$ 1,890.00
Water Meters	9	$ 150.00	$ 270.00	$ 1,620.00
Concrete base	2	$ 600.00	$ 240.00	$ 1,440.00
Bore hole electricity wire	100 m	11 per meter	$ 220.00	$ 1,320.00
Surface electricity wire	20 m	8 per meter	$ 32.00	$ 192.00
Skilled Labor		$ 500.00		$ 500.00
Electricity connection		$ 2,000.00		$ 2,000.00
Sub Total				$ 34,582.00
In-kind contribution (total)	1	$ 9,020.00		$ 9,020.00
Labor cost, pipe burying	1	$ 8,420.00		$ 8,420.00
Buildings, masonry	2	$ 300.00		$ 300.00
Total Cost with a 10% Contingency				$ 38,040

Table 4 shows the total expected purchasing cost of the water system that has been designed for Ugesa. This cost estimation was done using previous invoices received from a local Tanzanian supplier. This estimate is considered to be an upper bound on the expected costs because the borehole was priced for use of an air hammer, which is more costly than a mud-rotary drill. When a survey team checks the conditions of the soil, a mud-rotary drill may be used in place of an air hammer. This change would save approximately $5,000.

The village's in-kind contribution consists of connecting and burying the required pipeline, building concrete bases for the tanks, installing the tanks, and paying a local Tanzanian engineer to oversee the operation.

Table 5: Annual upkeep costs.

Item	Economic Design Life (yrs)	Annual Maintenance Cost (%)	Annual Maintenance Cost (USD)
Borehole	20	2.0%	$ 200.00
Pump (1hp)	5-10	10.0%	$ 240.00
Elevated Tanks	10-15	3.0%	$ 66.00
Buildings, masonry	30	1.5%	$ 9.00
DPs (Bombas)	10	5.0%	$ 157.50
Tools and Equipment	7-10	4.0%	$ 26.00
Yearly Pump Electricity	10,000 Kw/hr	280 Tsh per Kw/hr	$ 1,217.00*
Total Annual Cost			$ 1,915.50

*A conversion of 2,300 Tsh = 1 USD was used for determining electricity costs.

The maintenance costs shown in Table 5 were calculated using the design guidelines and the capital cost estimates from Table 4. The pump electricity cost was calculated using an electrical efficiency of 50% and the assumption that the pump will run continuously throughout the day. This estimation is considered to be an upper bound due to these assumptions. In reality, the pump should not run 24/7 and the pump efficiency is expected to be greater than 50%. The annual money pledged by the village (~1,900 USD per year) is expected to cover these yearly operating costs and leave additional money for future water projects funded by the village itself.

Impact of Design

Access to clean water has huge potential to improve the lives of villagers of Ugesa. When in Ugesa, the travel team witnessed a lifestyle unimagined to many Americans. Here in the U.S. we do not have to worry about our basic needs; water comes from the tap and food from the store. In Ugesa most residents live as subsistence farmers. They get up every day and fetch water from a stagnant puddle or stream before working their fields for food. There is no other option for them. Their daily chores consist of satisfying their most basic needs of drinking and eating, and even these needs are often unmet because their only sources of water are unsafe.

Health Impact

The current water sources in Ugesa were found to be contaminated with coliform, a signal bacteria that implies the presence of other waterborne contaminants. Water testing confirmed that the rainwater collected off roofs of houses was also contaminated and potentially more harmful than the surface sources that collect in streams and puddles near the village. When asked about disease rates, the village doctor reported an average of 10 cases of typhoid per week during the rainy season. This high number of illnesses during the rainy season is likely linked to an increase in runoff, particularly runoff from rooftops that ends up in gathered rainwater.

Implementation of the proposed water distribution system will give thousands of people access to safe groundwater from a deep, sealed borehole. This will allow the school children, dispensary patients, and many other villagers to have access to safe water. The impact of such a system has been shown to halve the rates childhood death in other villages where water systems were successfully implemented.

Economic Impact

The ability to fund the implementation of this project is outside the scope of the Ugesa villagers. The village has very little external economy. Even so, each household has pledged 6000 Tsh per year, which amounts to approximately $2 per household. While this amount is small in our eyes, it is enough to cover the upkeep of the system after implementation. The projected electricity costs of the pump and the required future maintenance money can be fully collected with this pledge.

The goal for implementing the proposed design is to be able to fully fund the initial installation of this water system with labor contributions from the village. This will allow the project to become a reality for people who would otherwise be unable to afford advanced infrastructure in a remote region. The cost breakdown of this project is shown in the previous section, 'Implementation Budget.'

Efficiency and Educational Impact

While discussing the water situation with the Water Committee, the headmaster of the secondary school, which is located 10 km away, stated that fetching water was very disruptive to the school schedule. Classes have to be put on hold for several hours so that the students can carry water from the local water source. Only one student can get water at a time and after 10-15 students they must wait for the water level to replenish in the dammed stream, which is their primary source of water. Having access to water from a tap would significantly decrease the amount of time students spend gathering water as well as the chance of falling ill with a waterborne disease.

Conclusion

The team's experience in Ugesa was profound. From the moment of arrival, it was clear how much the villagers appreciated the visit. They expressed willingness to assist in whatever way they could to make the team feel at home and to get access to a clean water distribution system faster. The villagers are clearly determined and willing to put in work to improve the community as a whole despite the fact that this system cannot reach the outskirts of the village. The proposed system is designed to provide safe drinking water to the schools, some churches, the dispensary, and several highly populated areas of the village. Safe and clean water disproportionately benefits the most vulnerable members of the community: the very young, the very old, and those with impaired health. Further, it will save a tremendous amount of time for those who fetch water as well as a significant amount of labor now required to carry water up the difficult pathways from the valleys back to their homes. The village leaders and Water Committee members of Ugesa are ready to take on a challenge and make sure this project will be a success.

References

[1] United Republic of Tanzania, “Design Manual for Water Supply and Waste Water Disposal.” Design Manual for Water Supply and Wastewater Disposal, 3rd ed, 2009.

Appendices

Appendix A: Excel Overview (Solving Simultaneous Equations)

The proposed design was modeled in Excel to ensure that the gravity-fed system would have sufficient flow at each distribution point under various scenarios. By writing out mechanical energy balances between each point and using the elevation and distance data obtained in the field, the flow rate between any two points can be determined. The mechanical energy balances were solved simultaneously by setting the flow rates equal to each other and using the Excel Solver Add-in to determine the pressure and velocity within each pipe. An outline of the expected maximum and minimum flow rates predicted in the Excel analysis is shown in Figure A.1.

Point	P (Pa)	z (m)
1(tank)	0	1989
2	62349	1980
2dp	0	1981
3	159119	1961
3dp	0	1962
4	90356	1961
4dp	0	1962
T	24142	1960
5	12062	1961
5dp	0	1962
6	36899	1956
6dp	0	1957
7	12145	1958
7dp	0	1959
8	0	1973
8dp	0	1971
9	33752	1967
9dp	0	1968
10	30902	1966
10dp	0	1967

Path/Joint	V (m/s)	L (m)	Q (m^3/s)	Q (L/hr)	Q (L/min)	Kv	d (m)
1 2	1.2428	65	0.0025	9069	151	NA	0.0508
2 3	0.7801	570	0.0016	5692	95	NA	0.0508
1 4	1.2494	457	0.0025	9117	152	NA	0.0508
4 T	0.6765	643	0.0014	4936	82	NA	0.0508
T 5	0.0958	957	0.0002	699	12	NA	0.0508
T 6	0.5807	304	0.0012	4237	71	NA	0.0508
6 7	0.2484	322	0.0005	1812	30	NA	0.0508
7 8	0.1508	395	0.0003	1101	18	NA	0.0508
8 9	0.6056	265	0.0012	4419	74	NA	0.0508
9 10	0.2932	570	0.0006	2139	36	NA	0.0508
2dp	1.8510	20	0.0009	3376	56	10	0.0254
3dp	3.1204	20	0.0016	5692	95	10	0.0254
4dp	2.2918	20	0.0012	4181	70	10	0.0254
5dp	0.3832	20	0.0002	699	12	10	0.0254
6dp	1.3291	20	0.0007	2424	40	10	0.0254
7dp	0.3903	20	0.0002	712	12	10	0.0254
8dp	1.1311	20	0.0006	2063	34	10	0.0254
9dp	1.2495	20	0.0006	2279	38	10	0.0254
10dp	1.1728	20	0.0006	2139	36	10	0.0254

Figure A.1: Excel output of distribution system.

Appendix B: Elevation Profiles

Elevation profiles were created for the stretch of pipeline near the borehole, shown in Figure B.1, the first through fifth DP, shown in Figure B.2, and southern stretch of the system, shown in Figure B.3.

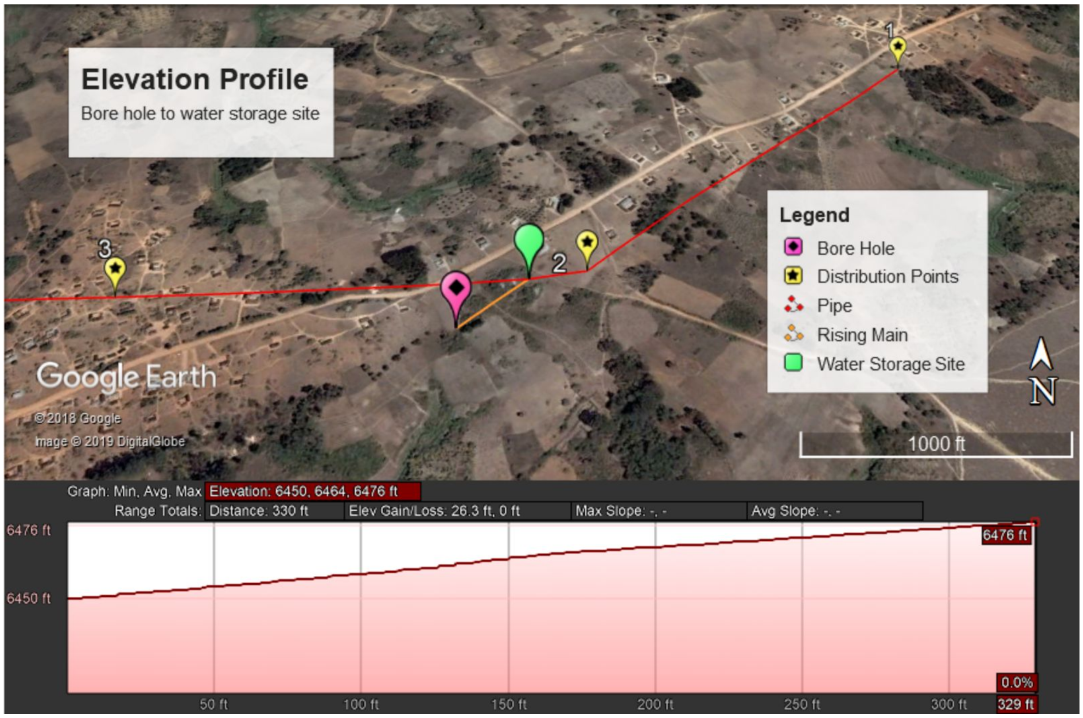

Figure B.1: Elevation profile for proposed borehole location to proposed water storage tank location.

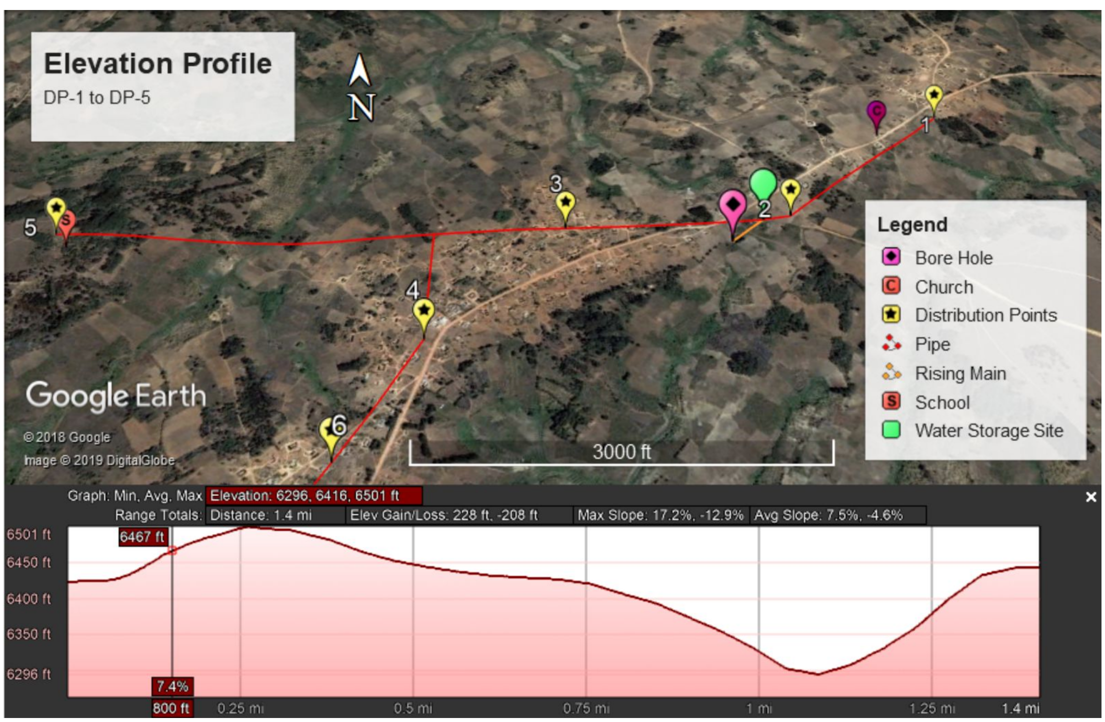

Figure B.2: Elevation profile for source DP1 to DP5.

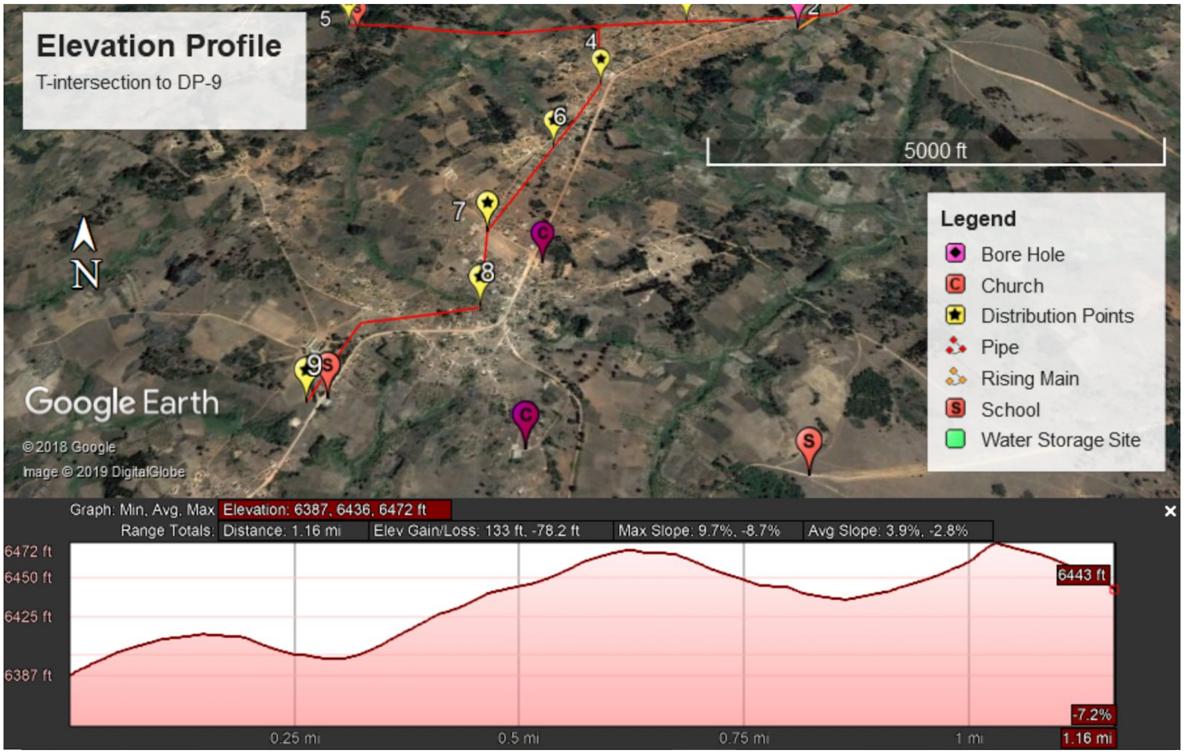

Figure B.3: Elevation profile from T-intersection to DP9. The school depicted in the lower right corner shows where the road became impassable on the way to the secondary school. The secondary school is actually 8-9 km further than this point.

Appendix C: Distribution Point, Storage Tank, and Borehole Coordinates and Elevations

Table C.1 contains an outline of the DPs and other noteworthy sites for the system, including their corresponding coordinates and elevations. A map of all locations is shown in Figure C.1.

Table C.1: Coordinates and elevations of DPs, water storage sits, and bore hold location.

Location Label	Coordinates	Elevation (m)
DP1	8°15'58.58"S, 35°36'59.30"E	1961
DP2	8°16'10.56"S, 35°36'45.05"E	1980
DP3	8°16'11.28"S, 35°36'28.07"E	1961
DP4	8°16'21.46"S, 35°36'18.32"E	1956
DP5	8°16'12.07"S, 35°35'50.02"E	1961
DP6	8°16'30.84"S, 35°36'13.51"E	1958
DP7	8°16'42.19"S, 35°36'7.61"E	1970
DP8	8°16'50.65"S, 35°36'7.51"E	1967
DP9	8°17'0.21"S, 35°35'53.82"E	1966
Water Storage Site	-8.26968, 35.6119	1986.6
Bore Hole	-8.2702, 35.6112	1964

Figure C.1: Locations of DPs labeled one through nine in addition to water storage site, makes in green, and borehole location, marked in blue.