Designing a Gravity-Fed Water Distribution System for Wangama, Tanzania

Design for Life: Water in Tanzania 2019

Daod Al Balushi
Aaron Bruinsma
Marines Chinchilla
Melissa Friese
Joseph Hynes
Kyle Rachel

College of Science and Engineering
University of Minnesota
Minneapolis, Minnesota 55455

Pictured: (from Left) Daod Al Balushi, Agness Saria, Hanael Gadwe, Aaron Bruinsma, Kyle Rachel, Joseph Hynes, Marines Chinchilla, and Melissa Friese

Executive Summary:

The purpose of this project is to design a water distribution system to supply safe and accessible water to the people in the village of Wangama, Iringa Region, Tanzania. Wangama has a population of approximately 1,000 people distributed among six different sub-villages. The existing water systems in Wangama consists of four shallow hand pumps and a hydraulic ram pump river water system. The four hand pumps were implemented by Saint Paul Partners and provide water during the rainy season but the pumps run dry during the dry season. The ram pump system, which uses an earthen furrow and unique ram pump to push water uphill to a storage tank of 23,000 liters (approximately 6,000 gallons) is located at the center of the village. From this point the water is distributed across the village at different distribution points, including one at the Village Office and one at the Primary School. The river water system supplies water year round when it is functioning properly. Additionally, the villagers currently collect water from other sources, including a hand-dug well and rainwater collection from rooftops. Based on our field water Colilert Test and a 3M™ Petrifilm E.coli/Coliform Count Plate Test, all the water sources including the hand pumps are not safe and the water must be boiled to be used for drinking.

The focus of this project is to supply safe water to the people in Wangama year-round. Proposed primary locations for water distribution are the Village Office, the Primary School, the Dispensary, and the Lutheran Church. Phase One of the project involves drilling a borehole 285 meters (607 feet) west of the Village Office, 120 meters (400 feet) deep, that we believe will supply groundwater year round. It is assumed that an air-hammer drill will be necessary to dig a borehole of that depth. From the borehole, water will be pumped using solar power to a 10,000 Liter Poly tank at the Village Office, which will in turn gravity feed the distribution points at the Village Office, the Primary School, and the Dispensary. There will be a second 10,000 Liter Poly tank that will be placed at the Lutheran Church to reset the pressure in the pipes. Four distribution points; one at each tank, one at the Primary School, and one at the Dispensary; will be installed as part of phase one. The second phase of the project extends the system to the east and west sides of the village. On the west side, the 10,000 Liter Poly tank that is placed at the Lutheran Church will gravity feed downhill to the heavily populated area on that side of the village. On the east side, the people will be served by the tank at the Village Office. A total of four distribution points will be installed as part of phase two, two on either end of the village. These taps will allow for more people to be in closer proximity to safe water, as these areas have a higher population density compared with the areas surrounding the Village Office, Primary School, and Dispensary.

The estimated budget for Phase One of the distribution system is $39,000. Phase Two has a budget of $12,000. Because Wangama has relatively little elevation change, the ratings used for the pipe design were PN 6 and PN 10 only. It is assumed that labor for the project would be an in-kind contribution from the village. The proposed solar-powered system has minimal maintenance costs; however, it is of utmost importance that the village creates an effective water committee to collect money for water usage. This is necessary to fund repairs for different parts of the system when they inevitably break in the future. Ideally much of the initial cost of the system will be covered by donations, the village must assume responsibility for the repair and maintenance costs. The proposed system is very expensive, but the health, economic, and political benefits that Wangama will receive outweigh these costs.

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1. Contact Details

1.1. University of Minnesota Students:

Name	Major	Phone Number	Email
Daod Al Balushi	Mechanical Engineering	+1 (612)-666-1944	albal022@umn.edu
Aaron Bruinsma	Civil Engineering	+1 (507)-226-4609	bruin029@umn.edu
Marines Chinchilla	Chemical Engineering	+1 (781)-708-2871	chinc009@umn.edu
Melissa Friese	Bioproducts and Biosystems Engineering	+1 (920)-257-9286	fries190@umn.edu
Joey Hynes	Civil Engineering	+1 (630)-777-4423	hynes040@umn.edu
Kyle Rachel	Civil Engineering	+1 (952)-688-3705	rache029@umn.edu

1.2. Program Leaders:

Name	Affiliation	Phone Number	Email
Dr. Paul Strykowski	University of Minnesota	+1 (612)-626-2008	pstry@umn.edu
Dr. Ken Smith	St. Paul Partners	+1 (651)-336-7273	klsmith@alum.mit.edu
Dr. Catherine French	University of Minnesota	+1 (763)-227-6575	cfrench@umn.edu
Ben Koch	University of Minnesota	+1 (612)-670-3667	koch0137@umn.edu

1.3. St. Paul Partners:

Name	Role
Brent Skillman	Chairman
Dr. Ken Smith	Vice Chairman
Hanael Gadwe	Office Manager Iringa, Tanzania
Onno Mella	Iringa, Tanzania
Peter Mwakatundu	Driver and Technician Iringa, Tanzania

1.4. University of Iringa Student

Name	Affiliation	Phone Number	Email
Agness Saria	University of Iringa, Community Development Program	+255 (719)-109-975	sariaagness27@gmail.com

1.5. Water Committee:

Name	Affiliation	Phone Number	Email
David Moyer	Water Committee Primary Contact	+255 (784)-287-266	daudi.simoya@gmail.com

2. Project profile

2.1. Project Location

Wangama is located 12.7 kilometers to the southeast of Iringa as shown in Figure 2.1; it is approximately 45 minutes by bus from the Lutheran Center in Iringa.

Wangama is a remote village relying primarily on subsistence farming. Spanning a narrow six kilometer stretch, the inhabited region is bordered by the Little Ruaha River on the eastern and northern edges of the village. To the southwest, a seasonal wetland lies near the Village Office. Wangama has a maximum elevation difference about 100 meters (330 feet).

Wangama currently has no grid power despite power lines reaching within two kilometers of the village. It was mentioned by local residents that power is expected to reach the village soon, but there is no definite timeline on when power will arrive. As a consequence, a solar-powered system has been designed.

Figure 2.2 presents of Wangama indicating the geographic coordinates of the dispensary, the primary school and the village office. The yellow line outlines the populated areas.

Climate: Wet season December - April, Dry season May - November
Elevation: Approximately 1570 to 1650 meters (5151 to 5413 feet)

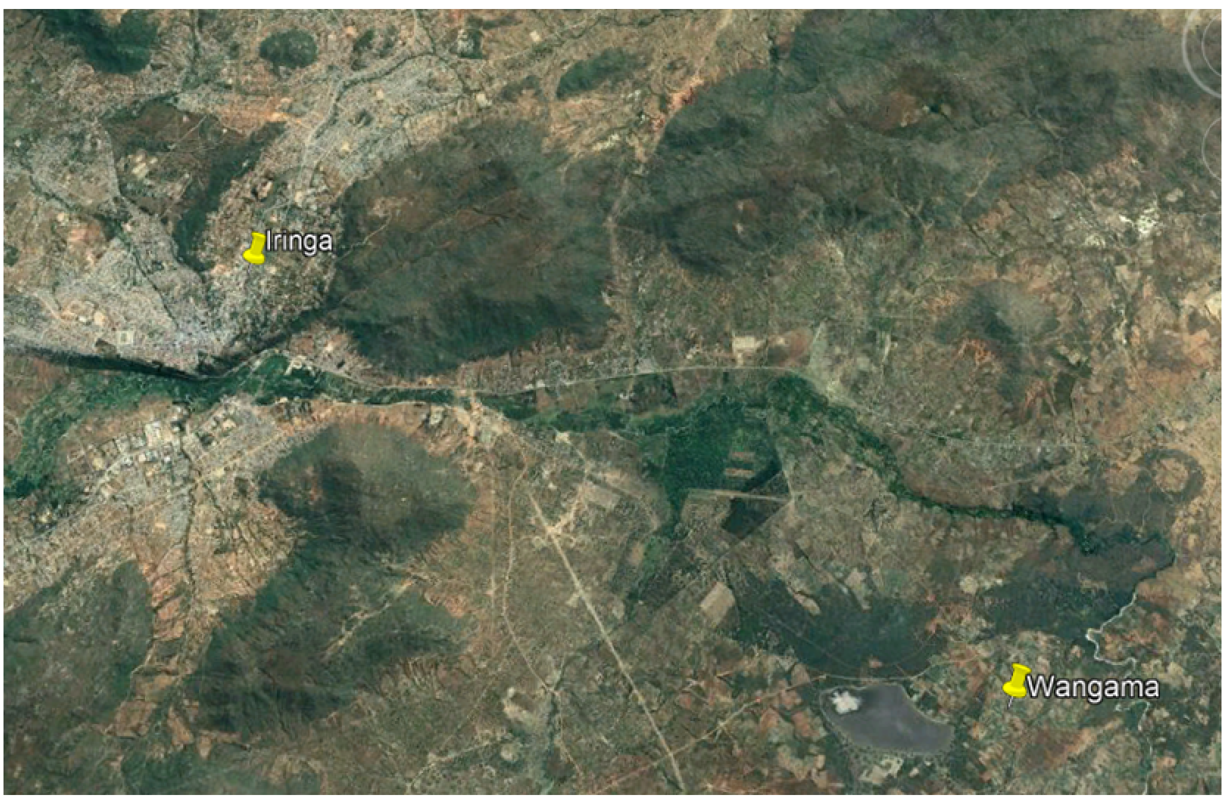

Figure 2.1 A map of the Iringa region with Wangama and Iringa marked.

Figure 2.2 A map of Wangama indicating the geographic coordinates of key landmarks.The yellow border indicates the general populated area of Wangama.

3. Background:

3.1. Wangama Culture

About thirteen kilometers southeast of Iringa lies the village of Wangama. The visit for preliminary surveying and data collection occurred over a three-day weekend. Because the roads were in good shape, it only took 45 minutes to get to the Wangama Village Office from Iringa town.. The drive into the village gave us some understanding of the village's layout. As we reached the Village Office, we were welcomed by the water committee and other leaders from the sub-villages. Additionally, a celebratory cultural dance and traditional singing were performed by some of the women. We had a brief meeting to introduce ourselves to the committee. The cultural differences between those of the rural villages and of the larger cities were astounding. People understood and spoke the national language of Tanzania, Kiswahili, but tribal languages, mainly Kihehe, were the most common forms of verbal communication. The people were very welcoming and hospitable; there were large amounts of food offered at meals despite the socioeconomic status of the village. We enjoyed some traditional food at the meals we shared with some of the village members. After the meeting, some of the members of the water committee showed us the current water system which utilizes river water. The need for safe water was noticeable and was also addressed by the water committee members. After speaking with some villagers, people on the water committee, and a doctor at the Dispensary, we realized how important this system will be for Wangama and how great an impact such a small system can make.

3.2. Village Structure

The village of Wangama is divided into six sub-villages: Itewaga, Iganga, Itemagwa, Idobogo, Kilengelange, and Ineyololo. The population of Wangama consists of 274 households with 1,062 total people. The estimated number of households and number of people in each sub-village are shown in Table 3.1. Most of the population make their living by farming. The village features one dispensary and one primary school with a total of 332 students.

Table 3.1: Sub-villages current population estimates given by the water committee of Wangama (January 2019)

Subvillages	Number of Households	Number of people
Idobogo	47	148
Iganga	44	133
Ineyololo	34	173
Itemagwa	78	350
Itewaga	30	108
Kilengelange	41	150

During our first team visit to Wanagama, the water committee revealed village priorities in regards to locations for water distribution. After a long conversation about internal politics with the water committee, the water committee decided that the main focus for distribution points were the Village Office, which is the highest point in the area, the Primary School, and the Dispensary. The village office is close to two sub-villages: Kilengelange, which is home to 150 people, and Ineyololo, which is home to 148 people. The Primary School is the second-highest point of the village, and is close to Itewaga, which is home to 108 people. The Dispensary is also close to two sub-villages: Idobogo, which is home to 148 people, and Iganga, home to 133 people.

3.3. Current System

The current water system in Wangama includes four hand pumps (three shallow wells and one deep well), one hydraulic ram pump river water system, and a hand-dug well. Of the three shallow well pumps implemented by Saint Paul Partners, only two of them are supplying water. One is working properly, and it feeds two sub-villages. The other shallow well is working, but it has a small yield. People in this area tend to use the directly adjacent hand dug well. This water was very turbid, and no cover was placed over it which allowed for contaminated runoff from agriculture and livestock to enter the well.

The two working hand pumps in operation were inspected in greater detail. The first pump, located on the west end of the village, supplied an average of 13.1 liters/minute (3.5 gallons/minute). This pump supplies water to two sub-villages (Itemagwa and Iganga) and never runs dry. However, we were informed that the color of the water changes throughout the year. The second, on the southeast end of the village, pumped an average of 6.5 liters/minute (2 gallons/minute) observed from a villager gathering water. The yield was very low, and the water quality was poor. The water was cloudy and had many visible particles.

The deep hand pump, near the Dispensary, was disconnected as of January 2019 due to the hole being too deep to pump by hand. However, it was told to us that this pump had worked in the past. Lastly, a shallow hand pump on the northeast end of the village was broken. This was largely due to misuse, and additionally the handle of the pump was bent and parts of the casing were worn through. No effort has been made to fix it since it broke in October 2018. It was reported that this pump can serve up to 50 households year-round when properly working, and without it, local villagers have a 40-minute round trip to the river to gather water. This water from the hand pump was also said to have been very clean.

The hydraulic ram pump system currently draws water from the river through an earthen furrow to a header tank where the hydraulic head powers the ram pump. The system exclusively pumps river water, which is not safe without disinfection or boiling. The system pumps water up to a main brick storage tank at the Village Office, shown in Figure 3.1. From there, distribution lines run to the Primary School, along the road to the east of the Village Office and a distribution point near the Village Office. The pump is capable of sending 19 liters/minute (5 gallons/minute) to the storage tank of approximately 23,000 liters (6,000 gallons), 4.1 meters (13.5 feet) deep, and 2.75 meters (9 feet) in diameter. The water in this system is raw river water which is contaminated with agricultural runoff during the rainy season and gets slightly cleaner in the dry season when runoff is low. There is a sedimentation basin near the inlet of the earthen furrow, but the water is still highly turbid. The ram pump was currently not working at full capacity as of January 2019 due to a leak in some of the valves, but we were informed that this was a very recent development.

The current water system of Wangama will not be included in the proposed clean water system. The hand pumps and ram pump system will be left in place.

Figure 3.1 The brick storage tank at Village Office with an elevation of 1647.1 meters (5404 feet).

Figure 3.2 shows the current water system. The blue circles indicate the working sources of water as of January of 2019, which includes two hand pumps and two distribution points from the ram pump river water system. The red circles indicate the two hand pumps that are currently not working. The yellow outline represents where most of the population lives.

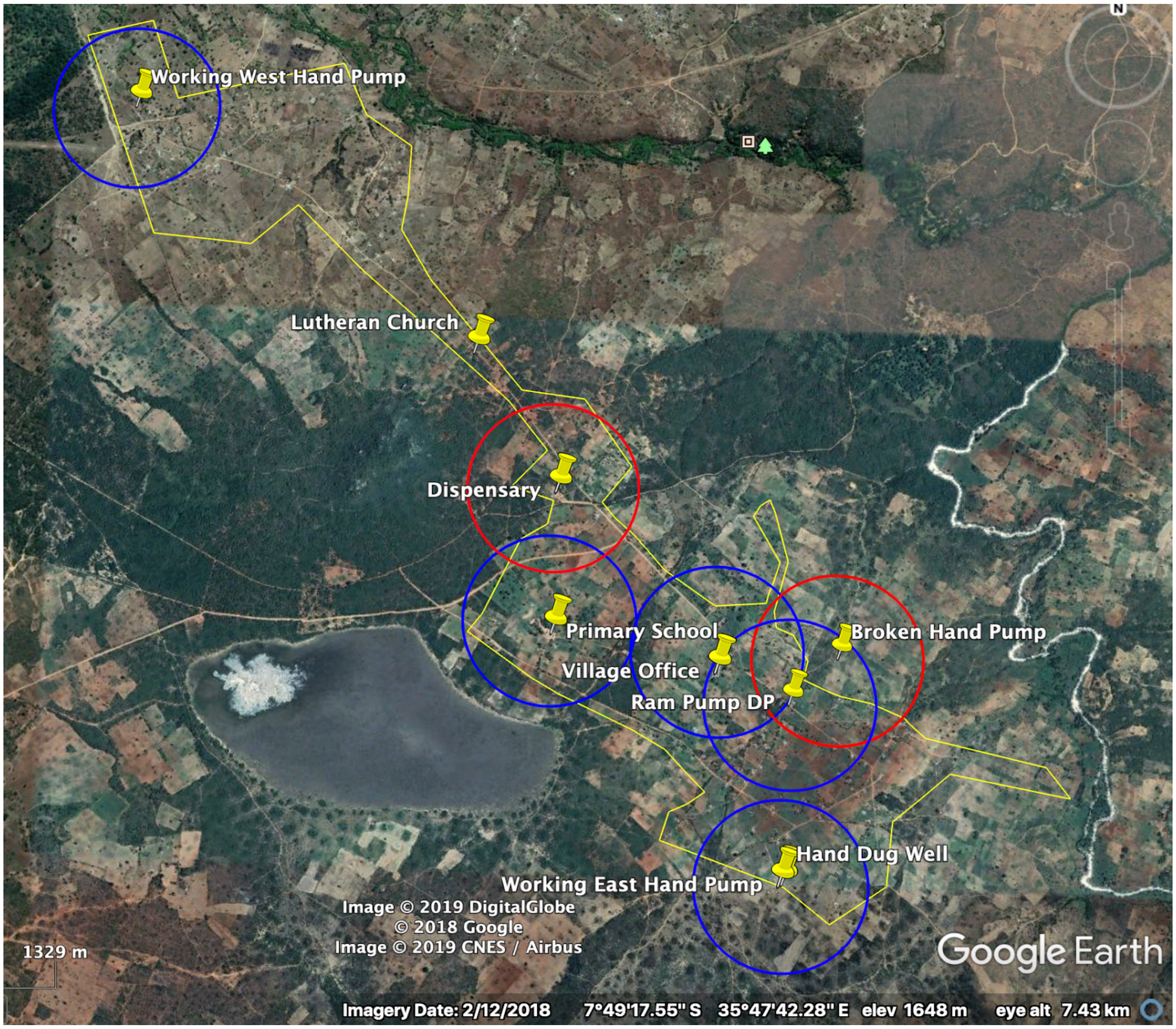

Figure 3.2 Current water sources, functioning and broken.

Figure 3.3 and 3.4 show three current water sources in the village. Figure 3.3 shows the broken hand pump on the East end of the village and the hand dug shallow well on the East end of the village. The well is covered by timber but cannot keep runoff out of the well and is thus a contaminated source of water. Figure 3.4 shows the ram pup for the existing water distribution system in the village.

Figure 3.3 Broken hand pump (left) and hand-dug well (right)

Figure 3.4 Hydraulic Ram Pump

3.4. Hand Drawn Map

The following figure presents a hand drawn map of Wangam including important landmarks, coordinates and paths. Scale of one inch to half a kilometer.

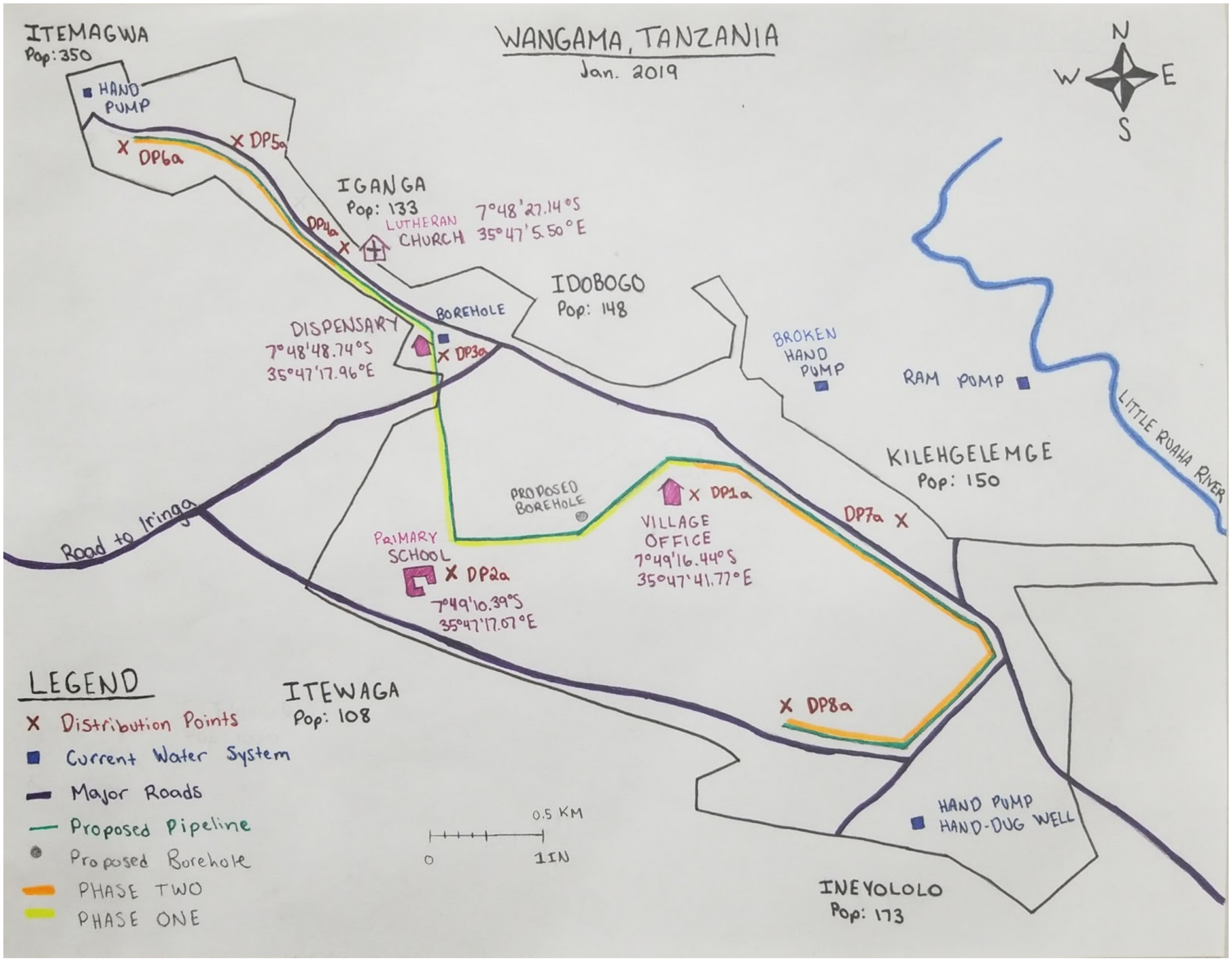

Figure 3.5 A hand drawn map of Wangama with important landmarks, coordinates, and paths indicated. Scale of one inch to half a kilometer.

3.5. Water Test Results

A Colilert Test and a 3M™ Petrifilm E.coli/Coliform Count Plate Test were conducted using water taken from each of the working hand pumps, hand dug well, runoff water, Iringa tap water and purchased bottled water. The Iringa tap water and bottled water both were used as control cases for our tests. Both of these control tests were negative for E.coli and coliform. All of the water sources from Wangama tested positive for coliform in both the Colilert test and the plates. In Figure 3.7, starting from the left, Test 1 is from the ram pump, Test 2 is from runoff from agricultural fields that will flow into the Little Ruaha River. Tests 3 and 4 are from the west working hand pump, Tests 5 and 6 are from the ram pump system, collected from the school distribution point. Tests 7 and 8 are from the other working hand pump on the east end of the village. Test 9 is from the shallow hand dug well next to the hand pump on the east end of the village. With the exception of Test 8, all of the water sources tested positive for E.coli in the Colilert test. This was indicated by a slight glow of the test tubes under ultraviolet light. The yellow color of the test tubes shown in Figure 3.7 indicates the presence of coliform. A plate test was conducted on the same water sources as the Colilert test and labeled with the same number system. Of the nine plate tests, five of them tested positive for E.coli. Plate 2 from the runoff and Plate 9 from the hand dug shallow well had the highest number of colony forming units (CFUs). Plates 1, 3, and 4 had less than five E.coli CFUs. These samples were taken from the ram pump and the west hand pump. The hand pump at the school and the hand pump on the east end of the village had no E.coli CFUs. These results are displayed in Table 3.2.

Table 3.2: Colilert Test and 3M^{TM} Petrifilm E.coli/Coliform Count Plate Test results for each sample collected.

		Colilert Test Results	3M^{TM} Petrifilm E.coli/Coliform Count Plate Test Results	
Sample	**Location**	**Presence of Coliform**	**Conc. of E.Coli (CFUs)**	**Conc. of Coliform (CFUs)**
1	Ram pump	Positive	360	4
2	Agricultural runoff	Positive	260	13
3	West hand pump	Positive	32	2
4	West hand pump	Positive	60	1
5	Ram pump (School)	Positive	33	0
6	Ram pump (school)	Positive	28	0
7	East hand pump	Positive	25	0
8	East hand pump	Positive	22	0
9	Hand dug well - East	Positive	820	17
Control 1	Iringa tap water	Negative	0	0
Control 2	Bottled water	Negative	0	0

Figure 3.6 Results of Colilert water tests after approximately 24 hours of incubation.

3.6. Village Needs

When we visited the Dispensary, we had the opportunity to talk with the village doctor and one of the water committee members. They informed us that many of the villagers suffer from waterborne diseases such as Typhoid. It was uncertain how many villagers were impacted by waterborne diseases in Wangama because many villagers travel to another village for care. If the villagers fall ill, they have to choose between attending school, working, and receiving the needed medical treatment. The water committee identified the Dispensary as one of their top priorities so that it could be better equipped to treat the villagers and thus save them inefficient trips to the neighboring village.

It was clear from the water test results that all of the water sources in Wangama were contaminated, some worse than others. The water committee is currently in a dysfunctional state resulting in half of the current water system to be in disrepair. This results in more of the villagers having to walk farther distances to collect water from the river at the far east side of the village, which is one of the worst sources in terms of bacteria contamination. In addition, surface water from the river likely contains higher levels of bacterial and potentially protozoa in comparison to groundwater from wells.

The water committee also prioritized having clean and accessible water at the school. Not only is it important for the 332 children to have access to clean water while at school, but the children are also able to bring clean water home to their families at the end of the school day. At the water committee meeting, the prioritization of the Dispensary, the Village Office, and the Primary School in the water design was discussed. Our design group has decided that the design project would be implemented in two phases. The first phase consists of a design to supply water to the three priority distribution points: the Dispensary, the Village Office, and the Primary School. The system ends at a tank that is located approximately 130 meters (427 feet) past the Lutheran Church. The second phase consists of expanding the main water system implemented in Phase One to the eastern and western extremities of the village, because high population densities occur at these extremities. Phase Two also includes the implementation of distribution points that are in the proximity of the households in each village.

4. Design criteria

The criteria used for the design on the Tanzania Design Manual for Water Supply and Waste Water Disposal. The criteria are as follows:

4.1. The water system design should be for a minimum of 10 years. Recent population data should be inflated at a rate of 2.7% per year, meaning that the design should accommodate a 30.5% population growth, i.e. $(1.027)^{10}$. The current population of Wangama is 1,062 people, 332 of whom are students. Accounting for population growth, the water system was designed to accommodate the estimated 1,392 people, 435 of whom we predict will be students.

4.2. The water demand should account for 25 liters (7 gallons) of water per person per day. For the school, the design should account for an additional 10 liters (3 gallons) per student per day. For the Dispensary, the design should account for 10 liters (3 gallons) of water per visitor per day. Using the estimated total population in 10 years, the water demand is 34,800 liters/day (9,200 gallons/day). An additional 4,350 liters/day (1,100 gallons/day) for the school and Dispensary. Thus, the water demand is 39,150 liters/day (10,300 gallons/day).

4.3. Design for a total water loss of 20% to account for leaks, valves left open, etc. Therefore, the water system will be designed to supply approximately 47,000 liters/day (12,400 gallons/day).

4.4. The water design should accommodate 2.5 times the average daily flow for the peak hour flow. 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. Assumed 12 hours of sunlight will be available to power the system. From section 4.3, the design should accommodate 47,000 liters/day (12,400 gallons/day), which will be collected at varying rates throughout the day. Thus, the average daily flow is approximately 3,900 liters/hour (1,030 gallons/hour), making the peak average flow 9,800 liters/hour (2,600 gallons/hour).

4.5. As a rule of thumb, the system should have a minimum water storage capacity equal to 50% of the average daily demand. The minimum water storage capacity is thus, 19,575 liters (5,200 gallons), which will be distributed in two 10,000 Liters Poly tanks.

4.6. One distribution point can serve a maximum of 250 people, with a maximum walking distance to the distribution point of 400 meters (1,300 feet). Based on the population of 1,392 individuals, a minimum of 6 distribution points are needed. Taking into account that the total length of the village is 6 kilometres (19,700 feet) and that the maximum walking distance to a distribution point is 400 meters (1,300 feet), a total of 8 distribution points are recommended for the design as a minimum.

4.7. The minimum capacity of each "spigot" should be 10 liters/minute (3 gallons/minute). Each distribution point should be designed with a T having 2 spigots and therefore, each distribution point should be able to provide 20 liters/minute (5 gallons/minute). Therefore, a minimum of 160 liters/minute (42 gallons/minute) in total will be distributed to the 8 distribution points.

4.8. For the gravity main, the maximum working pressure for a pipe should be approximately 80% of the rating. Maximum pressure occurs when all valves are closed at the lowest elevation. This case was evaluated to determine the rating of the piping system.

4.9. For the gravity main, the pipe surface roughness: PVC and HDPE 0.01mm; galvanized steel 0.15 millimeter (relative roughness ε/d is roughness divided by internal pipe diameter). For the pipe being used, the relative roughness is essentially zero.

4.10. The velocity of water in a pipe should typically be in the range of 0.5-1.5 meter/second (1.6-5.0 feet/second). Slower than 0.5 meter/second (1.6 feet/second) usually means the pipe is too large, larger pipes may lead to water hammer.

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

4.12. All minor losses should be modeled as 5% of major losses. Treat valves separately (K_v).

4.13. Add 15% to pipe costs for fittings and 20% to supply costs (pipe/tank/concrete) for shipping. These costs are detailed in section 7, budget.

5. **Prospective Design System Overview:**

The water distribution system for Wangama will be implemented in two phases. Phase One will consist of drilling a borehole near the Village Office and pumping water to a 10,000 Liters storage tank at the Village Office. From there, the water will be gravity fed to the Primary School, Dispensary, and finally to a second 10,000 Liters tank near the Lutheran Church in Wangama. This second tank will ensure a vacuum-free system. Phase One distribution points are represented with blue circles and the pipeline is represented with pink lines in Figure 5.1. To accommodate the rest of the population, Phase Two will be an addition of pipe and distribution points on the east and west ends of the village. In the east, two distribution points will be installed covering most of the population on that end of the village. These will feed from the tank at the Village Office. In the west, two extra distribution points will be installed. These points will be fed from the lower storage tank near the Lutheran Church. Phase two distribution points are represented with green circles and the pipeline is represented with red lines in Figure 5.1. Pipe specifications were based on a code developed in excel for the proposed pipe network using Bernoulli's equation. The velocity and flow output for each of the pipes were compared with the recommended values in the Design Guideline 4.6 and 4.9 to determine the diameter of each pipe. The pressure in each pipe was monitored for multiple scenarios of opened and closed valves to determine pressure ratings.

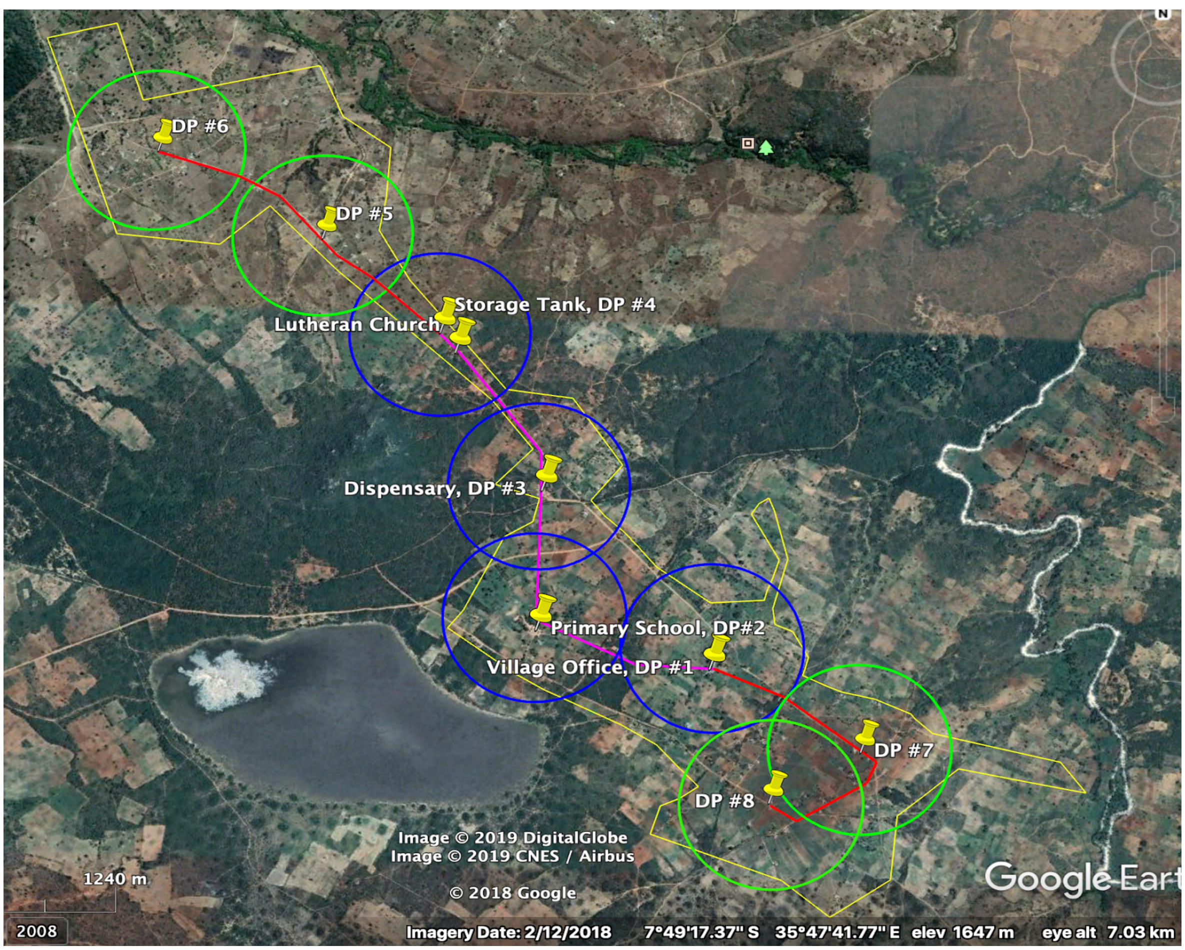

Figure 5.1 Proposed Water Distribution System for Wangama, Tanzania. Red and Pink lines represent pipelines. Circles represent a 400 meter service radius for villagers.

5.1. Proposed Phase One

5.1.1. Rising Main Design

The water for this distribution system will be sourced from a borehole drilled with an air hammer drill that will be trucked to the location. The location of this borehole will be approximately 285 meters (607 feet) west of the Village Office, 9 meters (30 feet) below the elevation of the Village Office. The coordinates of the borehole are S 7°49'16.14", E 35°47'33.07”. The design standard for total daily demand of 46,980 liters/day (12,411 gallons/day) was divided among 6 hours of full sunlight per day to obtain the pumping rate of 7,830 liters/hour (2,070 gallons/hour). This short window accounts for possible clouds on the average day. Calculations show that a pipe with a diameter between 1.75 and 3 inches will suffice for the water to be pumped to the main Village Office tank. This pipe size range will allow for adequate velocity of fluid in the pipe (0.5 to 1.5 meters/second). With these pipe sizes, the Horsepower required to pump the water will range from 2.10 HP (3” pipe) to 2.63 HP (1.75” pipe). The required horsepower will be doubled to accomodate for pump energy losses. As a result, the minimum required horsepower for the pump placed in the borehole will be 4 horsepower. The maximum pressure in the pipe will be 865 kPa, requiring PN 12.5 pipe after a factor of safety of 1.25 is applied (1.75” pipe) or 690.1 kPa, requiring PN 10 pipe after a factor of safety is applied (3” pipe).

The borehole will be drilled 120 meters (400 feet) deep, with the pump placed at 100 meters (330 feet) below grade. A steady drawdown level was assumed to be 60 meters (200 feet) below grade. Before the pump is installed, yield tests shall be performed to ensure adequate yield for the system. The location is subject to change based on yield and village preference. The location of the borehole was selected to be closer to the wetland area and downhill of the Village Office. The elevation profile of the rising main system is shown in Figure 5.4 below. The location of the borehole could be moved closer to the Village Office and be drilled slightly deeper. At the Village Office, the water will be stored and gravity fed to the rest of the distribution network.

The borehole pump will be powered by solar energy. An array of twelve 250 Watts solar panels will be placed on top of the Village Office. This will offer a secure place in full sun to power the borehole. A copper cable will be run from the Village Office to the borehole and buried a minimum of one meter deep for security. Figure 5.2 shows the solar capacity of Wangama, Tanzania throughout the year. From the graphs, it can be expected that the village will receive at least 8 kiloWatts-hour/meter^2/day. A four horsepower pump will require approximately 24 kiloWatts-hour everyday, when pumping for 8 hours during the day. So long as 3 square meters (32 square feet) of solar panels are provided, enough power will be supplied throughout the year to keep the pump running.

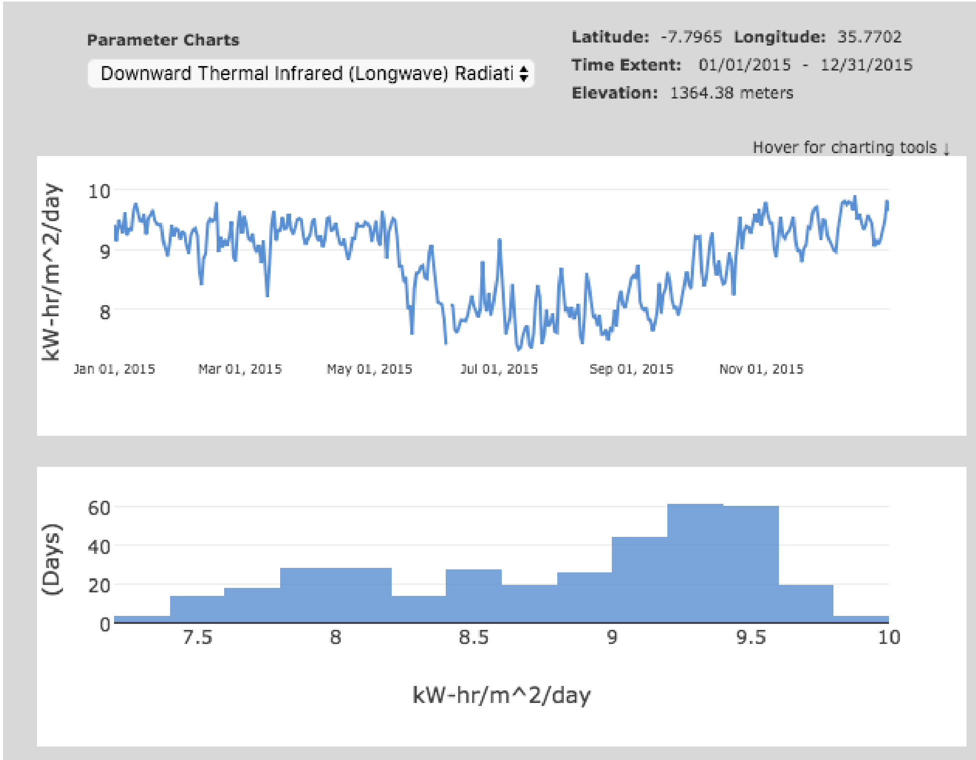

Figure 5.2 Solar capacity for Wangama, Tanzania.

Figure 5.3 The Village Office in Wangama. The roof will be suitable to hold the solar array that will power the pump in the borehole.

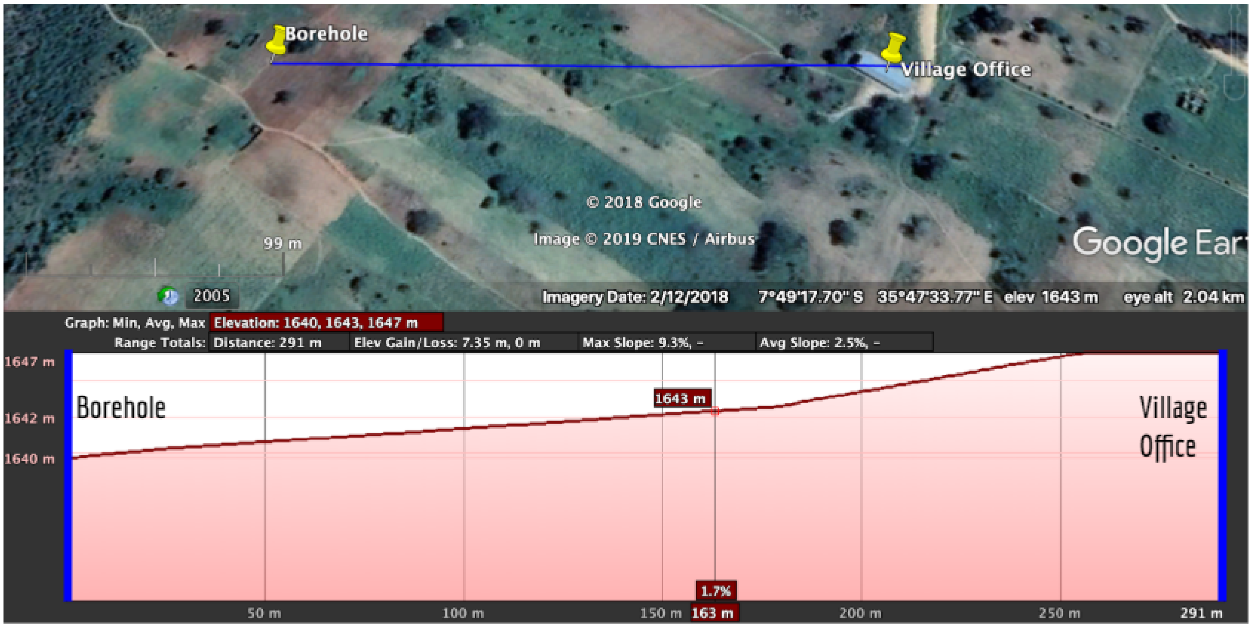

Figure 5.4 The elevation profile of the rising main system.

5.1.2. Storage Tanks

The highest point in Wangama was identified to be the Village Office at 1647.1 meters (5,400 feet). Two storage tanks will be a part of Phase One; the first 10,000 Liters Poly Tank is at the Village Office. This tank will be fed by the rising main coming from the borehole. The tank will gravity feed the distribution points at the Village Office, the Primary School, and the Dispensary. The pipeline will then fill the second 10,000 Liters Poly Tank which will be placed about 130 meters (430 feet) past the Lutheran Church. This location is critical because the system must be reset to avoid a vacuum occurring at the Primary School. A valve will be placed immediately before this tank so that once the tank is full it can be shut off. This will prevent overflow of the tank near the Lutheran Church and allow for the tank at the Village Office to be filled. The storage tank near the Lutheran Church will be able to gravity feed the rest of the northwest side of the village after Phase Two is implemented without causing any vacuums in the piping network. Both tanks will be raised on a two meter high platform to prevent a vacuum.

5.1.3. Elevation Profile

Figure 5.5 illustrates the elevation profile of the Phase One path from the storage tank at the Village Office to the storage tank near the Lutheran Church. This elevation profile does not include the two meter platforms that the storage tanks will be on. The path has relatively little change in elevation as the height difference between the storage tanks is only 15 meters (50 feet). A vacuum was avoided by careful placement of the tank about 130 meters (427 feet) past the Lutheran Church. Thus, the system has enough head from the Village Office highpoint to reach the storage tank at the Lutheran Church. Washout valves to remove water from low points in the pipe and Bleed valves to remove the risk of vacuum at high points should be installed as well. A minimum of two washout valves, one at the low point between distribution point (DP) One and DP Two and another just past DP Three should be installed.

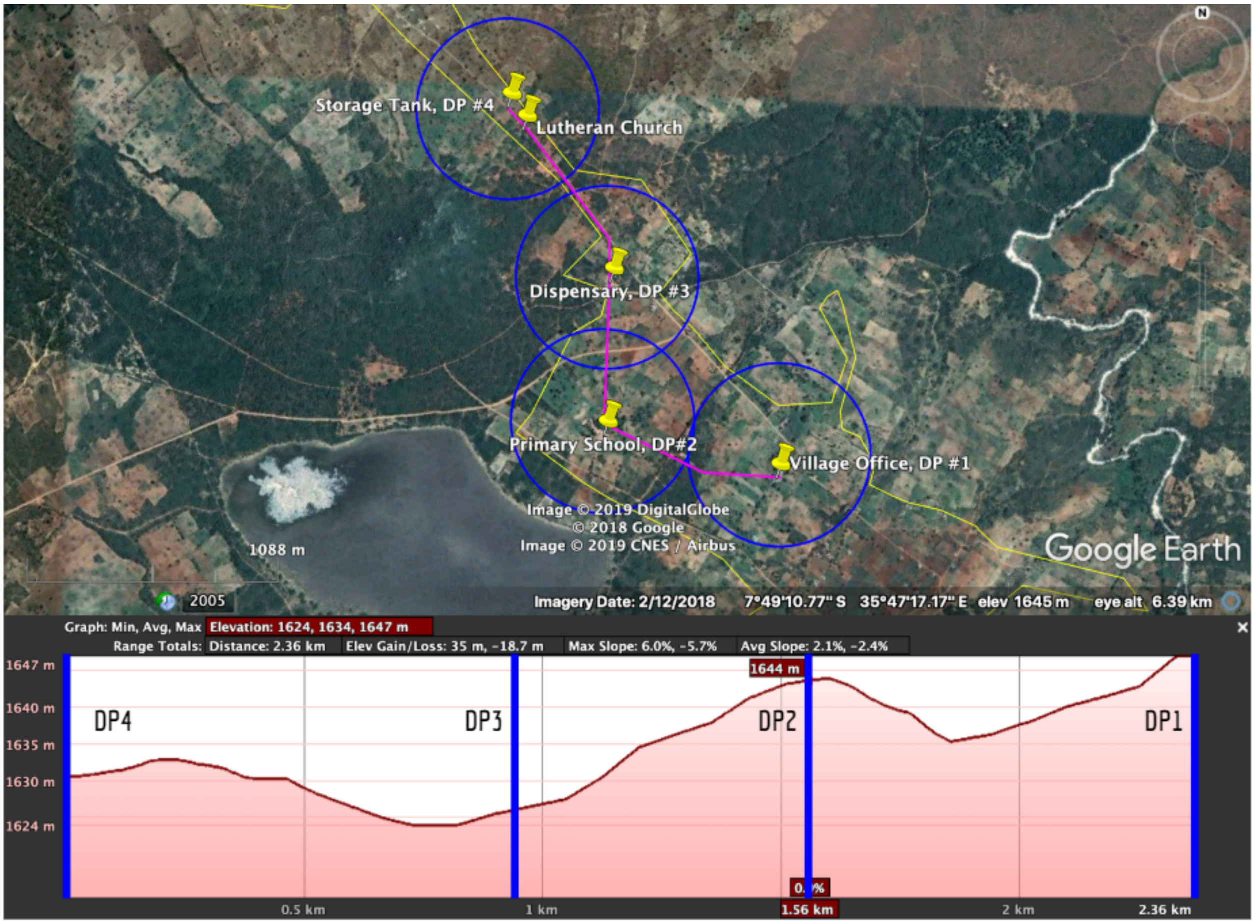

Figure 5.5 The elevation profile for Phase One. The pink line shows the pipe network for the four distribution points and two tanks included in this phase.

5.1.4. Distribution Points

The focus of Phase One was to place distribution points at the places deemed the most important by the residents of Wangama to have clean water sources. These places were identified as the Village Office, Primary School, and the Dispensary. As seen in Figure 5.5, each of these places will have a distribution point at the coordinates and elevations listed below. Conveniently, these places were in relative proximity to each other, so it was efficient to include all of these points in Phase One. In addition to these three priority points, a spot near the Lutheran Church was chosen to hold the second storage tank. Approximately 130 meters (427 feet) past the Lutheran Church, this spot is located along the main road to the west end of the village, and serves as another distribution point. A tank had to be added at this location to serve the west end during Phase Two and avoid a vacuum in the pipe network of Phase One.

Each distribution point will be fashioned with two standard solid bronze valves as well as a concrete pad. The concrete pad is necessary to direct water away from the filling station in order to avoid mud and erosion. As seen in Figure 5.5, these distribution points are within 400 meters (1,300 feet) of most of the residents in the central part of the village.

Coordinates Phase 1

Table 5.1: Google Earth coordinates for the distribution points in Phase One.

Marker	Name	Latitude	Longitude	Elevation (m)
1	Village Office	7.8212333 S	35.7949361 E	1647.1
2	Primary School	7.8195528 S	35.788075 E	1643.4
3	Dispensary	7.8135389 S	35.7883222 E	1626.0
4	Near the Church	7.8065972 S	35.7841556 E	1631.2

5.1.5. Pipe Sizing

The material and diameter of the pipes needed to be determined for the design in order to fit the Tanzanian Guidelines while also being efficient and cost-effective for the village of Wangama. Given the village's needs and the Tanzanian Guidelines, HDPE piping was chosen as the best material. The diameters of the pipe for Phase One vary depending on the elevation change of the pipe from distribution point to distribution point. The pipe dimensions are given in Table 5.2. The total elevation change of the system is under 25 meters (82 feet) meaning that even with 80% of the pipe rating taken into account the rating for the pipes in phase 1 is the minimum PN 6 pipe. The group decided that PN 6 HDPE piping at the different diameters listed above was sufficient for the Tanzania Design Guidelines and the most cost effective for the village.

Table 5.2: The pipe specifications for Phase One.

Pipe	Outside Diameter [mm]	Length [m]	Pressure Rating
1-2	90	830	6
2-2A	32	20	6
2-3	75	620	6
3-3A	32	20	6
3-4	63	920	6

Table 5.3: The total length of pipe in each diameter required for Phase One.

Outside Diameter [mm]	Length [m]	Pressure Rating
90	830	6
75	620	6
63	920	6
32	40	6

5.2. Proposed Phase Two

5.2.1. Elevation Profile

Figure 5.6 illustrates the elevation profile for the East side of Phase Two from the storage tank at the Village Office to DP 7 and 8 at the far East end of the village. This path is a gradual slope with a height difference of just over 10 meters (33 feet). There is no concern of a vacuum or high pressure in this pipe line. Figure 5.7 illustrates the elevation profile for the West side of Phase Two which extends from the tank at the Lutheran Church to DP 5 and 6 at the far West end of the village. This path has a relatively steep slope with a height difference of 62 meters (203 feet). Due to this steep slope and the elevation profile of Phase One, the tank at the Lutheran Church was required in order to distribute water to the west end of the village in Phase Two without creating a vacuum in the Phase One pipe network.

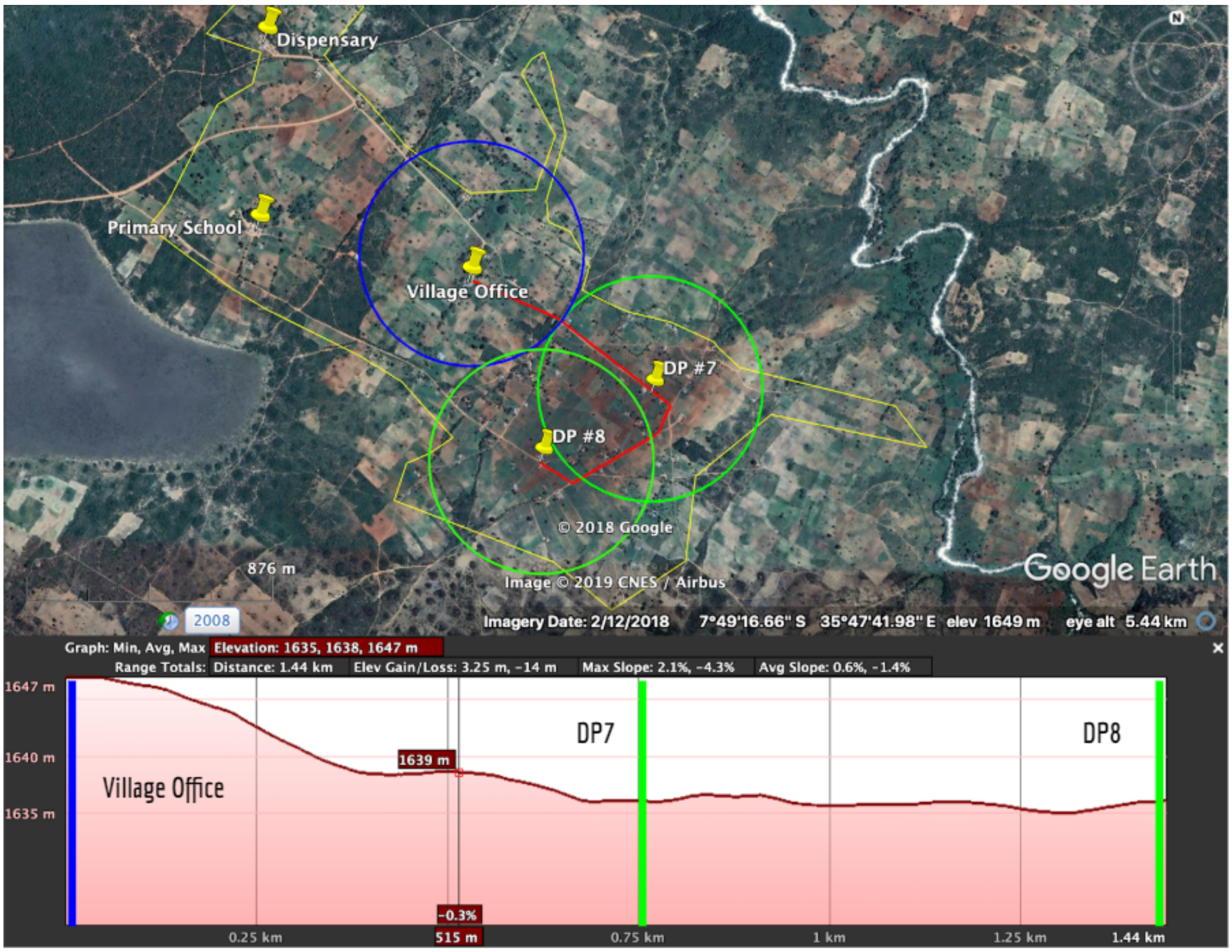

Figure 5.6 The elevation profile for the east side of Phase Two. The Village Office DP will be included in phase one. The red line shown is the path of the pipe for Phase Two.

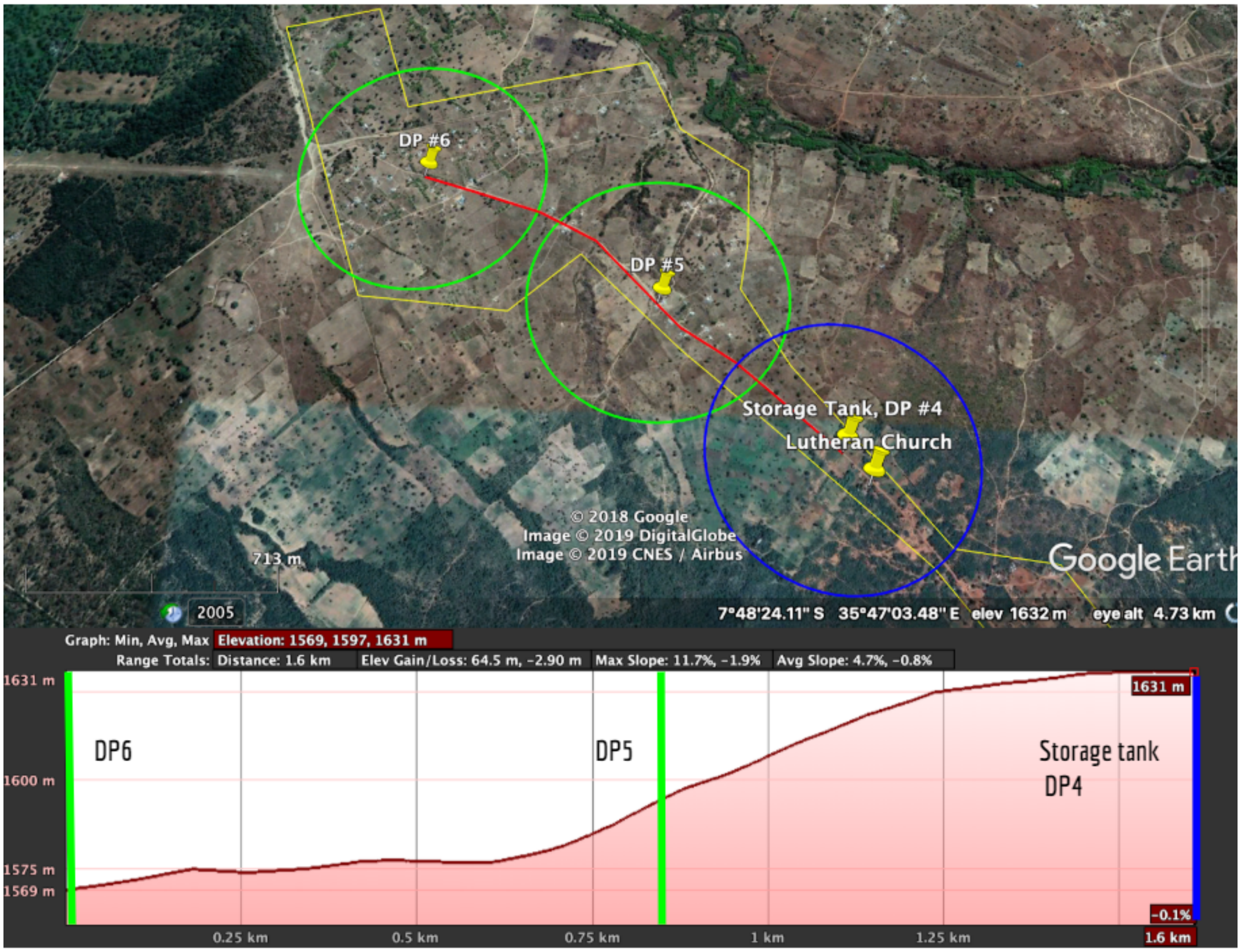

Figure 5.7 The elevation profile for the west side of Phase Two. The Church DP will be included in phase one, along with the storage tank. The red line shown is the path of the pipe for phase two.

5.2.2. Distribution Points

As a part of Phase Two, the group focused on expanding the influence of Phase One so that every resident of Wangama would have a distribution point within approximately 400 meters (1300 feet) of their home. Locations with the highest population density were chosen. These places were identified as seen in Figures 5.6 and 5.7, and each of these places will have a distribution point at the coordinates and elevations listed below in Table 5.4. This phase includes two separate sides; one to the east of the Village Office and one to the west of the Lutheran Church. The east side system will connect to the tank at the Village Office and run along the route seen in Figure 5.6. This route has two new distribution points, DP 7 and DP 8, along the roadway of the east side of the village. The west side system will connect to the tank near the Lutheran Church and run along the route seen in Figure 5.7. This system will also include two distribution points, DP 5 and DP 6, along the roadway in the northwest end of the village. Each distribution point will be fashioned with two standard solid bronze valves and a concrete pad to avoid erosion and the formation of mud.

Table 5.4: Google Earth coordinates for the distribution points in Phase Two.

Marker	Name	Latitude	Longitude	Elevation (m)
5	West End (5)	7.8024167 S	35.7794528 E	1598.6
6	West End (6)	7.7984167 S	35.7725778 E	1568.0
7	East End (7)	7.8247861 S	35.8008806 E	1636.0
8	East End (8)	7.8269694 S	35.7972861 E	1636.0

5.2.3. Pipe Sizing

The material and diameter of the pipes were determined using the Tanzanian Guidelines as well as by considering parameters such as efficiency and cost. Similar to Phase One, the pipe used in Phase Two will be HDPE. While most of the pressure ratings in Phase Two are PN 6, the West side of Phase Two has a large elevation change resulting in the need for a larger pipe pressure rating in some areas. For these pipes, PN 10 will be used. The pipe dimensions are given in Table 5.5.

Table 5.5: The pipe specifications for Phase Two.

Pipe	Outside Diameter [mm]	Length [m]	Pressure Rating
4-5	63	822	6
5-5A	32	20	6
5-6	50	903	10
6-6A	32	20	10
1-7	75	756	6
7-7A	32	20	6
7-8	63	677	6
8-8A	32	20	6

Table 5.6: The total length of pipe in each diameter required for Phase Two.

Outside Diameter [mm]	Length [m]	Pressure Rating
75	756	6
63	1499	6
50	903	10
32	60	6
32	20	10

5.3. Solar versus Grid Electricity

The village of Wangama is very close to Iringa, and power lines extend within two kilometers of the village. Unfortunately, the lines do not reach Wangama, so the village does not currently have grid power at their disposal. However, a local villager was confident that power would be supplied to the village within the next two years. This opened up the potential for a system that runs on electric power. While this option was explored, it was later rejected due to the unconfirmed accuracy of this information. Using solar power will be more expensive up front due to the panels and special power converter needed for the pump controller, but will not require the village to collect money to pay for electricity on top of the water fees that need to be implemented. One benefit of using grid power was that it would force the village to collect money for electricity to keep the taps running. Since the village currently struggles with management and collection of money, this option was strongly considered. The political atmosphere of the village will be discussed in Section 6.3. If grid power reaches Wangama by the time this system would be implemented, St. Paul Partners could fairly easily alter the system to be compatible with electric power as a final design change. Installing a solar system would not be a waste, even if electric power comes to the village soon after the solar system is implemented. The system could be switched to electric power, and the solar panels could be used for a multitude of other village systems or improvements.

6. Social Impact

6.1. Health and Safety

The health impact of this clean water system will dramatically change the way of life for nearly all residents in Wangama. The Dispensary in Wangama has a hand pump in place, but it has been disconnected due to poor yield. The implementation of a clean water system that will first serve the Village Office, Dispensary and Primary School will have a resounding impact.

First, the Dispensary will become much more effective as clean water for patients will be available onsite. In addition, for pregnant mothers, the need to bring their own water (over 100 Liters) for births would no longer be necessary. Clean water at the Dispensary will also encourage more patients to visit the local Dispensary rather than travelling the extra 15 kilometers (49,300 feet) to the next closest Dispensary for issues with waterborne illnesses. However, it is assumed that the occurrence of these diseases will likely drop dramatically once a clean water system is installed for the rest of the village in Phase Two of the design.

While the entire village would not be served until Phase Two is fully implemented, serving the Primary School will help more than just students who attend. Students leaving school for the day would be able to bring home a bucket of clean water. The DP at the Primary School has the capacity to help all those families with students who may not be near distribution points in Phase One.

6.2. Economic Impact

Ideally, an implementation of a water system would force the village of Wangama to become fully responsible for the system themselves. A collection system of fees per adult per household, or potentially a flat fee per bucket of water collected would need to be developed and implemented to allow for the running costs of the system (if grid power is used in the future) as well as for maintenance, repairs, and eventual replacement of components. Fundraising by St. Paul Partners would likely cover the initial cost of the system including drilling, installation, piping, and distribution points. To supplement this investment, the village of Wangama would be asked to contribute in-kind with labor such as to dig trenches for pipes and help with installation and maintenance whenever possible. Section 8 has more information regarding long term costs of the system.

6.3. Political Impact

Upon arrival in Wangama, it was clear from the start that there were many issues regarding the political landscape of this small and spread out village. During the Water Committee meeting, questions were posed to the village leaders about the existing systems and how they were operating. Of the four hand pumps, they claimed that three of them were not functioning. Two of them were believed to produce very little water yield, while another was speculated to be in disrepair due to children not operating them correctly. Upon inspection of the pumps, two of them were working, one with very little yield compared to the other.

This misinformation along with the fact that the broken pump had been in this state of disrepair for three months led to the realization that a better policy is needed for maintenance of the pumps and money collection. Learning that water committee members were paying themselves simply to open a bank account for the water committee was also a red flag. Finally, due to the lack of distribution of water to all villagers, not everyone agreed to pay water fees.

Before a new distribution system would be implemented, further communication between St. Paul Partners and the village of Wangama would be needed to ensure the following items: all water users are paying for water, a reduction of unnecessary expenditures, all wells are fixed properly and a maintenance plan is developed, and a detailed account ledger/history for the Water Committee. Any future water system should be the responsibility of the Village and the Water Committee. This will help the village in the long run to ensure that future leaders can create more unified village with clear goals and management systems.

Figure 6.1 Meeting of the Water Committee and other leaders of Wangama

7. Budget:

Table 7.1: The estimated budget for both phases of the Wangama water distribution system.

Phase 1		Units	Quantity	Price Per Unit	Total USD
120m Borehole		-	1	$ 10,800	$ 10,800
4 HP Pump		-	1	$ 3,000	$ 3,000
Drop Cable		m	100	$ 11	$ 1,100
Surface Cable		m	285	$ 8	$ 2,280
FDS Polycrstaline Solar Panel (250 W)		-	12	$ 328	$ 3,936
Control Unit		-	1	$ 917	$ 917
PN 6 (Class B)	32 mm (40 m)	150 m rolls	1	$ 48	$ 48
	63 mm (920 m)	150 m rolls	7	$ 212	$ 1,484
	75 mm (620 m)	150 m rolls	5	$ 376	$ 1,880
	90 mm (830 m)	100 m rolls	9	$ 360	$ 3,240
10,000L Tank		-	2	$ 884	$ 1,769
Concrete Tank Foundations		m^3	2	$ 588	$ 1,176
D.P.		-	4	$ 175	$ 700
Extra Pipe Costs		-	-	-	$ 998
Shipping Costs		-	-	-	$ 2,153
Labor		-	-	-	$ 3,233
Total Costs		-	-	-	**$ 42,600**

Phase 2		Units	Quantity	Price Per Unit	Total USD
PN 6 (Class B)	32 mm (60 m)	150 m rolls	1	$ 48	$ 48
	63 mm (1499 m)	150 m rolls	11	$ 212	$ 2,332
	75 mm (756 m)	150 m rolls	6	$ 376	$ 2,256
PN 10 (Class C)	32 mm (20 m)	150 m rolls	1	$ 102	$ 102
	50 mm (903 m)	150 m rolls	7	$ 210	$ 1,470
D.P.		-	4	$ 175	$ 700
Extra Pipe Costs		-	-	-	$ 931
Shipping Costs		-	-	-	$ 691
Labor		-	-	-	$ 691
Total Costs		-	-	-	**$ 10,100**

Total Cost For Both Phases	**$ 52,700**

The required budget for Phase One is $42,600 while the budget for Phase Two is $10,100. Phase One has a significantly higher cost due to the borehole, pump, solar panels, control unit, tanks, concrete foundations, and cables all being included during this phase. The only items in Phase Two are piping and distribution point hardware. These costs are conservative estimates based on the Trans-Africa Water Manual, past systems, and the provided Tanzanian design guidelines. The total costs include 10 percent contingency. Due to the relatively low elevation changes throughout Wangama, only PN 6 and PN 10 rated pipes are required. The listed size refers to the outside diameter of the pipe, and the distance in parenthesis is the length of pipe being installed. Approximately half an extra roll was included in the quantity estimates to ensure enough pipe. The extra pipe costs were calculated as an additional 15% of the pipe costs to allow for costs such as fittings and elbows. The shipping costs were estimated as an additional 10% on items requiring transport to Wangama. While the guidelines recommended 20% for shipping, Wangama is very close to Iringa and likely requires a much smaller shipping fee. Labor was estimated as an additional 10% on items requiring installation. It was unclear what the village would be able to provide in regards to in-kind contributions, but they did mention they could supply some labor which could reduce the labor costs. Implementing Phase Two may require a monetary in-kind contribution from the water committee. The total budget for both phases was calculated as $52,700 for the scenario in which both phases are installed at once. All costs are listed in U.S. dollars.

8. Long Term Cost:

8.1. Maintenance and Sinking Costs

Because the proposed system was designed for solar power, there are minimal operation costs associated with the system. As long as the system parts are not abused and the solar panels are cleaned on occasion, the system should work for many years without malfunction. This is beneficial to the village of Wangama because the socioeconomic status of the people is extremely low, even compared to other villages in the region. The rather small need for maintenance of the system poses an issue. To reiterate, it is critical that the village creates a stable and responsible water committee in order to collect money for water usage. Although the system is relatively cost free after installation, parts will inherently fail in the future, whether it be 5 or 10 years down the road. While it is perfectly feasible to collect enough money in this period of time, a better collection model needs to be implemented immediately. Also, this system will probably need to be expanded or replaced many years down the road This would ideally come from the water committee funds.

8.2. Individual Responsibility of the Distribution System

While discussing the potential of a water system in Wangama, it was determined that a distribution system would not be built until the water committee can demonstrate more responsibility in their duties and actions. The committee has to demonstrate their capability by collecting money to fix the multiple broken hand pumps that have fallen into disrepair. A water collection could involve every adult paying 500 TSH every month for access to the distribution points. This would allow the village to collect more than enough money to replace the pump if it fails in 5 years which is a conservative estimate. Ultimately, it is up to the water committee to decide on a collection model that satisfies the needs of the committee and the constituents of the village. However, a water distribution system can only be feasible long-term if the people it is serving take responsibility and ownership of the system. The proposed system is split into two phases which is another method that can be used to make sure that the village collects money. Phase Two may require that the village donate some money towards the construction of the system. While the proposed system is very expensive up front, the overall benefit that the residents will receive both immediately and long-term far outweigh the costs.

9. Summary and Conclusion:

Our time in Tanzania was an incredible experience that none of us will forget. From the initial drive in to the village of Wangama, to the moment we left, the people made us feel at home and treated us with the utmost respect. The village of Wanagama is located about 12.7 kilometers southeast of Iringa town in Tanzania. The village consists of six sub-villages with a total population of approximately 1,000 people. The village has multiple current water systems consisting of four shallow wells and a hydraulic ram pump that drives river water to different distribution points across the village. All of the current water sources are contaminated and they are in need of clean and accessible water. The proposed design suggests implementing a two-phase system in the village of Wangama with 8 distribution points, including the distribution points at the Primary School, Village Office, and the Dispensary, which will overcome the desperate need of water.

The proposed system will provide the village of Wangama with access to safe and accessible water for the population of over 1000 people. This will be a safe alternative to the bacteria-contaminated sources that have been used in the past. It will relieve the burden of walking many kilometers every day for a bucket of water because it will provide a clean source within 400 meters of most dwellings. If the village leaders and water committee members of Wangama are ready to take initiative to fix their current water systems and to take on a new challenge, this project is a very feasible, long-term solution to their water problems.

10. Appendix:

10.1. Gravity Main System

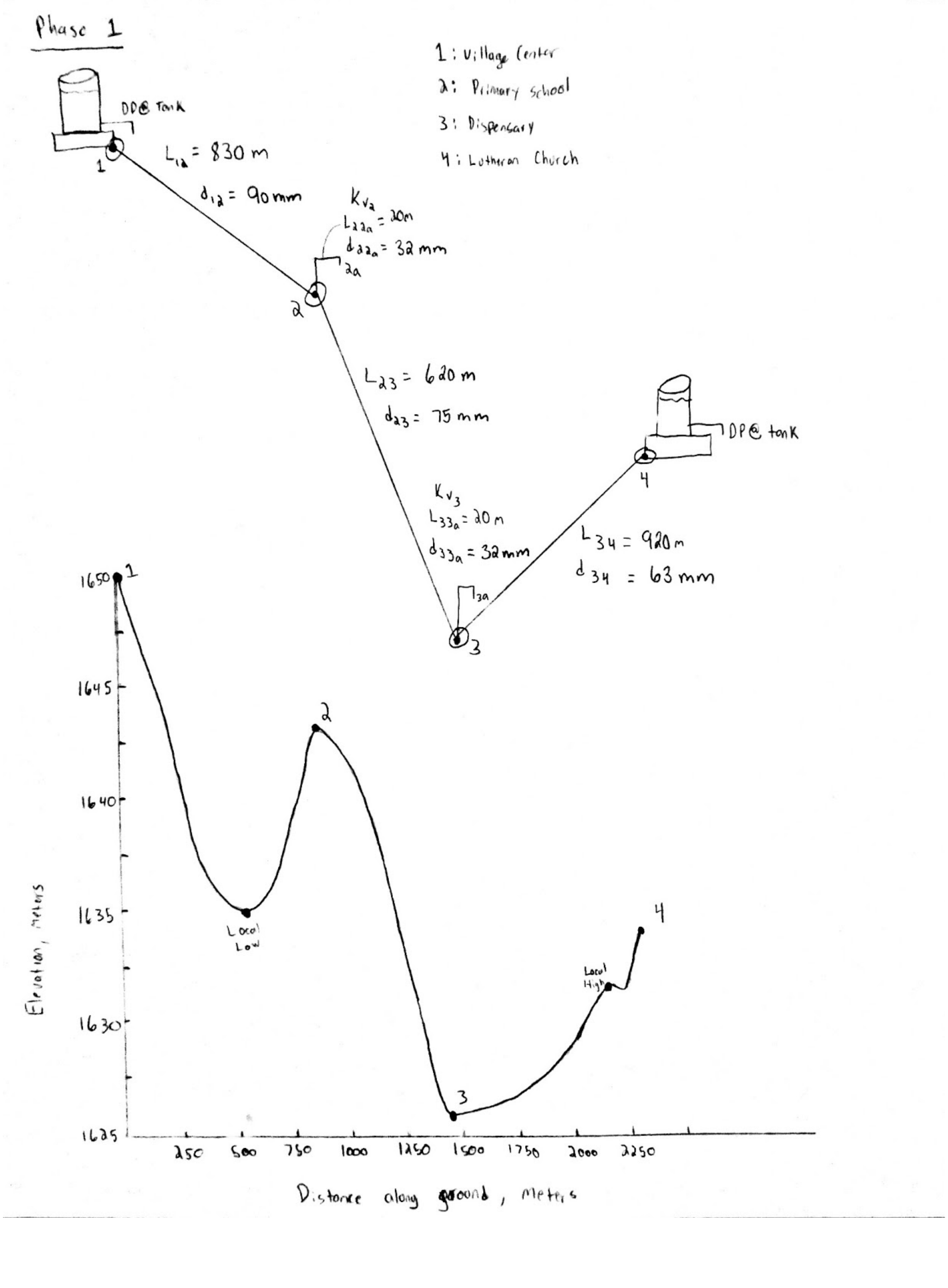

Figure 10.1: A sketch of the Phase One gravity main

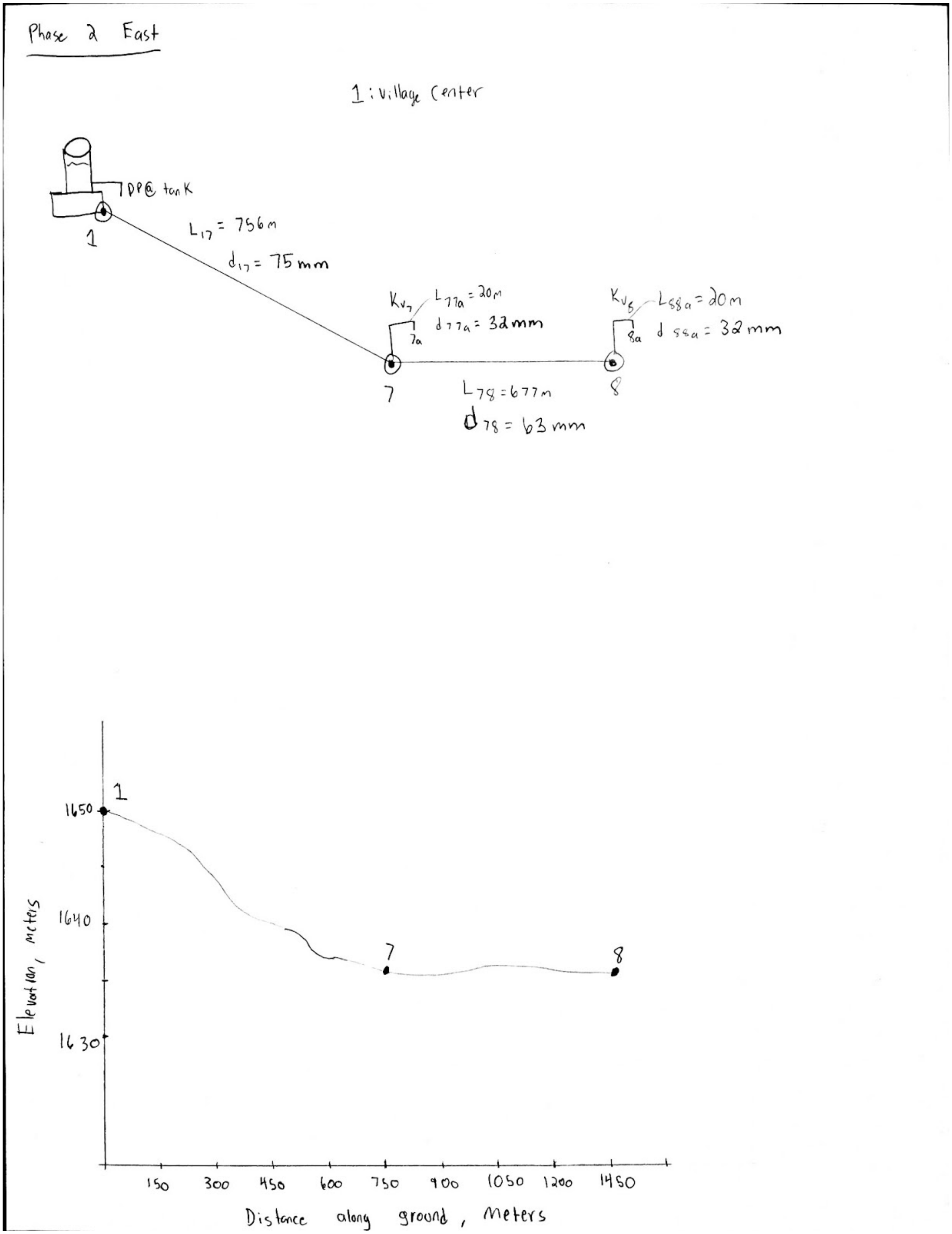

Figure 10.2: A sketch of the Phase Two East gravity main.

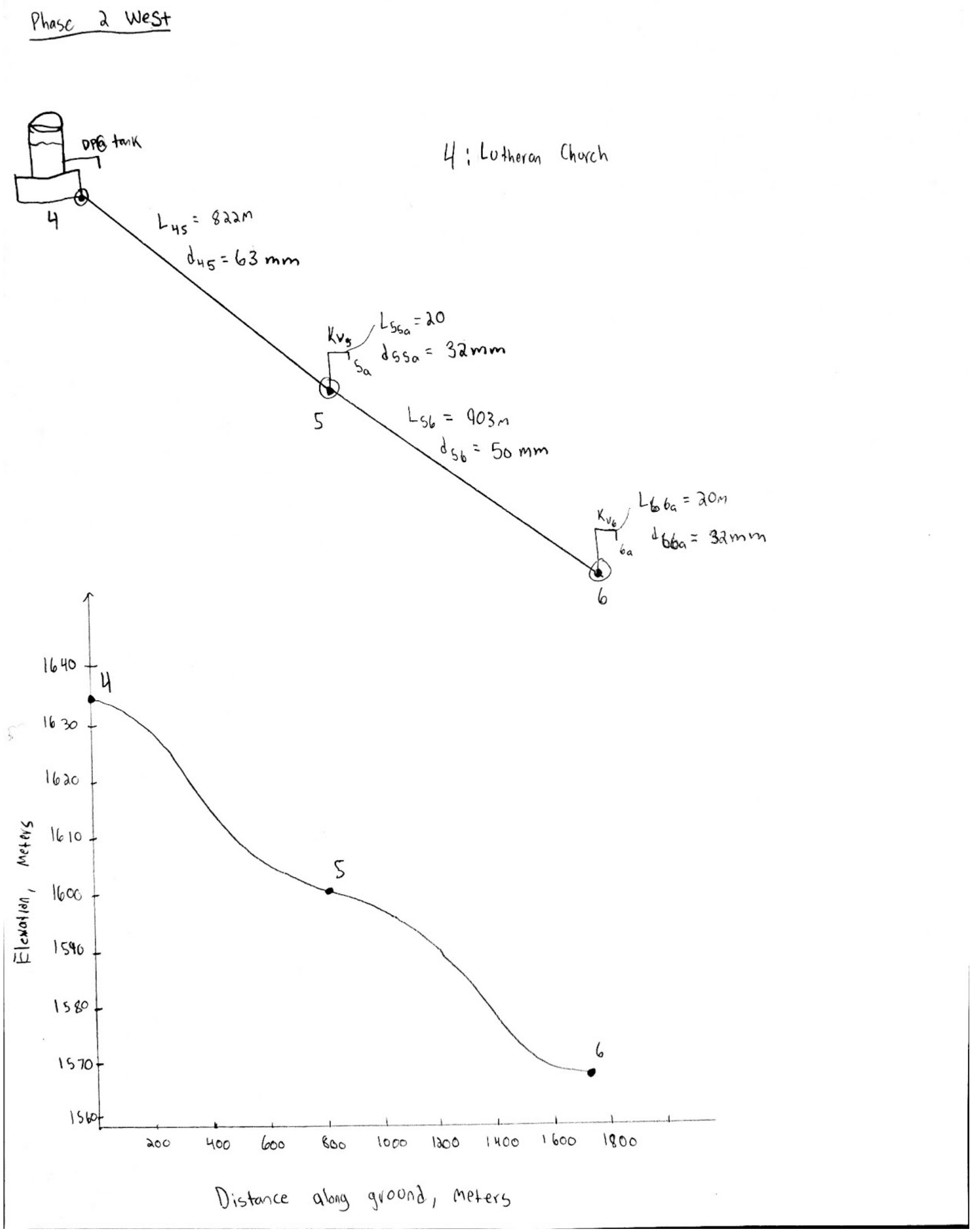

Figure 10.3: A sketch of the Phase Two West gravity main.