Design of a Water Distribution System for Kidilo Village

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1.0 Executive Summary

The intent of this project is to design a low-maintenance water distribution system to supply clean drinking water for the Ifuwa sub villages of Kidilo and Ikovelo. Currently, residents receive their water from a small underground flowing source that briefly breaks the surface. This source was tested for harmful bacteria and was found to be unsafe for consumption. A centrally located hand pump well also exists, but is non-functional for unknown reasons. Kidilo is located on a hill, with the well approximately 400 m from the top. The surrounding area is a generally steady decreasing elevation radiating outward from the hilltop with extreme lows that begin to rise again. These findings set the basis for designing a suitable water distribution system.

The proposed gravity main provides to seven distribution points. Proposed distribution points are located to ensure no community member must walk more than 400 m. During peak demand wherein the storage tank water level is low and all distribution points are being utilized, all seven outputs are greater than 20 L/min. The total pipelength of the proposed gravity main is 2101 m. The supply line provides to not only Kidilo but also extends over to the neighboring subvillage Ikovelo.

The optimal design is a solar-powered system integrating battery storage for a total of 21 hours pump time per day. This will supply the Kidilo and Ikovelo's population with 12 liters of clean water per day, which, while below standard Tanzanian design criteria, is more than enough for each person's daily drinking water.

The people of Kidilo village act expressed their willingness to contribute to the implementation of this design. The Materials cost sums up to 25,300 USD, with a net labor cost of 3658 USD that will be deducted through in-kind contributions from the community. The total estimated cost with a 10% contingency sums up to 31,800 USD. Saint Paul Partners work on site to develop an implementation plan that is best suited to the community. This may include on side adaptations to the proposed design.

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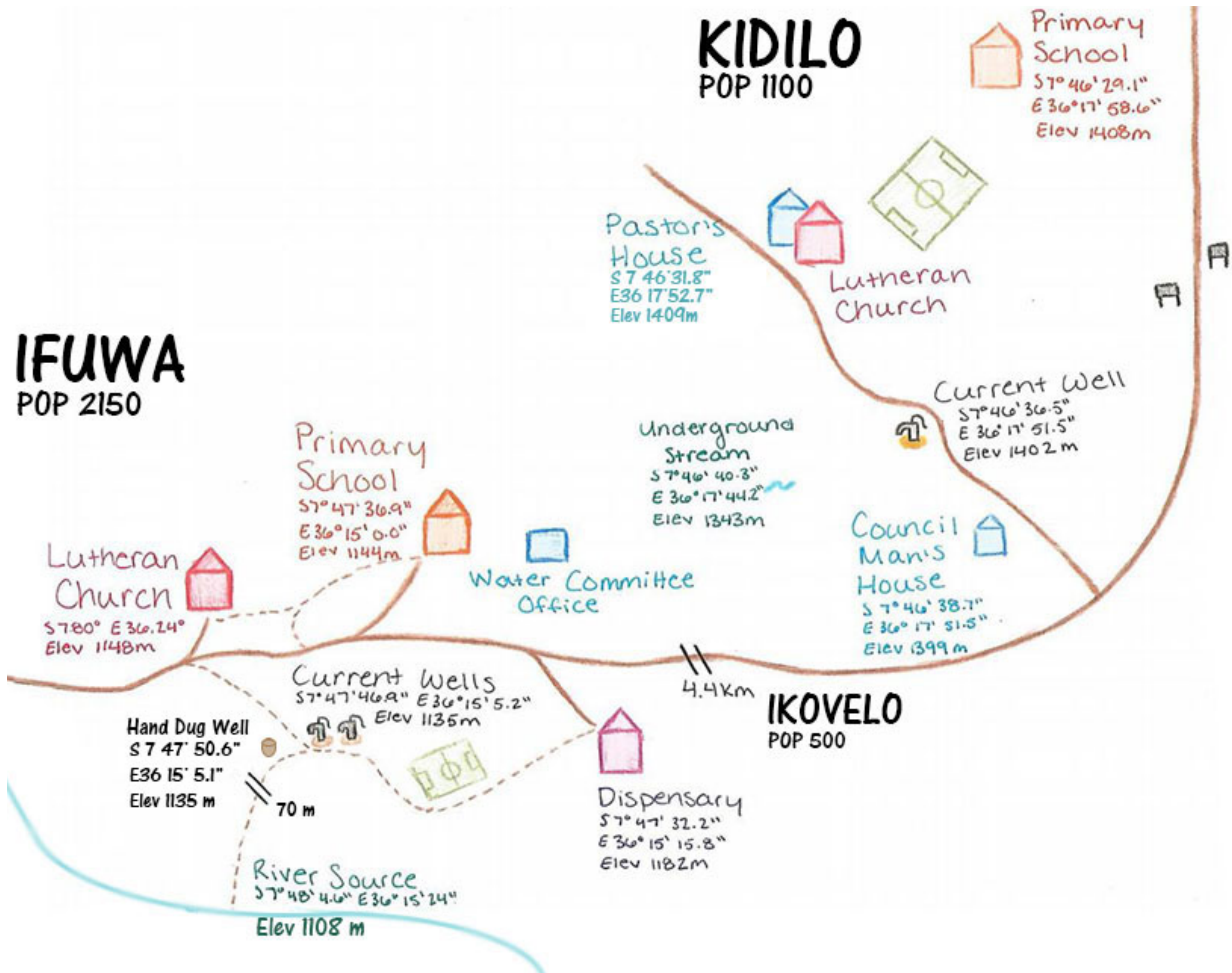

KIDILO
POP 1100
Primary School
S7° 46' 29.1"
E 36° 17' 58.6"
Elev 1408m
Pastor's House
S 7 46'31.8"
E36 17'52.7"
Elev 1409m
Lutheran Church
Current Well
S7° 46' 36.5"
E 36° 17' 51.5"
Elev 1402 m
Underground Stream
S 7° 46' 40.3"
E 36° 17' 44.2"
Elev 1343m
Council Man's House
S 7° 46' 38.7"
E 36° 17' 51.5"
Elev 1399 m
IFUWA
POP 2150
Primary School
S7° 47' 36.9"
E 36° 15' 0.0"
Elev 1144m
Lutheran Church
S7.80° E 36.24°
Elev 1148m
Water Committee Office
Current Wells
S7° 47' 46.9" E 36° 15' 5.2"
Elev 1135m
Hand Dug Well
S 7 47' 50.6"
E36 15' 5.1"
Elev 1135 m
70 m
4.4Km
IKOVELO
POP 500
Dispensary
S7° 47' 32.2"
E 36° 15' 15.8"
Elev 1182m
River Source
S7° 48' 4.6" E 36° 15' 24"
Elev 1108 m

3.0 Project Profile

3.1 Project Location

Region: Iringa, Tanzania

District: Iringa Rural Region

Village: Ifuwa

Sub-village: Kidilo

Climate: The area is classified as warm and temperate with an annual average temperature of 68 degrees Fahrenheit and receiving approximately 800 mm of rain each year. The vast majority of this rain is received in the wet season (December – April).

3.2 Project Duration

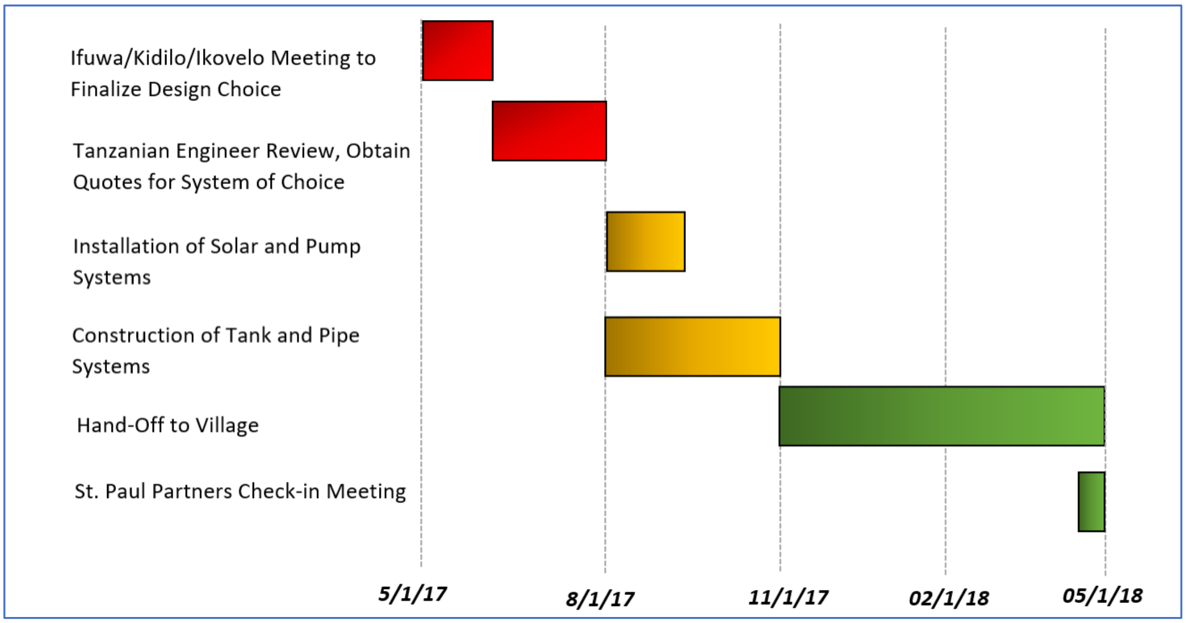


Figure 1: Project Timeline

3.3 Project Budget Summary

The ideal design of three explained later is summarized in Table 1 as two cost factors, those of materials and labor (the latter provided by the village).

Table 1: Budget Summary (Solar with Storage)

Materials Cost	25288.45 USD
Net Labor Cost	3657.98 USD
Total estimated Cost (w/10% contingency)	31841.08 USD

4.0 Background

4.1 Ifuwa

After our fearless driver Michael had trundled and rattled over 56 kilometers of highway and 32 more kilometers of what can only be loosely described as roads, the team arrived in Ifuwa. We learned that the town we had thought of as a single entity was in composed of 5 sub-villages: Ifuwa, Kidilo, Ikovelo, Kitolomela, and Mwagidawa. Pastor Gervas, with whom our group would be lodging, lives in Kidilo, about 6 km past Ifuwa on the main road we had trundled in on. Ifuwa, with a population of about 2150 people, is the main sub-village and hosts a primary school, dispensary, and church. For reference, Ifuwa is shown in its geographical context in Figure 2.

Figure 2: Topographical map of Iringa Region with significant villages marked.

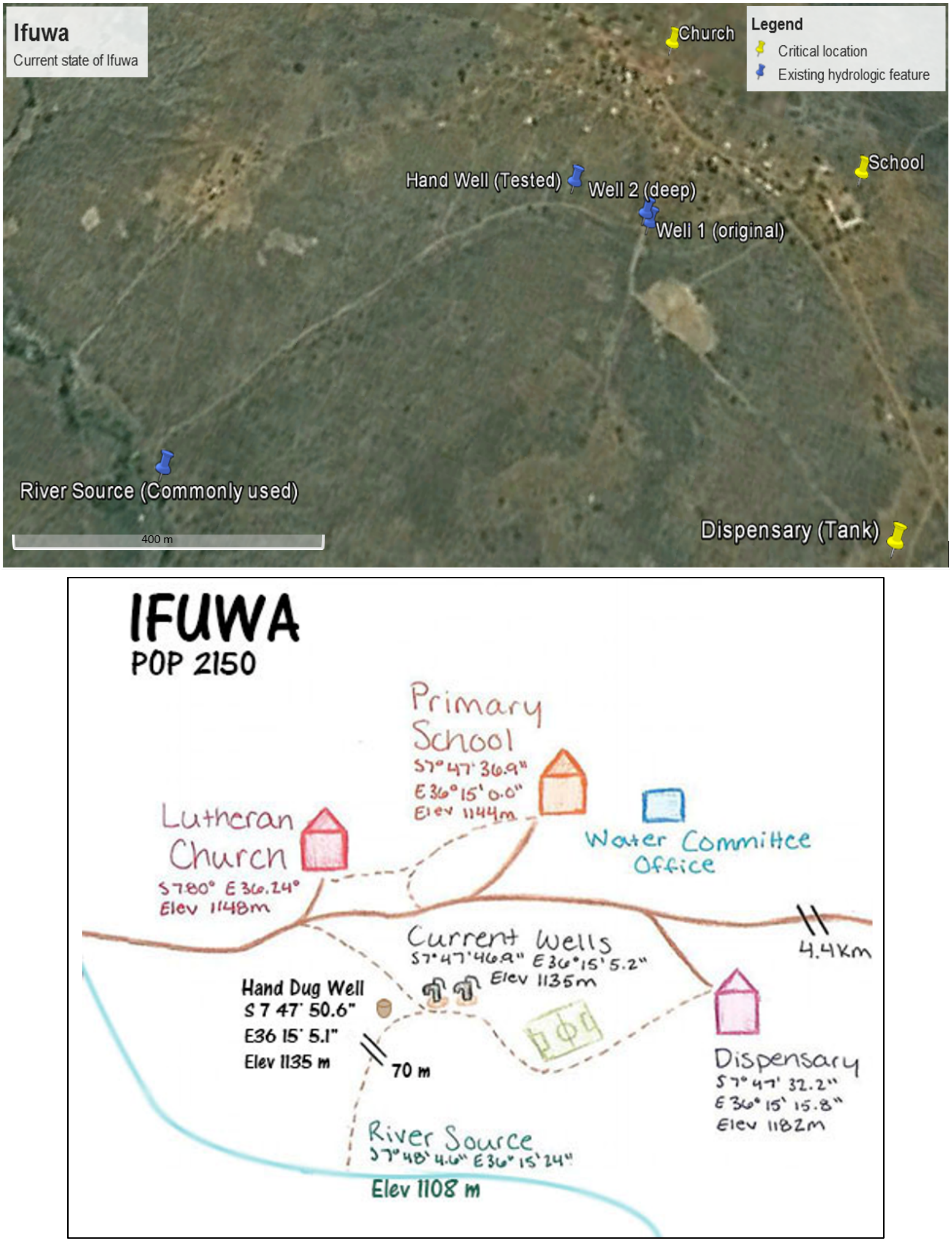


Figure 3: Ifuwa proper with important landmarks indicated and labeled (a) Google earth (b) Hand-drawn map.

4.1.1 Existing System

Ifuwa has two non-functional wells, and their story is as comical as it is heartbreaking. The first well, a 50-meter-deep borehole drilled in 2008, functioned with a hand pump, but only during the rainy season. After three years of intermittent success with this well, a new well was drilled about 20 feet from the original. This well was twice as deep, giving the villagers hope that it would provide water year-round. They took the pipes from the original well, and in the process of placing them in the new well, they were dropped and went plummeting down into the new borehole and were not retrieved. This created an obstruction that would limit the length of pipe able to be used for the pump. The village got new piping for the pump, but due to unknown reasons, likely blockage or collapse due to the fallen pipe, only a measly few liters of water were pumped from the new well before it simply stopped functioning.

Figure 4 : Both Ifuwa hand wells indicated with red arrows
(Location: S 07° 47’ 46.4’’, E 36° 15’ 5.5’’; Elev: 1157 ± 16m)

Figure 5: Villagers hold up the head of the well as the team attempts to measure the static water level

After meeting with villagers and leaders from all five sub-villages, we journeyed to the object of this sad story surrounded by an entourage of people from the meeting and an agglomeration of curious children. We decided to use our water sounder to see if we could at least gauge the static water level in the newer well. As some of the villagers held up the wellhead and piping (which are extremely heavy) we tried and failed to get the sounder wire past the obstruction in the well (Figure 5). It was here we began to realize the sheer scale of the Ifuwa problem: this village is fairly large in population and in sheer geographic scale, and to even think about designing a system for so many people would be immensely difficult when our supply options are to either fix this well, about which we have no information of its reliability or sustainable draw, or make an even bigger guess and recommend a new well. This ultimately led to our decision to focus on Kidilo, which is covered in the next section.

Dejected and slightly sweaty, we asked our new posse if we could see where the village gets their water now. We had heard about a river during the meeting but wanted to know more. From the wells we walked down into a valley for about a kilometer until we reached a scene of women talking and hanging clothes out to dry, children running around and screaming out of joy (though they fell silent as the strange *wazungu* approached) (Figure 6). This was our first encounter with the cultural reality of water in Tanzania: in places where there is little, life happens at the water. The need for the social centralization of the river is more apparent when considering what we learned at the village meeting: villagers from Kitomela and Mwagidawa walk up to 8 kilometers just to get to the water, and the nucleation of social life around the water is largely a result of the convenience of a single daily sojourn to the river rather than possible multiple trips.

Figure 6: Women and children located near the river water source bathing and washing clothes.

However, this town nucleus is not perfect. During the wet season disease vectors are attracted to the river and the villagers informed us that incidents of waterborne illness increase as detritus runs into the river from animals and farmland. During the wet season water used for purposes other than drinking is lifted from shallow wells hand-dug into the landscape.

We went upstream of the clothes-washing and bathing to get a water test sample akin to what the villagers would be consuming. As curious children looked on we took our sample from the slow-flowing, shallow water under the shade of unfamiliar trees and began incubating it. Upon returning to the wells where Michael and Hanael were waiting with the Land Cruiser, Steph, Noah, and Cathy decided to go back down the hill briefly to sample the water from a hand well (Figure 8) like those described earlier, but also filled with debris and frighteningly large wasps.

The water from both sources was found to be contaminated with *E. coli*. By EPA standards, that confirms what the village had told us: this precious water source is not safe for consumption. The sources themselves and their quality testing results can be seen in Figures 7-10. The test results shown in these pictures do not lend themselves to proper interpretation, as the lighting is significantly different in the before and after pictures and the black gunk (positive test for coliforms) that formed in the bottles cannot be seen, nor are there adequate photos of the UV-fluorescence examination on these samples (positive for *E. coli*).

Figure 7: Ifuwa river water source (during end of wet season)
(Location: S 07° 48’ 4.6’’, E 36° 15’ 24’’; Elev: 1108 m)

Figure 8: Ifuwa river water test before (left) and after (right) 24 hours waiting time

Figure 9: Ifuwa hand dug well water source (during dry season)
(Location: S 07° 47’ 50.6’’, E 36° 15’ 5.1’’; Elev: 1134 m)

Figure 10: Ifuwa hand dug well water test before (left) and after (right) 24 hours waiting time

4.1.2 Determination of Village Water Needs

During the site visit, the team met with the water committee, village leaders, and community members to discuss their wants and needs in regards to a prospective water system (Figure 11). Due to the presence of the dispensary in Ifuwa proper, clean and easily accessible water is a high priority to the villagers. Currently, patients need to bring their own water with them to the dispensary and, as can be seen in Figure 3, it is a long walk (1.4 km) from the river when carrying a bucket of water to the dispensary, and it is all uphill (a 75 m elevation change). Not only is it a burden to get water to the dispensary, but the water brought is contaminated as seen in Figures 6 and 8. Thus, the water is ill-suited for treatment of disease or abrasions. The primary school is also a priority for receiving clean and accessible water. 331 students attend the school and all need water to drink during the day while attending classes. While clean drinking water access to all villagers was highlighted as a critical human health, the Ifuwa Water Committee nonetheless placed the highest priority on the school and dispensary.

Figure 11: Water Committee Meeting in session in a classroom of the Ifuwa primary school

4.2 Kidilo Village

Kidilo, one sub-village of Ifuwa, is located 6.3 kilometers away from Ifuwa proper. The village has a church and is in the process of construction a new primary school. The church and pastor's house were built in 2014 by a Swedish church group headed by Pamela Sjödin-Campbell (email: pamela@familj-sjodin.se). During our stay in the village we resided in the pastor's house. Table 2 shows populations specific to Kidilo and nearby Ikovelo. Figure 12 shows both a Google Earth and hand-drawn map of Kidilo with major land-marks labeled.

Table 2. Population Statistics for Kidilo and Ikovelo

Total Population of Ifuwa	8000
Kidilo and Ikovelo	1600
Kidilo Primary School	
Prospective Total	200

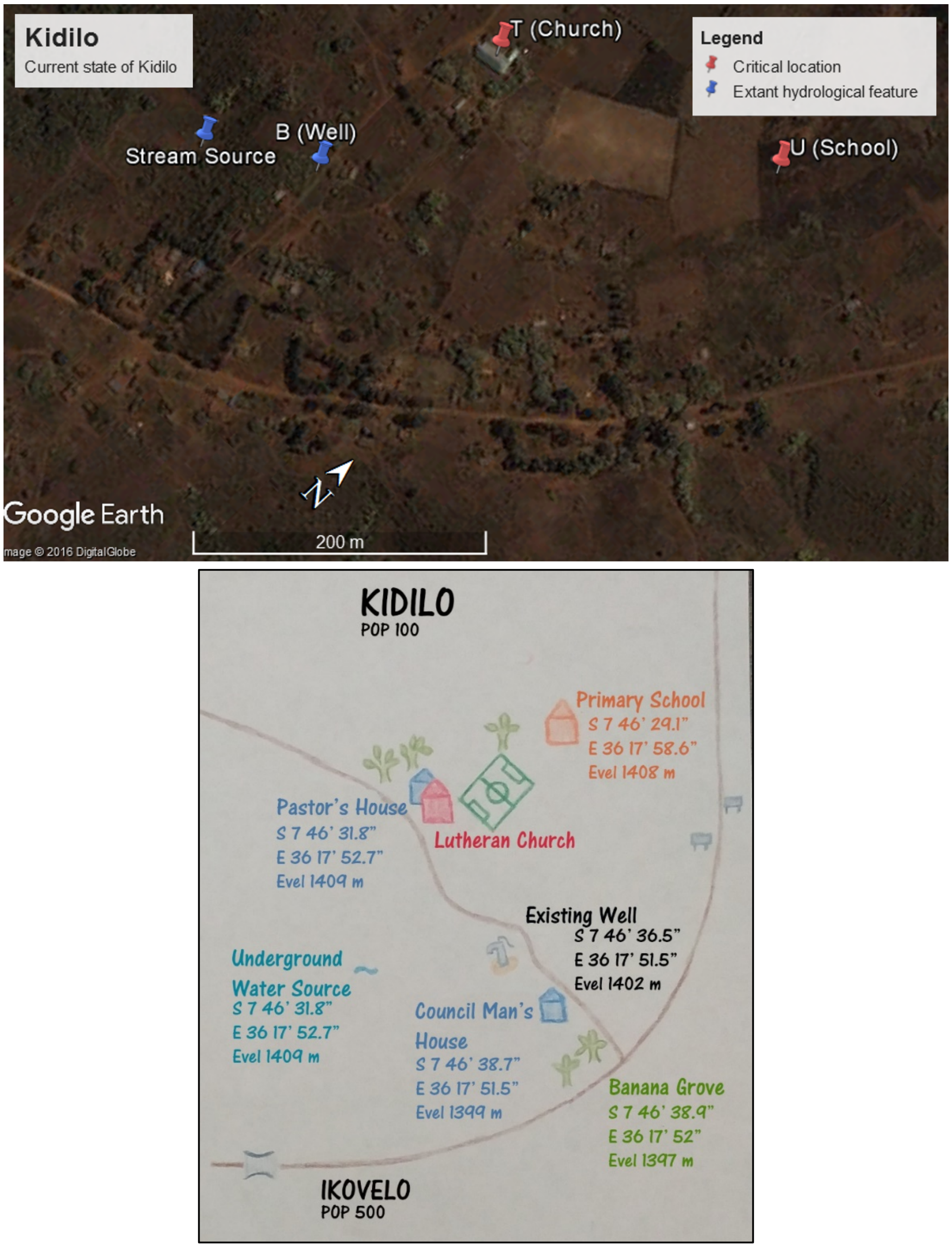


Figure 12: (a, top) Kidilo with important landmarks indicated, Ikovelo ~1 km to the West, not shown. (b, bottom) Hand-drawn map of Kidilo and Ikovelo (not to scale)

4.2.1 Existing System

Kidilo has one centrally located non-functional hand pump well (shown in Figures 12 and 13). The Swedish church group previously mentioned drilled the 152 meter deep borehole well in 2014. The hand pump that was installed was not sufficient to draw water from the deep well. A well test with an electric pump was performed prior to our arrival indicating the static water level was 16 meters below ground level and had a sustainable output of 1200 L/hr with a dynamic water level of 140 meters below ground. We were unsure of the reliability of this previous test, so we decided to test the static water level for ourselves. In order for us to complete the test, the well head had to be taken apart. Hanael and the villagers didn't think twice before jumping on the task before us. The men were more than willing to help us in any way they could and the children were always eager to be observe what the alien *wazungu* were doing throughout their village, standing quiet and wide-eyed at a leery distance (Figure 12). As the villagers watched, we lowered our sounder until its buzzer rang clear at 16 meters, adding a new level of certainty to the design parameters given to us by the previous test of the borehole.

Figure 13: Kidilo hand pump well
(Location: S 07° 46' 36.5'', E 36° 17' 51.5''; Elev: 1402 m)

Based on the depth of the well and that there has never been any water retrieved from the well, we concluded two theories for why the pump is non-functional. From information provided by our St. Paul Partners contact, Hanael Gadwe, the hand pump that was installed was one of two types: the Afridev – which meant for lifting water 45 m or less, or the Indian Mark ii – which is meant for lifting water from 50 m or less. The first theory is that the pump installed was modified so that the pipe placed in the bore hole draws at a depth greater 50 m. If this is the case, the pump is unable to generate enough force to lift the water to the surface. The second theory is that either of the pumps listed previously were installed with the standard length of pipe, but something with pumping mechanism is damaged preventing the pump from working. This theory was supported by Hanael Gadwe, as she believes the pump was designed for a 40 m water level. Based on a comparison of the well in Kidilo to images found in research about each pump (Figure 14), the pump installed was an Afridev hand pump. Regardless of which theory holds water, the aquifer drawdown (to 120 m) known from the previous test guarantees that neither of these two hand pumps could possibly be sufficient for this borehole.

Figure 14: (left) India Mark ii hand pump, (right) Afridev hand pump. A simple comparison of appearance to the well in Figure 11, shows that the Kidilo hand pump is an Afridev pump.

The current water source is a ground water source located approximately 600 m west of the hand pump at a ~40 m lower elevation. Typically, women carry water from this source in 20 liter buckets to the main village, occasionally enlisting donkeys to help carry water. Steph attempted to hold a full bucket on her head and found this extremely difficult. At this point the gravity of this daily task weighed upon us as well. The outflow from this source is minuscule, and the village has no redundancy in their water plan. This tenuous source the villagers so casually expend so much effort in utilizing needs to be supplanted with something more robust. The quality of this source is no miracle, either. We tested it in the same way we did in Ifuwa, and found contamination of *E. coli*, meaning the lifeline of Kidilo is not safe for human consumption. The source itself and its quality testing result can be seen in Figures 15 and 16, respectively.

Figure 15: Ground source water supply in Kidilo
(Location: S 07° 46’ 40.3’’, E 36° 17’44.2’’; Elev: 1143)

Figure 16: Kidilo ground source water test before (left) and after (right) 24 hours incubation

4.2.2 Determination of Village Water Needs

During the Water Committee meeting conducting in Ifuwa and separate discussions with the leaders of Kidilo, it was conveyed that the primary school currently under construction and the church which doubles as the kindergarten have a high priority. It is also important to the villagers that a sufficiently sustainable water source is provided, as they hope to one day build a dispensary in Kidilo since the closest one is in Ifuwa proper and Kidilo resident can walk over 7 km while sick or pregnant to this location. There is a predicted student attendance of 200 and all will need clean drinking water. Since the church doubles as the classroom for kindergarten, and will continue to be used as a classroom after the primary school is finished; these children also need drinking water. Kidolo and Ikovelo account for 20% of Ifuwa's population, and their main water source is a small underground stream giving rise to the groundwater source seen Figure 14. This source is located down a steep hill (~40 m elevation drop) approximately 600m from the rest of the village and is furthermore not safe of human consumption due to bacterial contamination. The possibility of long-lasting dry seasons in future years could also render this source dry, thus further necessitating a permanent and reliable water solution.

5.0 Village Focus

As presented in Section 4, both Ifuwa proper and Kidilo-Ikovelo are in dire need of a reliable clean water source that can service the entirety of their populations. However, given the relative size of both endeavors, as well as the 7 km distance between the two sets of sub-villages, this investigation will focus on addressing a solution to Kidilo-Ikovelo's water needs. With an output of just 1200 L/hr, the current hand-well located in Kidilo would not be sufficient to serve the populations of Kidilo, Ikovelo, and Ifuwa proper. As such, offering extensive design solutions to Ifuwa proper is beyond the scope of this work, but it is hoped the information gathered regarding Ifuwa proper can be of use to future groups investigating the water situation in Ifuwa. The following design proposal includes a solution to providing a functional hand pump well in Ifuwa proper in section 11.

The well output of 1200 L/hr, is a satisfactory output to service Kidilo and Ikovelo. In addition, the Swedish group who financed the installment of the well has shown substantial interest in providing financial support to implement a water distribution system.

While the villagers believe the water needs in Ifuwa proper are extensive, it was acknowledged during the water committee meeting their concerns were eased knowing there would be a proposal to address the non-functional wells (Section 11) and knowing that a good performance of the water committee in sustaining the smaller water distribution system of Kidilo-Ikovelo could prove a larger water distribution system in Ifuwa could be sustained. By the water committee proving their abilities, other groups would be more willing to design a system and donors would be more willing to fund the installment of these designs.

6.0 Design Criteria

6.1 Needs Expressed by water committee

The needs expressed by the villagers at the water committee meeting and during surveying drove the definition of design requirements for this project. These needs highly impacted the location of distribution points and pipeline locations for the final design.

The primary school currently under construction will become a highlight of the village and attract children of nearby villages. Having adequate clean water available to these students promotes their learning by reducing the rates of sickness that would keep them home from school, keeps them hydrated which increases their cognitive abilities, and eliminates the need for students to bring their own water which could be a source of missing class as some students may have to walk several kilometers every day to go to school. Each of these benefits of a clean water supply for the primary school apply to the church that doubles as a kindergarten classroom. Kindergarten sets the stepping stones into primary school, making it important that students can attend kindergarten.

The primary source of water for the villagers of Kidilo and Ikovelo is an underground stream that briefly surfaces (Figure 15). While centrally located, the source is small and there is no way to ensure that the source will always supply water. Villagers also walk up and down various elevations that make it a strenuous process to get water home. Thus, it is important that distribution points are located at neutral elevations and the water source is knowingly sustainable.

6.2 Tanzania Water Code

The Tanzania Water Code will dictate a significant portion of the design criteria for this project. The major components are as follows:

1. The system should be designed to be sustainable for a 10 year project lifetime.
2. The system should be able to provide 25 liters of water per person per day.
3. The maximum distance a villager must walk to reach a distribution point should be no greater than 400 meters.
4. Each distribution point should service no more than 250 people.
5. Each distribution point should have a minimum output of 20 liters per minute

7.0 Proposed Design

A complete map of the proposed Kidilo-Ikovelo water distribution system design is shown for reference in Figure 17 below.

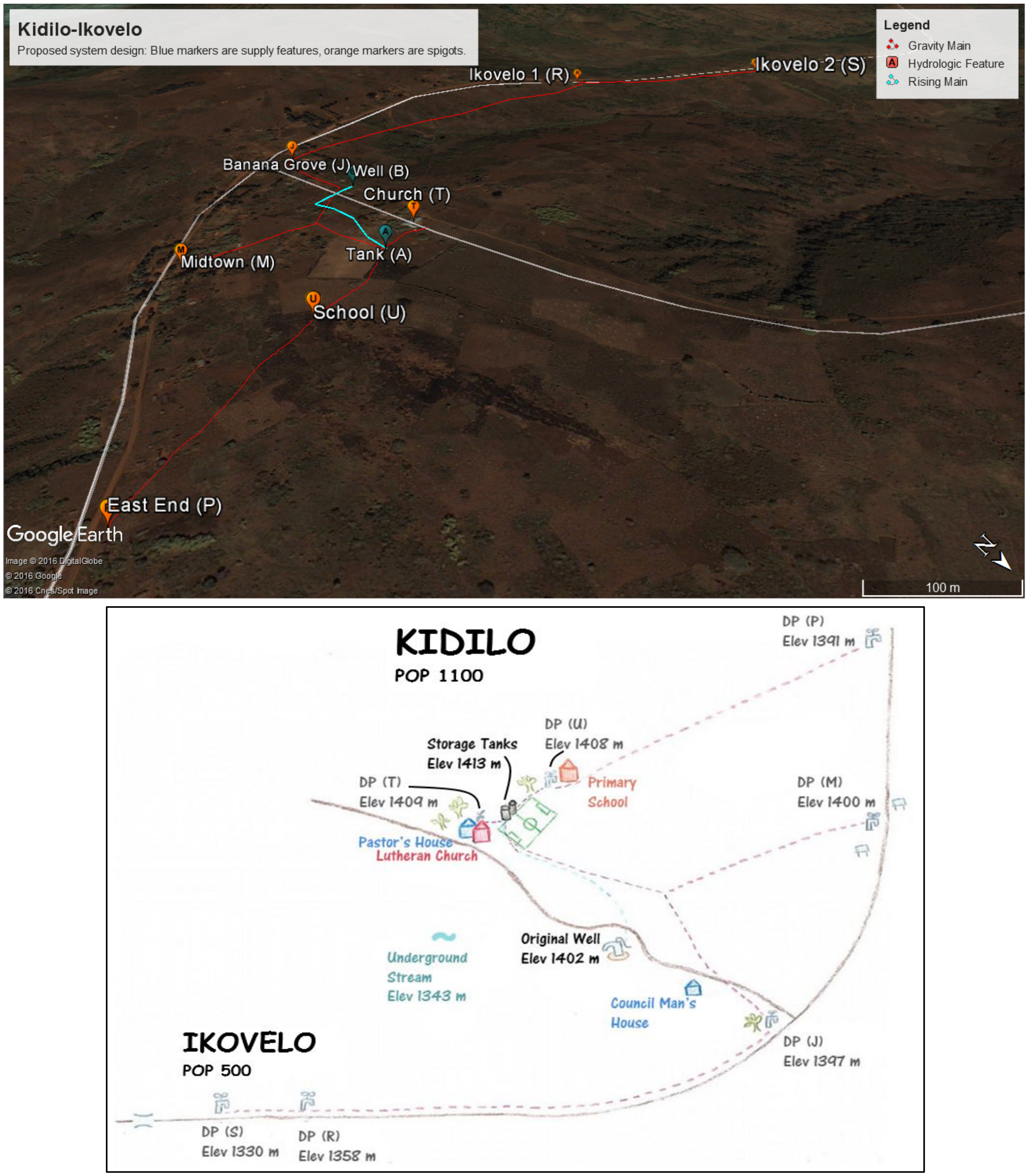


Figure 17: Proposed distribution system for Kidilo-Ikovelo utilizing the pre-existing well. (a, top) Google Earth (b, bottom) hand drawn map

7.1 Rising Main Design and Pump System

The proposed design will utilize the 152 m well discussed in section 4.2.1 located approximately 200 m south of the church (point B in Figure 11). A Grundfos 1.1 kW submersible pump (sized according to the required vertical head and friction loss head) will be placed approximately 140m below the ground level. A previous report suggests that the sustainable output of the well is 1200 L/hr with a dynamic water level 120 m below the ground level. The pump will be solar powered and will operate 21 hours per day via a battery storage system as discussed in Section 6.2. A ~200 m 1" class D high density polyethylene (HDPE) pipe will be buried 1 m deep to the location of the tank, where it will emerge from the ground, the above-ground portion being 1" galvanized steel pipe. Here 21 hours per day of operation as selected as maximize the water output per day from the low output well while not pumping water to the point of tank over flow during periods of low water need (such as at night). Therefore we suggest that the three hours of non-operation occur in the evening after everyone has received their water for the day.

The rising main will route water to two 10,000 L water storage tanks located between the church and school (Elev: 1413 m), denoted as point A in Figure 11. The two tanks will be connected near the top such that water from the pump is deposited in one tank while the second tank then serves as an overflow. The two tanks will reside on a 1 m concrete pad in order to elevate the tanks to overcome head loss in the gravity driven water distribution system. The proposed design will provide 12.6 L of clean water per day to each of Kidilo and Ikovelo's 1600 residents. While this is below the 25 L/person/day guideline suggested for this work, supplying additional water per resident is not possible given the low fluid output of the borehole at 1200 L/hr. If the populations grow the expected rate of 1.5% per year, the expected 1857 residents will have 10.9 L/person/day after ten years of operation.

7.2 Solar Setup

Solar panels located on the roof of the church (point T in Figure 11) will be used to power the submersible pump for the requisite 21 hours/day. The proposed design will consist of 13 1.64 m^2 polycrystalline solar modules (TAW FDS FP-350O-24) capable of supplying 250 W at 37.6 V. The solar panels will be mounted on the slanted roof as to be northward facing at an 8 degree angle relative to the Earth's surface. Energy storage capacity to power the submersible pump in non-peak daylight hours will be provided by 12V deep cycle batteries. A DC-AC pump inverter will be required to power the AC motor to the submersible pump. The TAW JFY DC-AC pump inverter (model SPRING 1100SLA) is suggested for use and is capable of converting the 120 V start voltage to 240 V with a maximum power output of 1.1 kW. All power from the solar panels will be routed through the inverter to charge the batteries which will subsequently run the submersible pump. Assuming a 60% decharge for the deep cycle batteries, 32 12 V at a 100 A*hr rating batteries will be required to store one day worth of energy. Therefore the design will include 24 batteries as the batteries will be continually supplying power to the pump 21 hours/day. The batteries and control panel for the submersible pump will be stored in the church for safety and as a theft deterrent. Given the expenses associated with the equipment, a guard will be hired to tend to the solar panel array as well as the inverter and batteries. The guard will also be responsible for turning the pump on and off at the appropriate times of the day. This serve as in kind contribution from the village, and thus we hope this inspires project ownership within the community, as well as background knowledge into the set-up.

7.3 Gravity Distribution System

7.3.1 Storage Tanks

The identified highest point in Kidilo was point A in Figure 11. In the design, the storage tanks rest at this point. The water storage system will consist of two 10,000 L Poly tanks. Poly tanks are simply, easier to install, clean and offer plenty of redundancy with regards to cleaning, fixing and replacing them. This is under the assumption that the tanks are plumbed properly.

7.3.2 Distribution Points

The tap stand locations and the piping paths to them were designed carefully with input from the community and the Tanzanian design guidelines to fulfil their needs and with respect to utility and performance criteria. The primary criteria considered were as follows: be built to accommodate the various uses of the community members, and be structurally sound and durable. The proposed distribution system provides 7 tap stands. Each supply line location will receive a water meter, a globe valve, and a galvanized steel faucet assembly. Meters are politically essential for village culture to divide the burden of paying for systemic repairs based on water volume only. The use of meters also reduces the likelihood of specific users chronically using more waters than others and draining the system. A designated community member will be responsible for handling an individual spigot and keeping track of usage.

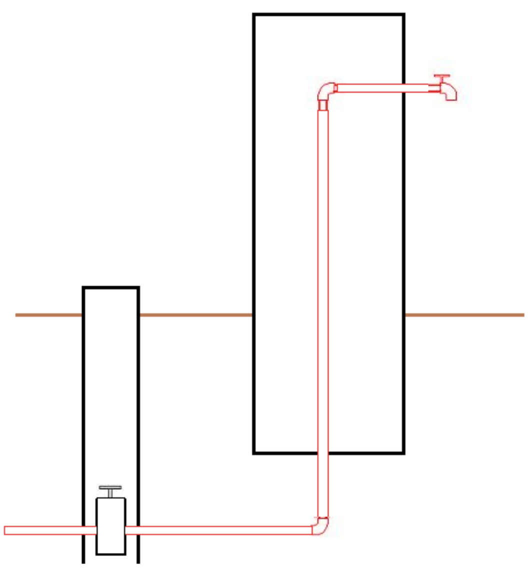


Figure 18: Proposed tap stand along with globe vale.

A globe valve will act as a flow restrictor and will be installed to reduce static pressure prior to the meter valve where needed thus reducing the possibilities of tap valve failure, refer to figure 18. Upon completion of construction and at system startup, the pressure at each of the taps will be measured and the globe valve adjusted to reduce pressures to the manufacture recommended values. Serious consideration was put into whether or not the valve boxes will be locked. We have decided that the water meters will not be locked. Members of the Water Committee will be trained on pressure testing and valve adjustment. Given that only seven tap stands are to be installed, the designs of the tap stands will be fairly advanced. The tap stands involve a wooden framework surrounding the steel piping. The wooden framework will then be concreted to ensure durability. The piping will be approximately 1 m above ground. Tape will be used at all connections and the pipe will be screwed tightly to prevent leakage of water. The spigot piping will be ¾" galvanized steel piping for added protection from wear and UV. Much care was given into considering where exactly to place the tap stands. Village members' opinions and Tanzanian design guidelines were taken into account. The area around the tap stand needs to be convenient for washing, laundering and vessel filling. The height of the taps were decided to be 1 m above the ground to allow for filling of large containers.

7.3.3 Pipeline

The distribution pipeline will originate as a 2" galvanized steel pipe connected to the water storage unit above ground. The pipeline will then be adapted to 50 mm HDPE, 1 m below the ground. These tap stands will be connected to junctions along the proposed pipeline shown in figure 16 above. Depiction of where the pipe will be laid relative to path and how it will run to DP is in section 13.4. The supply line will extend all the way across the community to the houses on the far west side of the village. The community has consented to the distribution path. The path takes advantage of open spaces and walking paths where accessible. The whole line comes to approximately 2101 m in total.

7.3.4 Pipe Selection

Both the materials and diameter of the new pipeline had to be determined in order to meet system specifications while being a cost effective and sustainable solution for the community. Due to the low required flow rate, relative ease of acquisition, and affordability, HDPE pipe was the decided choice of material due to its high availability and high cost efficiency in Tanzania. As opposed to a constant 50 mm diameter pipeline, a range of diameters (25 mm to 50 mm for HDPE) were used in to ensure appropriate flow to all tap stands in the community. As stated earlier, the initial pipeline coming out of the large tank will have a diameter of 50 mm and then narrow toward the ends of lines, more so on the eastward line. High frictional losses required ahead of specific distribution points such as J were required to achieve reasonable flows. For this reason a relatively low diameter piping was used upstream of distribution point J, and even lower at R and S. For this reason, a constant diameter pipeline was not possible.

Refer to Table A1 in appendix 13.5 for the diameter of pipe and pipe rating used for each path. The diameters were altered to achieve appropriate flows of 20 L/min at all distribution points in a worst case scenario wherein the tank is near empty and all taps are open. Furthermore pipe diameters were selected to have velocities within the range of 0.5 and 2.0 m/s (http://aquaforall.org/wp-content/uploads/2014/12/Hydraulic-design-for-gravity-based-water-schemes_publication_2014.pdf). With too low flows, the self-cleaning capacity of the pipes will be lost and sediments can settle permanently. With too high velocities, the flow becomes turbulent and loaded with air particles can be destructive for piping. With regards to the type of HDPE, PN4 HDPE piping was used throughout the entire Kidilo side as pressures no more than 3 bar were experienced. The path extending to the Ikovelo side however utilized PN6 HDPE and PN8 to account for much higher static pressures.

7.3.5 Distribution System Route

The proposed route was chosen by analyzing the topographical survey of the village along with the assistance of the water committee regarding access and land ownership. Refer to section 13.4 for elevation grade diagrams of all paths along the proposed route. The distribution pipes generally cannot run in straight lines, as that would mean crossing large elevation gradients and would lead to a number of problems within the system. To minimize drastic elevation changes in the pipeline, GPS data was analyzed along with Google Earth. Some elevation change is inevitable, but by keeping the pipeline elevation gradient as constant as possible, problems with sediment buildup and high pressure can be avoided. Specific high and low points along each path were identified as shown in the profiles in section 13.4. These points were noted as high/low pressure areas and hence were checked to ensure water flow was uninhibited.

EES was used to perform calculations and analyses on the performance of the proposed distribution system. The diameter and length of the proposed pipe were varied in order to optimize flow and pressure. Relative surface roughness of 0.00001 m was used for the HDPE piping. The inner diameter for each pipe size was determined using an HDPE specification sheet based on the pressure rating of pipe to be used (http://www.performancepipe.com/en-us/Documents/PP165%20ISO%20Metric%20Size%20and%20Dimension.pdf).

7.3.6 Valves and Fixtures

Isolation ball valves will be placed at splits in the pipelines to allow for the shut off of water flow at critical areas along the pipeline, thus preventing the corruption of the whole

Figure 17 Tee Junction

system from a single defect. Following the tee junction in the main line at point G, there will be a ball valve. The community can use this valve to throttle or shut off the flow in particular directions (on both downstream portions off the tee. Additionally, in the event of pump malfunction or shut off, this section of the system can operate by gravity at reduced capacity. At high points along the pipeline, air bleed valves will be placed to bleed off accumulated air, relieving the pressure caused by air in the system. Sediment cleanouts will be placed at local low points along the main pipeline. They will predominantly be used from points to J to S, where local low points exist. Valves will be housed by PVC hand holes as is shown in figure 18.

For assembly of the pipeline, proper fittings, bends and intersections must be used. With a range of HDPE diameters (25 mm to 50 mm), a range of couplings must be used when changing pipe sizes or when simply extending the line with more pipe. Elbow bends, tee and wye intersections will all be points of increased stress.

7.3.7 Elevation Profiles

In order to properly assess points of critical pressure in the gravity mains, elevation profiles were created in Google Earth to visualize possible nodes of interest. In the absence of GPS data for endpoint elevation changes, the Google Earth data was used, correcting for what appears to be a "hitch" 85% of the way through each profile by adding or subtracting the change shown in this apparent glitch in the profile generation. The profiles are shown In section 13.4 (the Appendix), using the letter notation of Figure 16a for naming endpoints of each pathline. Also given in section 13.4 is an example of the aforementioned "hitch" correction for one leg of the distribution system, though the necessary data for each profile is shown.

7.4 Design concerns

Major concerns with the proposed design can be addressed in terms of the rising main and gravity main technical issues, as well as general village issues that could arise with a project of this scale. Here the primary concern in the battery with storage option is the cost and lifetimes of the batteries themselves and the replacement. Additionally, with a solar powered system, with or without storage, there is always the potential for a cloudy weather pattern that would not allow for solar energy to be captured to run the pump, thus resulting in a village water shortage. Additionally, there is some level of uncertainty in the well's performance, as the pump output and water drawdown level could be highly subject to seasonal shifts. Here it is also noteworthy that the rising main pipe was sized to effectively eliminate the majority of frictional head loss given the excessive cost of pumping power owing solar panel and battery expenses.

The major design concerns in the gravity main system regard the large elevation drops over the village, particularly in the distribution points to neighboring Ikovelo. As such, enough frictional head loss is required in the these distribution points such that a flow of at least 20 L/min is achievable at all distribution points when the tap is turned on. Additionally, there is also concern over the large pressures achieved in such a system. Due to the low elevation in Ikovelo relative to Kidilo, high pressure rated pipes must be incorporated into the distribution system such that the pipes will hold when the taps are turned on at these low elevation distribution points. As such, this both increases the cost of the pipes and does increase the potential damage if there were to be a pipe failure in the system.

8.0 Alternative Designs

Two additional design solutions to bring water from the well to the tank for further distribution (the rising main) are also addressed in addition the solar with storage option. The costs associated with these options are discussed in further detail in the project budget section. Final selection of the design will be up to the village water committee after further discussion with the community and available funds for the project. The budget for both alternative options is given section 13.3 with the total estimated costs for the solar without storage option at 16,368.70 USD and the generator totaling 49,704.59 USD over their 10 year lifespans.

8.1 Non-Storage Solar

While the solar power with storage option for pumping water in the Kidilo well offers the largest volume of clean water to each resident on a daily basis, solar storage systems have a number of drawbacks. 12 V batteries in series offer potential hazards, and are expensive and could be stolen from their storage location in the church. Furthermore, the use of batteries requires a DC to AC converter which is both expensive and has the potential to be stolen or damaged. Additionally, the solar with storage option does necessitate additional panels such that the pump can be operated and additionally energy stored for non-peak daylight hours. For these reasons, we also propose an alternative solar powered submersible pump solution to Kidilo and Ikovelo's water shortage that does not necessitate a battery storage system. A storage-free solution would consist of five 250 W solar panels (as described above providing 37.5 V of potential) arranged to provide 120 V directly to a 1.1 kW DC submersible motor. This system lacks battery storage and an inverter, and thus will only pump water during peak daylight hours (approximately 6.5 hours/day). Under these design constraints, the proposed storage-free solar solution will only provide 7,800 L per day. This under capacity operation would allow each of Kidilo's residents approximately 7.5 L of water per day (given the current population), but the capacity would be such that water could not be pumped to Ikovelo. At the ten year point in this project, given the expected growth of 1.5% per year, this system would be able to provide 5.5 L/person daily for the residents of Kidilo. While this is substantially below the recommended 25 L/person daily, the 5.5 L/person does offer clean drinking and cooking water to all the residents of Kidilo and should substantially reduce the prevalence of seasonal illness in the sub village.

8.2 Generator Power Supply

In addition to the solar powered solutions suggested, a diesel generator was also considered to act as a power supply to operate the rising main pump. Here diesel generators can be equipped specifically to operate with specific pump sizes, so here a 1.1 kW generator will be used. The set-up will be effectively identical to the former systems described, but here the solar panels will be replaced with the generator, thus a DC pump will be used, and no battery storage will be used. Additionally, the cost of diesel is assumed to rise roughly 10% annually in Tanzania in calculating the 10 year lifecycle cost with a 20% addition to cover transportation costs. The pump would operate via generator 21 hours per day with the same distribution system as the solar plus storage option. Similar to the precious systems discussed, the generator will be housed in the church for security given its close proximity to the current borehole. One of the advantages here of using a diesel generator is the lower capital material costs, as well as the ability to function in non-ideal conditions, as the solar systems are limited in functionality in overcast conditions.

9.0 Impact of Design

9.1 Social Impact

The stream sources in both Ifuwa and Kidilo are not only sources of drinking water, they are also important points for social life in the villages, similar to the churches. A vibrant scene of women and children talking, laughing, and doing laundry greeted us at the river in Ifuwa.

The completion of a decentralized network of distribution points may change the way in which the villagers interact, creating smaller nuclei of community socialization. On a larger scale, there appeared to be no obvious divisions in religious or cultural association in the area (no Wahehe vs. Maasai tension), so the location of distribution points and the proportion of accessibility in regards to such associations should not be a source of tension. However, as is inevitable with such systems, some villagers will be farther from the distribution points than others, and it is conceivable that some alteration to the design even during construction may be inevitable, owing to disputes over such matters.

As mentioned in section 8.2, charges will be assessed per unit of water from the system. In such a low-income economy, any economic inequality may be exacerbated (or at least become apparent) with such a routine fee being taken for the system's use, where the difference between the resource of clean water and water with potential pathogens is having or not having money.

Managing such a system, both on the paying utility user end and the end of community administration, is an exercise in complex common good ownership, and will better prepare the villages for developing effective collective initiatives in the future.

Having the distribution points will allow residents to decrease the distance to a water source.

9.2 Economic Impact/Operating Cost/Sustainability

The economic impact of such a system in a rural area such as Kidilo must not go unappreciated, though it may be that they can be negligible in such an agrarian, noncommercial area. The operating cost of the system will be paid for by the villagers who utilize the system. The system has a design life of ten years, meaning that in ten years the community must collect money equal to the cost of any (or all) system component(s) during that period. A small economy of charge will be created by the low-cost purchase of each bucket of water used. St. Paul Partners actually helps the village set up an economic system and educates the community on the importance of administration and funding.

Being vigilant about replacement and planned design life will bolster the sustainability of the project, and having the water committee active in administering the system will bolster the sense of community ownership. Given that the water committee we met with was the contingent for Ifuwa proper, there is every possibility that this group, and the rest of Ifuwa, will be watching this project closely. There is interest in using the Kidilo project as a case test for management of an upscaled system in Ifuwa (see 11.0).

10.0 Implementation Budget

The budget for the primary implementation is given below, which covers the capital costs, as well as the 10-year lifecycle cost of the project. Additionally, in kind contributions from the village will also be considered here for construction as well as guarding the solar panel array. Material costs for the project were estimated based on prices in past years with 10% inflation per year and an additional 20% added for transportation costs. Here the only effective operating costs that are included are the battery replacements and guard. All other replacements such as the pump after a give amount of time will be addressed by funds raised by the village water committee.

Table 3: Material Costs

Item	price (TSH)	price (USD)	unit basis	Qty	total price (USD)
1.1 kW Grundfos Submersible Pump	3,052,000.00	1,400.00	per each	1	1400.00
FDS Polycrstalline Solar Panel (250W, TransAfrica Water)	715,000.00	327.98	per each	13	4263.76
Control Panel (TransAfrica Water)	1,998,425.00	916.71	per each	1	916.71
Core Drop Cable (6 mm²x 4)	13,934.80	6.39	per m	140	894.90
Core Surface Cable (6 mm²x 4)	13,249.50	6.08	per m	225	1367.49
Borehold cover plate (7")	176,000.00	80.73	per each	1	80.73
10,000 L PolyTank	2,134,000.00	978.90	per each	2	1957.80
Concrete Materials (for tank pad)	1,100,000.00	504.59	per each	2	1009.17
Batteries (12V, replaced 3 times over 10 year lifetime)	196,200.00	90.00	per each	72	6480.00
AC-DC inverter	654,000.00	300.00	per each	1	300.00
25mm PN4 pipe (436 m)	51,906.78	23.81	per roll (150 m)	3	71.43
32 mm PN4 pipe 65 m)	86,694.92	39.77	per roll (150 m)	1	39.77
40 mm PN4 pipe (249 m)	139,880.51	64.17	per roll (150 m)	2	128.33
50 mm PN4 pipe (258 m)	216,101.69	99.13	per roll (150 m)	2	198.26
32 mm PN6 pipe (663 m)	110,762.71	50.81	per roll (150 m)	5	254.04
1" Class D (PN12) HDPE pipe (229m)	279,840.00	128.37	per roll (150 m)	2	256.73
25 mm PN8 pipe (430 m)	107,966.10	49.53	per roll (150 m)	3	148.58
spigot taps	143,880.00	66.00	per each set	7	462.00
tank fittings	143,880.00	66.00	per each set	2	132.00
fitting, 2” GS to 50 mm PN4	43,600.00	20	per each	1	20.00
fitting, 0.75” GS to 50 mm PN4	43,600.00	20	per each	1	20.00
fitting, 50 mm to 25 mm PN4	13,080.00	6	per each	1	6.00
fitting, 25 mm to 25 mm PN4	4,360.00	2	per each	1	2.00
fitting, 0.75” GS to 25 mm PN4	43,600.00	20	per each	1	20.00
fitting, 2” GS to 32 mm PN4	43,600.00	20	per each	1	20.00
fitting, 0.75” GS to 32 mm PN4	43,600.00	20	per each	1	20.00
fitting, 2” GS to 50 mm PN4	43,600.00	20	per each	1	20.00
fitting, Tee split to 50mm and 25 mm and 40 mm PN4	21,800.00	10	per each	1	10.00
fitting, 0.75” GS to 25 mm PN4	43,600.00	20	per each	1	20.00
fitting, 40 mm to 40 mm PN4	4,360.00	2	per each	1	2.00
fitting, 0.75” GS to 40 mm PN4	43,600.00	20	per each	1	20.00
fitting, 40 mm PN4 to 32 mm PN6	13,080.00	6	per each	1	6.00
fitting, 32 mm to 32 mm PN6	17,440.00	8	per each	1	8.00
fitting, 0.75” GS to 32 mm PN6	43,600.00	20	per each	1	20.00
fitting, 25 mm PN8 to 32 mm PN6	13,080.00	6	per each	1	6.00
fitting, 25 mm to 25 mm PN8	8,720.00	4	per each	1	4.00

fitting, 0.75" GS to 40 mm PN8	43,600.00	20	per each	1	20.00
fitting, Sediment Cleanout	104,640.00	48	per each	1	48.00
fitting, 1" GS	43,600.00	20	per each	2	40.00
Air Bleed valve	65,400.00	30	per each	1	30.00
Globe valve	381,500.00	175	per each	2	350.00
TOTAL (with 20% transport costs)					**25288.45**

Table 4: Labor

Item	Price (TSH)	Price (USD)	Unit basis	Qty	Total price (USD)
Installation for solar panels (TAW)	7000000.00	3211.01	per installation	1	3211.01
Review by Tanzanian Engineer	50000.00	22.94	per hour	16	366.97
Guard (1.5 USD/day every day)	3270.00	1.50	per day	3650	5475.00
Cleaning Solar Panals (8 hrs/twice per year)	1090.00	0.50	per hour	160	80.00
Trench digging/pipe laying	4360.00	2.00	per meter	2330	4660.00
TOTAL (with in kind contributions)					**13792.98**
TOTAL Required (total- in kind)					**3657.98**

Table 5: Summary Costs over 10 years

Materials Cost	25288.45 USD
Net Labor Cost	3657.98 USD
Total estimated Cost (w/10% contingency)	31841.08 USD

11.0 Extension to Ifuwa - Potential Phase II

It was apparent from the meeting with the water committee that the villagers had concerns about the plan to focus design efforts in Kidilo and Ikovelo. As stated in section 4, Ifuwa has a primary school and dispensary which services the 8000 residents of all five subvillages of Ifuwa. After the water committee meeting, surveying was performed in Ifuwa and the current state of their non-functional wells and their current sources of water were further investigated. Based on the knowledge that the well drilled in 2008 produced a supply of water in the wet season, it is assumed that there is a useable aquifer where the wells are located. In addition, because the well drilled 3 years later supplied a very limited amount of water, it is assumed that the pipe that was dropped in the borehole prevented the new piping from being long enough to reach a level below the static water level that would allow the pump to be functional. Thus, it is proposed that the dropped pipe be retrieved and the static water level be measured. If the assumptions about a reliable aquafer are proven correct and it seems appropriate, addition pipe sections will be added to the existing pipe to result in a functional hand pump well. Because the static and dynamic water levels of the well are unknown, the St Paul Partners office in Iringa will be highly involved in this process. St Paul Partners will determine if there is money to be allotted to the operation. If the money is available, they will also oversee the removal of the fallen pipe and evaluation of the functionality of the aquafer. It will be at their discretion whether or not the addition of pipe sections to the current well will make it functional.

As discussed in section 5, it is a possibility that a large water distribution system could be designed and implanted for Ifuwa proper in the future. This is one of many points where St. Paul Partners is critical, as the management of a system as large as that which would be required for Ifuwa necessitates some prior experience with system administration. Through the village learning about managing the Kidilo system, the villagers and the reformed water committee will gain the experience necessary for SPP to make a call as to whether or not the investment in designing and constructing something as large as a system for Ifuwa, Kitolomela, and Mwagidawa is wise. SPP will be there much of the way to this realization, taking the initiative to educate the villagers and water committee about how to properly and ethically construct, maintain, and administer the water distribution system. As we learned from Hanael in the village meeting, this education even includes helping the village learn just why this system is important, not for convenience alone, but for safety.

12.0 Summary/Conclusion

Kidilo has not had a successful water distribution system in operation in the past. Under the supervision of the Ifuwa committee, Kidilo has expressed its willingness to accrue revenue to pay for maintenance costs in the future as sustain the proposed distribution system. With no potable water accessibility, their needs are not met current, it is evident that changes must be made. The proposed designs provide from six to twelve liters of safe drinking water per day to all 1600 villagers in both Kidilo and Ikovelo. Given the pump test data that has already been collected from the well, this proposition holds a high chance for success.

13.0 Appendices

13.1 EES code

Section A: Pump to Tank Code

```
Function ff(Re,ed)
If (Re>2300) Then
{ff:=0.025}

	ff:=1/(1.8*log10((ed/3.7)^1.11+6.9/Re))^2
Else
{ff:=0.025}
	ff:=64/Re
Endif
End

{Constants}
rho = 1000 [kg/m^3]
mu = 0.0011 [Pa*s]
g = 9.8 [m/s^2]
epsilon = 0.00001 [m]

{Reference points are 1: Surface of the water in the well, 2: Pump exhaust, 3: Water in pipe at the water surface,
and 4: Top of the tank.}
z_1 = 1282 [m]
z_2 = 1262 [m]
z_3 = 1282 [m]
z_4 = 1413 [m]

{At points 1 and 4, the system is open to the atmosphere, e.g. a gauge pressure of 0 Pa}
P_1 = 0 [Pa]
P_4 = 0 [Pa]

q_lph=1200
WT = 0.002545[m] {this is wall thickness}

d_o= 0.032[m]

D= d_o-(2*WT)

Q=q_lph/(3600*1000)

L_HDPE =229 [m]

v = Q /( 3.14 * ( d^2 ) / 4)
```

{specs for non-linear eq'n friction factor}

ed=epsilon/D
Re=rho*v*D/mu

f=ff(Re, ed)

{Omitted in these modified Bernouilli equations are irrelevant (zero) terms for each state equation}
0 = W / (rho*g*Q) - v^2 / (2*g) * (1.05 * f * (z_3-z_2) / d) - (z_3-z_1) - (P_3-P_1) / (rho*g)
0 = -v^2 / (2*g) * (1.05 * f * (z_2-z_1) / d) - (z_2-z_1) - (P_2-P_1) / (rho*g)
0 = W / (rho*g*Q) - v^2 / (2*g) * (1.05 * f * (L_HDPE+140) / d) - (z_4-z_2) - (P_4-P_2) / (rho*g) {pump is going to sit 100 m down}

{The actual power required to pump the water assuming a 65% pump efficiency}
W_req = W / 0.65

{The head imparted to the water by the pump}
H_imparted = W / (rho*g*Q)

Section B: Tank to Distribution Points Code

*****Note that for Static Pressures, K values were altered to 150000 from 15*****
*****Note that for min. flow rates (taps open), z_A was altered to 1414 m (near empty tank)*****

```
Function ff(Re,ed)
If (Re>2300) Then
{ff:=0.025}

    ff:=1/(1.8*log10((ed/3.7)^1.11+6.9/Re))^2
Else
{ff:=0.025}
    ff:=64/Re
Endif
End

{Constants}
rho = 1000 [kg/m^3]
mu = 0.0011 [Pa*s]
g = 9.8 [m/s^2]
epsilon = 0.00001 [m]

{Reference points are 1: Surface of the water in the well, 2: Pump exhaust, 3: Water in pipe at the water surface, and 4: Top of the tank.}
z_A = 1416 [m]
z_U = 1408 [m]
z_Ua = 1410 [m]
z_P =1391 [m]
z_Pa = 1393 [m]
z_T=1409 [m]
z_Ta=1411 [m]
```

z_G = 1409.5 [m]
z_M = 1400 [m]
z_Ma = 1402 [m]
z_J =1397 [m]
z_Ja =1399 [m]
z_R =1358 [m]
z_Ra =1360 [m]
z_S =1330 [m]
z_Sa =1332 [m]

{u1 is 85 m from A to U, p1 is 175 m from U to P, t1 is 18 m from A to T, j1 is 160 m from G to J, r1 is 160 from J to R}
z_u1 = 1411.86 [m]
z_p1 = 1398 [m]
z_t1 = 1413.6 [m]
z_g1 = 1413 [m]
z_m1 = 1410 [m]
z_j1 = 1388.7 [m]
z_s1 = 1344 [m]

{At points 1 and 4, the system is open to the atmosphere, e.g. a gauge pressure of 0 Pa}
P_A = 0 [Pa]
P_Ua = 0 [Pa]
P_Pa = 0 [Pa]
P_Ta = 0 [Pa]
P_Ma = 0 [Pa]
P_Ja=0 [Pa]
P_Ra=0 [Pa]
P_Sa=0 [Pa]

{velocity and flow rates for each ref. point}

(v_AU) *(3.14 * ((d_AU)^2) / 4)= Q_AU
(v_UUa) *(3.14 * ((d_UUa)^2) / 4)= Q_UUa
(v_u1) *(3.14 * ((d_u1)^2) / 4)= Q_u1

(v_UP) *(3.14 * ((d_UP)^2) / 4)= Q_UP
(v_PPa) *(3.14 * ((d_PPa)^2) / 4)= Q_PPa
(v_p1) *(3.14 * ((d_p1)^2) / 4)= Q_p1

(v_AT) *(3.14 * ((d_AT)^2) / 4)= Q_AT
(v_TTa) *(3.14 * ((d_TTa)^2) / 4)= Q_TTa
(v_t1) *(3.14 * ((d_t1)^2) / 4)= Q_t1

(v_AG) *(3.14 * ((d_AG)^2) / 4)= Q_AG
(v_g1) *(3.14 * ((d_g1)^2) / 4)= Q_g1

(v_GM) *(3.14 * ((d_GM)^2) / 4)= Q_GM
(v_MMa) *(3.14 * ((d_MMa)^2) / 4)= Q_MMa
(v_m1) *(3.14 * ((d_m1)^2) / 4)= Q_m1

(v_GJ) *(3.14 * ((d_GJ)^2) / 4)= Q_GJ
(v_JJa) *(3.14 * ((d_JJa)^2) / 4)= Q_JJa
(v_j1) *(3.14 * ((d_j1)^2) / 4)= Q_j1

(v_JR) *(3.14 * ((d_JR)^2) / 4)= Q_JR

```
(v_RRa) *( 3.14 * ( (d_RRa)^2 ) / 4)= Q_RRa

(v_RS) *( 3.14 * ( (d_RS)^2 ) / 4)= Q_RS
(v_SSa) *( 3.14 * ( (d_SSa)^2 ) / 4)= Q_SSa
(v_s1) *( 3.14 * ( (d_s1)^2 ) / 4)= Q_s1

Q_AU=Q_UUa+Q_UP
Q_UP=Q_PPa
Q_AT=Q_TTa
Q_AG = Q_GM+Q_GJ
Q_GM = Q_MMa
Q_GJ=Q_JJa+Q_JR
Q_JR=Q_RRa+Q_RS
Q_RS=Q_SSa

Q_AU=Q_u1
Q_UP=Q_p1
Q_AT=Q_t1
Q_AG=Q_g1
Q_GM=Q_m1
Q_GJ=Q_j1
Q_RS=Q_s1

d_HD = 0.04576 [m]
d_25 = 0.02339
d_32 = 0.02994
d_40 = 0.03743
d_50 = 0.04576
d_Cu = 0.0189 [m]

{realistic diameters are 25, 32, 40, 50}

d_AU = d_50
d_UUa = d_Cu
d_UP =  d_25
d_PPa = d_Cu
d_AT = d_32
d_TTa = d_Cu
d_AG = d_HD
d_GM = d_25
d_MMa = d_Cu
d_GJ= d_40
d_JJa = d_Cu
d_JR= d_32
d_RRa = d_Cu
d_RS= d_25
d_SSa = d_Cu

d_u1 = d_AU
d_p1 = d_UP
d_t1 = d_AT
d_g1 = d_AG
d_m1 = d_GM
d_j1 = d_GJ
d_s1 = d_RS
```

{Expressions for the Re dependent f}

```
ed_AU=epsilon/d_AU
ed_UUa=epsilon/d_UUa
ed_UP=epsilon/d_UP
ed_PPa=epsilon/d_PPa
ed_AT=epsilon/d_AT
ed_TTa=epsilon/d_TTa
ed_AG=epsilon/d_AG
ed_GM=epsilon/d_GM
ed_MMa=epsilon/d_MMa
ed_GJ=epsilon/d_GJ
ed_JJa=epsilon/d_JJa
ed_JR=epsilon/d_JR
ed_RRa=epsilon/d_RRa
ed_RS=epsilon/d_RS
ed_SSa=epsilon/d_SSa

ed_u1=epsilon/d_u1
ed_p1=epsilon/d_p1
ed_t1=epsilon/d_t1
ed_g1=epsilon/d_g1
ed_m1=epsilon/d_m1
ed_j1=epsilon/d_j1
ed_s1=epsilon/d_s1

Re_AU=rho*v_AU*d_AU/mu
Re_UUa=rho*v_UUa*d_UUa/mu
Re_UP=rho*v_UP*d_UP/mu
Re_PPa=rho*v_PPa*d_PPa/mu
Re_AT=rho*v_AT*d_AT/mu
Re_TTa=rho*v_TTa*d_TTa/mu
Re_AG=rho*v_AG*d_AG/mu
Re_GM=rho*v_GM*d_GM/mu
Re_MMa=rho*v_MMa*d_MMa/mu
Re_GJ=rho*v_GJ*d_GJ/mu
Re_JJa=rho*v_JJa*d_JJa/mu
Re_JR=rho*v_JR*d_JR/mu
Re_RRa=rho*v_RRa*d_RRa/mu
Re_RS=rho*v_RS*d_RS/mu
Re_SSa=rho*v_SSa*d_SSa/mu

Re_u1=rho*v_u1*d_u1/mu
Re_p1=rho*v_p1*d_p1/mu
Re_t1=rho*v_t1*d_t1/mu
Re_g1=rho*v_g1*d_t1/mu
Re_m1=rho*v_m1*d_m1/mu
Re_j1=rho*v_j1*d_j1/mu
Re_s1=rho*v_s1*d_s1/mu

f_AU = ff(Re_AU, ed_AU)
f_UUa = ff(Re_UUa, ed_UUa)
f_UP = ff(Re_UP, ed_UP)
f_PPa = ff(Re_PPa, ed_PPa)
f_AT = ff(Re_AT, ed_AT)
f_TTa = ff(Re_TTa, ed_TTa)
```

f_AG = **ff**(Re_AG, ed_AG)
f_GM = **ff**(Re_GM, ed_GM)
f_MMa = **ff**(Re_MMa, ed_MMa)
f_GJ = **ff**(Re_GJ, ed_GJ)
f_JJa = **ff**(Re_JJa, ed_JJa)
f_JR = **ff**(Re_JR, ed_JR)
f_RRa = **ff**(Re_RRa, ed_RRa)
f_RS = **ff**(Re_RS, ed_RS)
f_SSa = **ff**(Re_SSa, ed_SSa)

f_u1= **ff**(Re_u1, ed_u1)
f_p1= **ff**(Re_p1, ed_p1)
f_t1= **ff**(Re_t1, ed_t1)
f_g1= **ff**(Re_g1, ed_g1)
f_m1= **ff**(Re_m1, ed_m1)
f_j1= **ff**(Re_j1, ed_j1)
f_s1= **ff**(Re_s1, ed_s1)

L_AU = 147 [m]
L_UP = 271 [m]
L_AT = 64.8 [m]
L_AG = 111 [m]
L_GM = 165 [m]
L_GJ = 249 [m]
L_JR = 663 [m]
L_RS = 430 [m]

L_u1 = 83.3 [m]
L_p1 = 175 [m]
L_t1 = 19.8 [m]
L_g1 = 25 [m]
L_m1 = 20 [m]
L_j1 = 155 [m]
L_s1 = 150 [m]

K_Ua=15
K_Pa=15
K_Ta=15
K_Ma = 15
K_Ja=15
K_Ra=15
K_Sa=15

{Omitted in these modified Bernouilli equations are irrelevant (zero) terms for each state equation}
{A to U with sub point at 94 m intervals}
0 = - (v_AU)^2 / (2*g) * (1.05 * f_AU * (L_AU) / d_AU) - (z_U-z_A) - (P_U-P_A) / (rho*g)
0 = -(v_UUa)^2 / (2*g) * (K_Ua) - (z_Ua-z_U) - (P_Ua-P_U) / (rho*g)
0 = ((v_u1)^2)/(2*g) + (z_u1-z_A)+((P_u1-P_A) / (rho*g))+ ((v_u1)^2 / (2*g) * (1.05 * f_u1 * (L_u1) / d_u1))

0 = - (v_UP)^2 / (2*g) * (1.05 * f_UP * (L_UP) / d_UP) - (z_P-z_U) - (P_P-P_U) / (rho*g)
0 = -(v_PPa)^2 / (2*g) * (K_Pa) - (z_Pa-z_P) - (P_Pa-P_P) / (rho*g)
0 = (z_p1-z_U)+((P_p1-P_U) / (rho*g))+ ((v_p1)^2 / (2*g) * (1.05 * f_p1 * (L_p1) / d_p1))

0 = - (v_AT)^2 / (2*g) * (1.05 * f_AT * (L_AT) / d_AT) - (z_T-z_A) - (P_T-P_A) / (rho*g)

```
0 = -(v_TTa)^2 / ( 2*g ) * (K_Ta) - ( z_Ta-z_T ) - ( P_Ta-P_T ) / ( rho*g )
0 = ((v_t1)^2)/(2*g) + (z_t1-z_A)+(( P_t1-P_A ) / ( rho*g ))+ ((v_t1)^2 / ( 2*g ) * ( 1.05 * f_t1 * ( L_t1 ) / d_t1))

0 =  - (v_AG)^2 / ( 2*g ) * ( 1.05 * f_AG * ( L_AG ) / d_AG) - ( z_G-z_A ) - ( P_G-P_A ) / ( rho*g )
0 = ((v_g1)^2)/(2*g) + (z_g1-z_A)+(( P_g1-P_A ) / ( rho*g ))+ ((v_g1)^2 / ( 2*g ) * ( 1.05 * f_g1 * ( L_g1 ) / d_g1))

0 =  - (v_GM)^2 / ( 2*g ) * ( 1.05 * f_GM * ( L_GM ) / d_GM) - ( z_M-z_G ) - ( P_M-P_G ) / ( rho*g )
0 = -(v_MMa)^2 / ( 2*g ) * (K_Ma) - ( z_Ma-z_M ) - ( P_Ma-P_M ) / ( rho*g )
0 =  (z_m1-z_G)+(( P_m1-P_G ) / ( rho*g ))+ ((v_m1)^2 / ( 2*g ) * ( 1.05 * f_m1 * ( L_m1 ) / d_m1))

0 =  - (v_GJ)^2 / ( 2*g ) * ( 1.05 * f_GJ * ( L_GJ ) / d_GJ) - ( z_J-z_G ) - ( P_J-P_G ) / ( rho*g )
0 = -(v_JJa)^2 / ( 2*g ) * (K_Ja) - ( z_Ja-z_J ) - ( P_Ja-P_J ) / ( rho*g )
0 = (z_j1-z_G)+(( P_j1-P_G ) / ( rho*g ))+ ((v_j1)^2 / ( 2*g ) * ( 1.05 * f_j1 * ( L_j1 ) / d_j1))

0 =  - (v_JR)^2 / ( 2*g ) * ( 1.05 * f_JR * ( L_JR ) / d_JR) - ( z_R-z_J ) - ( P_R-P_J ) / ( rho*g )
0 = -(v_RRa)^2 / ( 2*g ) * (K_Ra) - ( z_Ra-z_R ) - ( P_Ra-P_R ) / ( rho*g )

0 =  - (v_RS)^2 / ( 2*g ) * ( 1.05 * f_RS * ( L_RS ) / d_RS) - ( z_S-z_R ) - ( P_S-P_R ) / ( rho*g )
0 = -(v_SSa)^2 / ( 2*g ) * (K_Sa) - ( z_Sa-z_S ) - ( P_Sa-P_S ) / ( rho*g )
0 = (z_s1-z_R)+(( P_s1-P_R ) / ( rho*g ))+ ((v_s1)^2 / ( 2*g ) * ( 1.05 * f_s1 * ( L_s1 ) / d_s1))

{Key Flowrates}
Q_school = Q_UUa*60*1000
Q_church = Q_TTa*60*1000
Q_DPP = Q_PPa*60*1000
Q_DPM = Q_MMa*60*1000
Q_DPJ = Q_JJa*60*1000
Q_DPR = Q_RRa*60*1000
Q_DPS = Q_SSa*60*1000
```

13.2 Solar Power Calculations

Determining the number of required solar panels

(21 hrs/day pumping)(1.1 kW)=23.1 kW hours required

(7.2 hrs/day sunlight)*(0.25 kW solar panel)=1.8 kW hours per panel

23.1 kW hours/ (1.8 kW hours per panel)=12.8 panels

Determining the number of required number of batteries

100 A*hr capacity at 12 V battery used (car battery)

Battery Capacity=100A*hr*12V=1.2 kW hours

Assuming 60% discharge, number of batteries=23.1 kW/(1.2 kW*0.6)=32 batteries to hold one day of energy, batteries to be replaced after ~2.5 year lifetime

13.3 Budget for Alternative Designs

Table A1: Material Costs for Solar without Storage Option

Item	price (TSH)	price (USD)	unit basis	Qty	total price (USD)
1.1 kW Grundfos Submersible Pump	3,052,000.00	1,400.00	per each	1	1400.00
FDS Polycrstalline Solar Panel (250W, TransAfrica Water)	715,000.00	327.98	per each	5	1639.91
Control Panel (TransAfrica Water)	1,998,425.00	916.71	per each	1	916.71
Core Drop Cable (6 mm²x 4)	13,934.80	6.39	per m	140	894.90
Core Surface Cable (6 mm²x 4)	13,249.50	6.08	per m	225	1367.49
Borehold cover plate (7")	176,000.00	80.73	per each	1	80.73
10,000 L PolyTank	2,134,000.00	978.90	per each	1	978.90
Concrete Materials (for tank pad)	1,100,000.00	504.59	per each	2	1009.17
25mm PN4 pipe (436 m)	51,906.78	23.81	per roll (150 m)	3	71.43
32 mm PN4 pipe 65 m)	86,694.92	39.77	per roll (150 m)	1	39.77
40 mm PN4 pipe (249 m)	139,880.51	64.17	per roll (150 m)	2	128.33
50 mm PN4 pipe (258 m)	216,101.69	99.13	per roll (150 m)	2	198.26
32 mm PN6 pipe (663 m)	110,762.71	50.81	per roll (150 m)	5	254.04
1" Class D (PN12) HDPE pipe (229m)	279,840.00	128.37	per roll (150 m)	2	256.73
25 mm PN8 pipe (430 m)	107,966.10	49.53	per roll (150 m)	3	148.58
spigot taps	143,880.00	66.00	per each set	7	462.00
tank fittings	143,880.00	66.00	per each set	2	132.00
fitting, 2” GS to 50 mm PN4	43,600.00	20	per each	1	20.00
fitting, 0.75” GS to 50 mm PN4	43,600.00	20	per each	1	20.00
fitting, 50 mm to 25 mm PN4	13,080.00	6	per each	1	6.00
fitting, 25 mm to 25 mm PN4	4,360.00	2	per each	1	2.00
fitting, 0.75” GS to 25 mm PN4	43,600.00	20	per each	1	20.00
fitting, 2” GS to 32 mm PN4	43,600.00	20	per each	1	20.00
fitting, 0.75” GS to 32 mm PN4	43,600.00	20	per each	1	20.00
fitting, 2” GS to 50 mm PN4	43,600.00	20	per each	1	20.00
fitting, Tee split to 50mm and 25 mm and 40 mm PN4	21,800.00	10	per each	1	10.00
fitting, 0.75” GS to 25 mm PN4	43,600.00	20	per each	1	20.00
fitting, 40 mm to 40 mm PN4	4,360.00	2	per each	1	2.00
fitting, 0.75” GS to 40 mm PN4	43,600.00	20	per each	1	20.00
fitting, 40 mm PN4 to 32 mm PN6	13,080.00	6	per each	1	6.00
fitting, 32 mm to 32 mm PN6	17,440.00	8	per each	1	8.00
fitting, 0.75” GS to 32 mm PN6	43,600.00	20	per each	1	20.00
fitting, 25 mm PN8 to 32 mm PN6	13,080.00	6	per each	1	6.00
fitting, 25 mm to 25 mm PN8	8,720.00	4	per each	1	4.00
fitting, 0.75” GS to 40 mm PN8	43,600.00	20	per each	1	20.00
fitting, Sediment Cleanout	104,640.00	48	per each	1	48.00
fitting, 1" GS	43,600.00	20	per each	2	40.00
Air Bleed valve	65,400.00	30	per each	1	30.00
Globe valve	381,500.00	175	per each	2	350.00
TOTAL (with 20% transportation costs)					**12829.15**

Table A2: Labor Costs for Solar without Storage Option

Item	price (TSH)	price (USD)	unit basis	Qty	total price (USD)
Installation for solar panels (TAW)	3500000.00	1605.50	per installation	1	1605.50
Review by Tanzanian Engineer	50000.00	22.94	per hour	16	366.97
Guard (1.5 USD/day every day)	3270.00	1.50	per day	3650	5475.00
Cleaning Solar Panals (8 hrs/twice per year)	1090.00	0.50	per hour	160	80.00
Trench digging/pipe laying	4360.00	2.00	per meter	2330	4660.00
TOTAL (with in kind contributions)					**12187.48**
TOTAL Required (total- in kind)					**2052.48**

Table A3: Summary Costs over 10 years for Solar without Storage

Materials Cost	12829.15 USD
Labor Cost	2052.48 USD
Estimated Costs (w/10% contingency)	16369.79 USD

Table A4: Material Costs for Generator Option

Item	price (TSH)	price (USD)	unit basis	Qty	total price (USD)
1.1 kW Grundfos Submersible Pump	3,052,000.00	1,400.00	per each	1	1400.00
1.1 kW generator	3270000	1500	per each	1	1500
diseal gasoline	3126.48	1.43416514	per liter	17706.15	25393.54
Control Panel (TransAfrica Water)	1,998,425.00	916.71	per each	1	916.71
Core Drop Cable (6 mm²x 4)	13,934.80	6.39	per m	140	894.90
Core Surface Cable (6 mm²x 4)	13,249.50	6.08	per m	225	1367.49
Borehold cover plate (7")	176,000.00	80.73	per each	1	80.73
10,000 L PolyTank	2,134,000.00	978.90	per each	1	978.90
Concrete Materials (for tank pad)	1,100,000.00	504.59	per each	2	1009.17
25mm PN4 pipe (436 m)	51,906.78	23.81	per roll (150 m)	3	71.43
32 mm PN4 pipe 65 m)	86,694.92	39.77	per roll (150 m)	1	39.77
40 mm PN4 pipe (249 m)	139,880.51	64.17	per roll (150 m)	2	128.33
50 mm PN4 pipe (258 m)	216,101.69	99.13	per roll (150 m)	2	198.26
32 mm PN6 pipe (663 m)	110,762.71	50.81	per roll (150 m)	5	254.04
1" Class D (PN12) HDPE pipe (229m)	279,840.00	128.37	per roll (150 m)	2	256.73
25 mm PN8 pipe (430 m)	107,966.10	49.53	per roll (150 m)	3	148.58
spigot taps	143,880.00	66.00	per each set	7	462.00
tank fittings	143,880.00	66.00	per each set	2	132.00
fitting, 2” GS to 50 mm PN4	43,600.00	20	per each	1	20.00
fitting, 0.75” GS to 50 mm PN4	43,600.00	20	per each	1	20.00
fitting, 50 mm to 25 mm PN4	13,080.00	6	per each	1	6.00
fitting, 25 mm to 25 mm PN4	4,360.00	2	per each	1	2.00
fitting, 0.75” GS to 25 mm PN4	43,600.00	20	per each	1	20.00
fitting, 2” GS to 32 mm PN4	43,600.00	20	per each	1	20.00
fitting, 0.75” GS to 32 mm PN4	43,600.00	20	per each	1	20.00
fitting, 2” GS to 50 mm PN4	43,600.00	20	per each	1	20.00
fitting, Tee split to 50mm and 25 mm and 40 mm PN4	21,800.00	10	per each	1	10.00
fitting, 0.75” GS to 25 mm PN4	43,600.00	20	per each	1	20.00
fitting, 40 mm to 40 mm PN4	4,360.00	2	per each	1	2.00
fitting, 0.75” GS to 40 mm PN4	43,600.00	20	per each	1	20.00
fitting, 40 mm PN4 to 32 mm PN6	13,080.00	6	per each	1	6.00
fitting, 32 mm to 32 mm PN6	17,440.00	8	per each	1	8.00
fitting, 0.75” GS to 32 mm PN6	43,600.00	20	per each	1	20.00
fitting, 25 mm PN8 to 32 mm PN6	13,080.00	6	per each	1	6.00
fitting, 25 mm to 25 mm PN8	8,720.00	4	per each	1	4.00
fitting, 0.75” GS to 40 mm PN8	43,600.00	20	per each	1	20.00
fitting, Sediment Cleanout	104,640.00	48	per each	1	48.00
fitting, 1" GS	43,600.00	20	per each	2	40.00
Air Bleed valve	65,400.00	30	per each	1	30.00
Globe valve	381,500.00	175	per each	2	350.00
TOTAL (with 20% transportation costs)					**43133.51**

Table A5: Labor Costs for Generator Option

Item	price (TSH)	price (USD)	unit basis	Qty	total price (USD)
Installation for solar panels (TAW)	3500000.00	1605.50	per installation	1	1605.50
Review by Tanzanian Engineer	50000.00	22.94	per hour	16	366.97
Cleaning Solar Panals (8 hrs/twice per year)	1090.00	0.50	per hour	160	80.00
Trench digging/pipe laying	4360.00	2.00	per meter	2330	4660.00
TOTAL (with in kind contributions)					**6712.48**
TOTAL Required (total-in kind)					**2052.48**

Table A6: Summary Costs over 10 years for Generator Option

Materials Cost	43133.51 USD
Labor Cost	2052.48 USD
Estimated Cost (w/10% contingency)	49704.59 USD

13.4 Elevation Profiles

On the pages that follow are the elevation profiles mentioned in section 7.3.7 along with the “correction algorithm” used to determine elevation differences in cases where this was necessary. Points circled in blue are additional points written into the EES code 13.2 as locations where pressure was checked for minimum and maximum values (for pipe sizing). The notation in the captions of each individual profile follows the location notation developed in Figure 16. That is, point A is the tank, J is the banana grove, etc. Immediately below is a composition of each individual path of the gravity main, for some additional context.

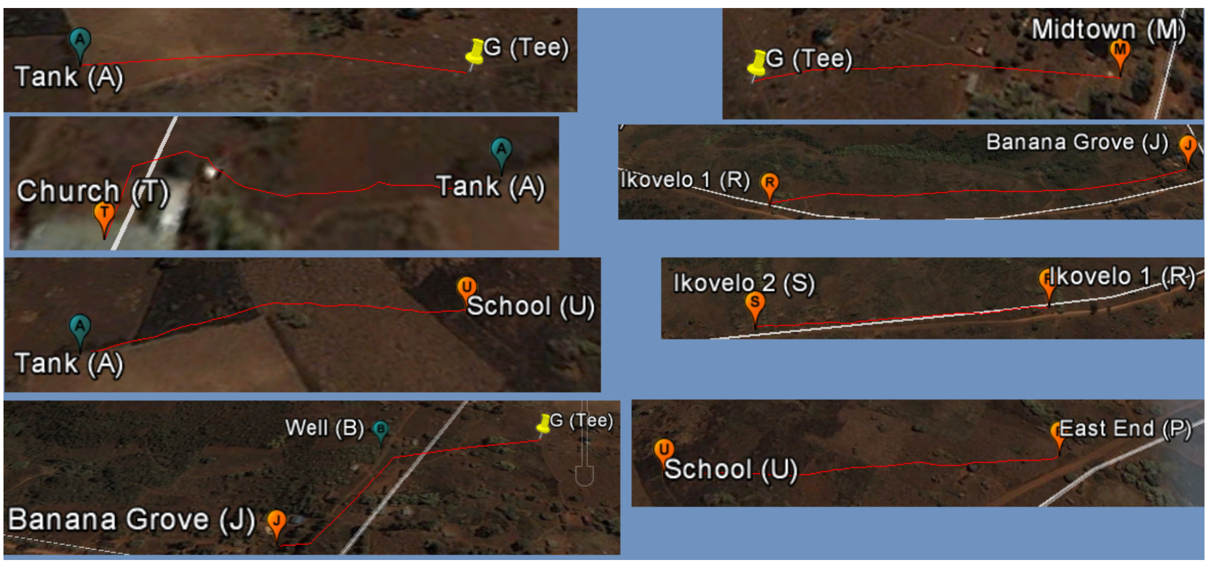
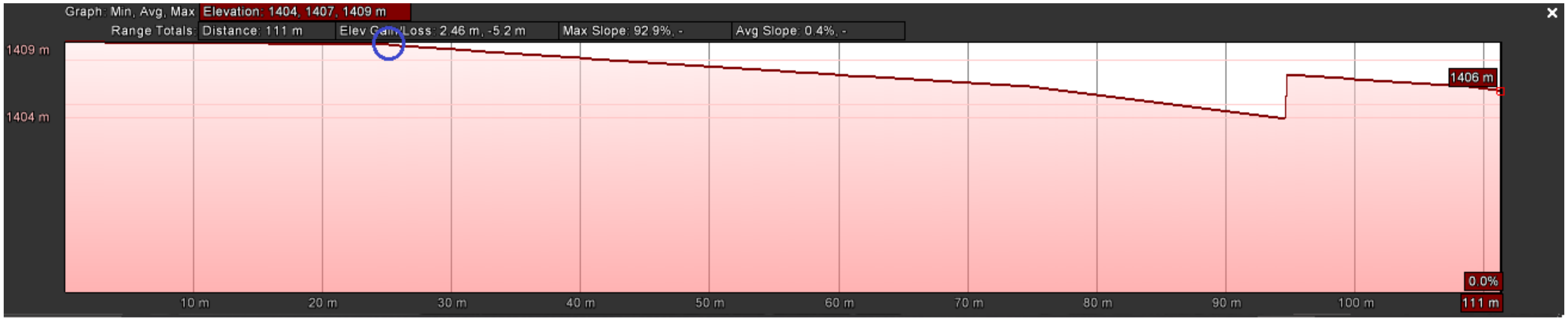
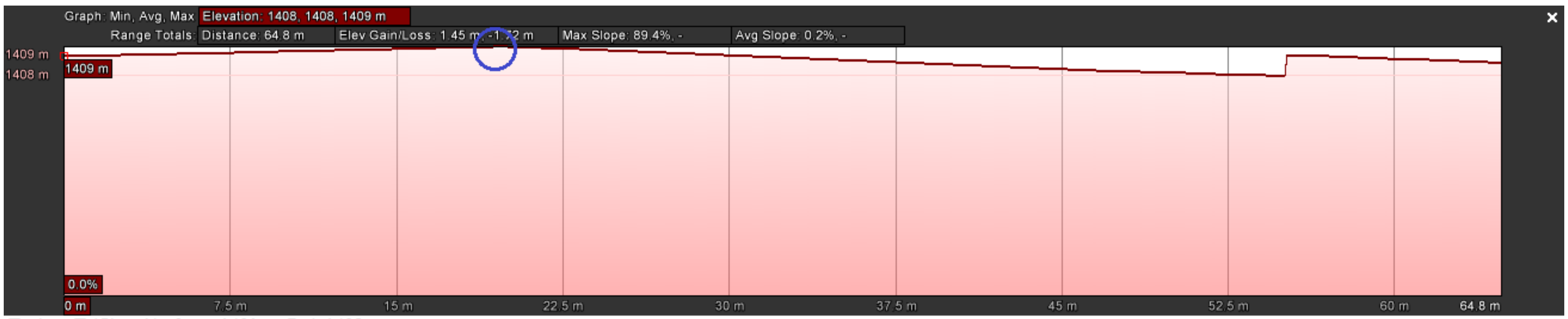


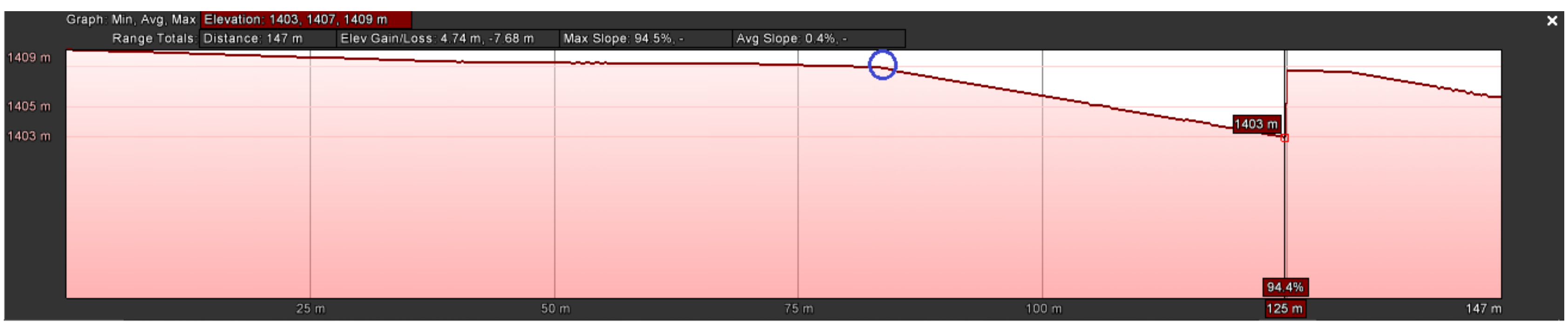
Figure A1: Individual Pathway Composite



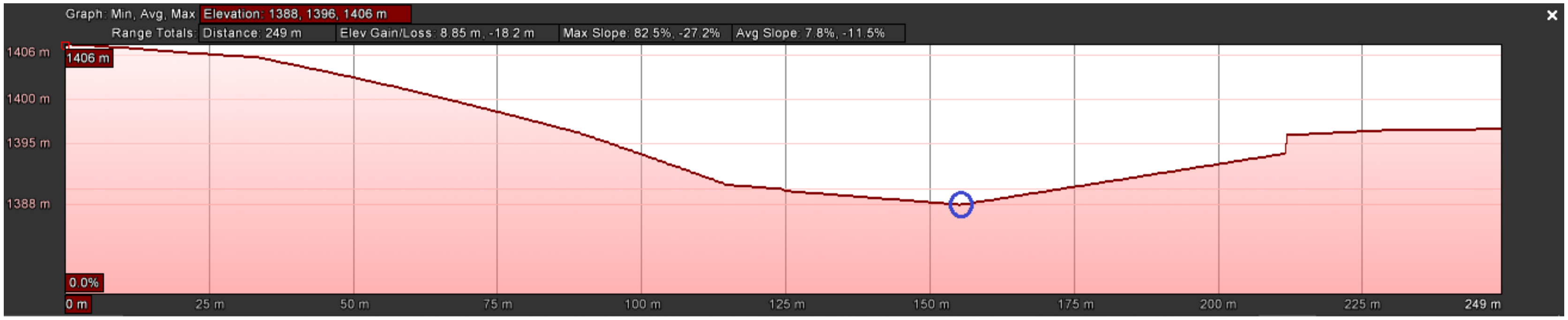
A (tank) to G (tee) Start: 1409 m End: 1406 m
Δh (hitch): +3 m



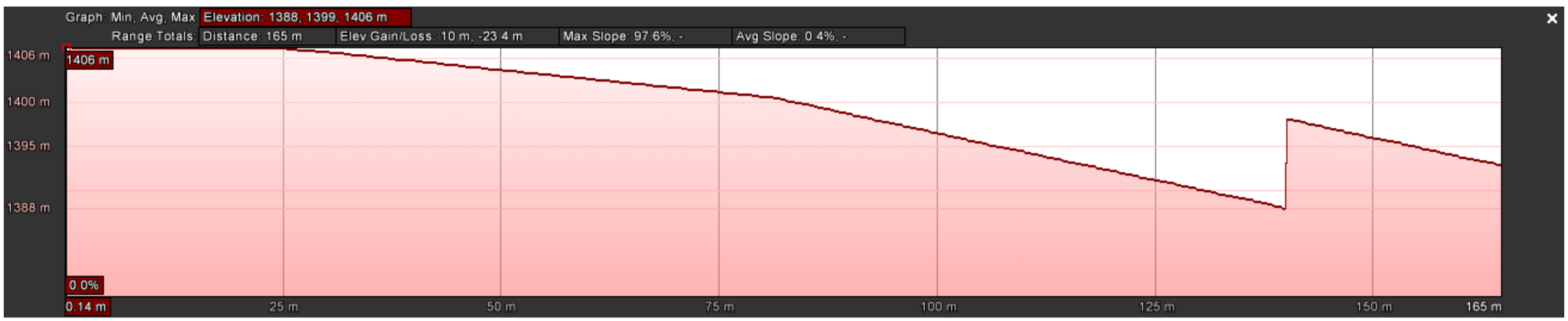
Tank to T (Church) Start: 1409 m End: 1408 m
Δh (hitch): +1 m



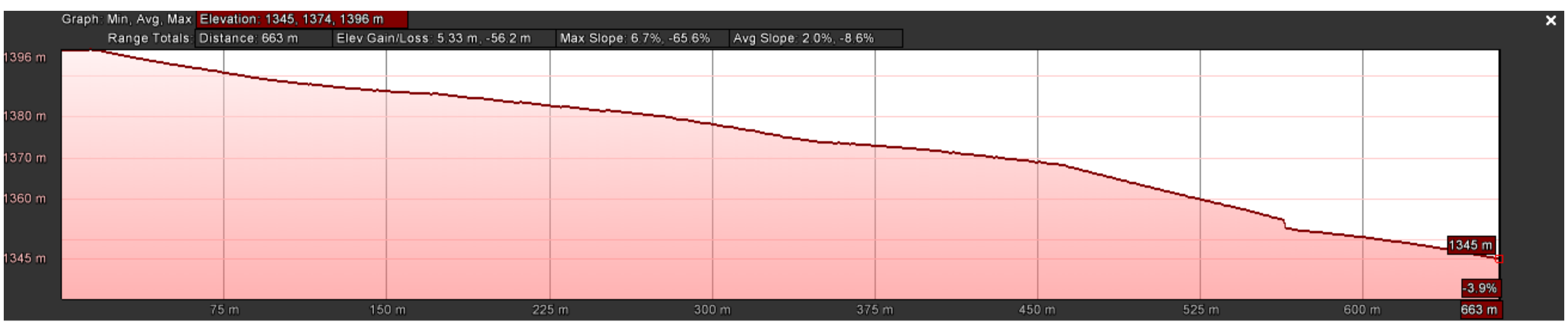
A to U (school) Start: 1409 m End: 1406 m
Δh hitch: +4 m



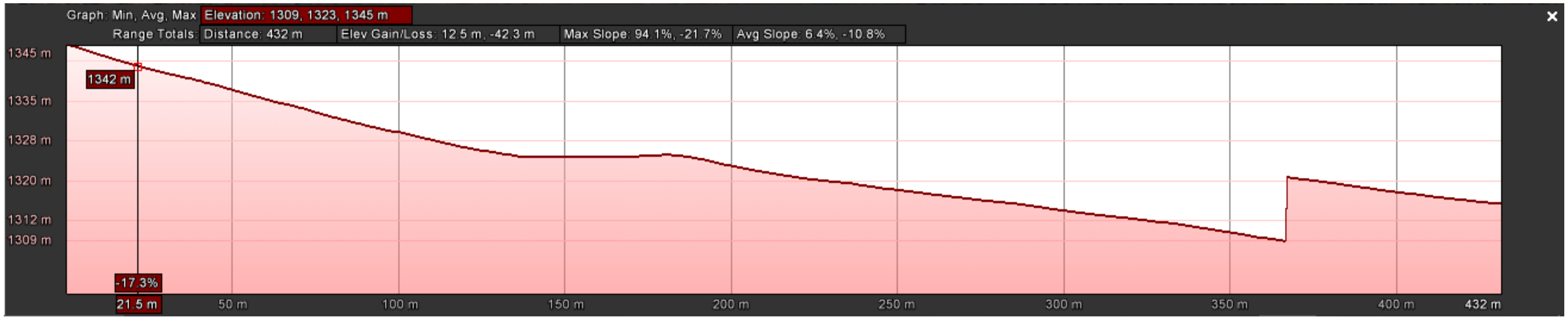
G (tee) to J (banana grove) Start: 1406 m End: 1379 m
Δh (hitch): +2 m



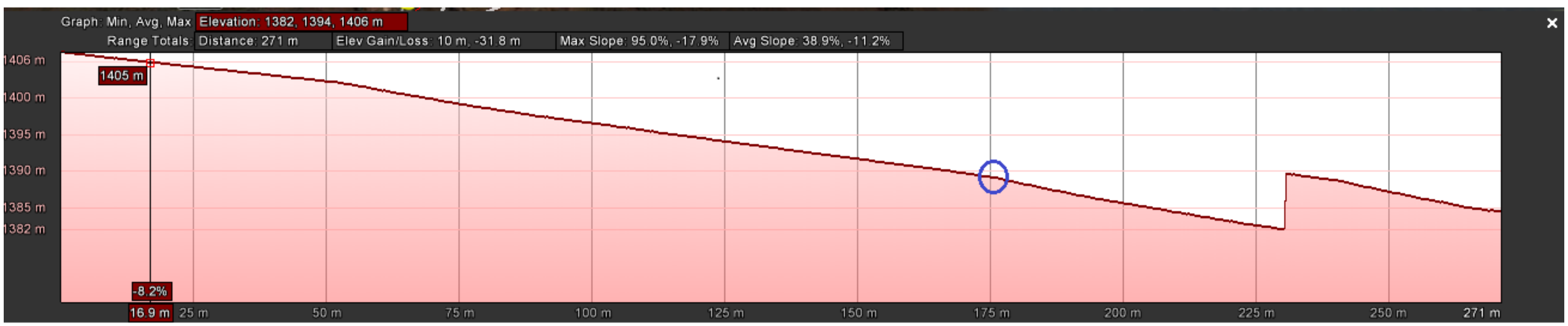
G (tee) to M (middle) Start: 1406 m End: 1393 m
Δh (hitch): +10 m



J (banana grove) to R Start: 1396 m End: 1345 m
Δh (hitch): - 2m



R to S Start: 1345 m End: 1316 m
Δh (hitch): +12 m



U (School) to P (end) Start: 1406 m End: 1385 m
Δh (hitch): +8 m

In the individual captions, “Start” and “End” are the elevations at the beginning and end of the path, whereas Δh (hitch) is the adjustment necessary to correct for Google Earth’s misreading of the profile. For example, a factor of +8 means that all elevation values after the hitch (including “End” elevation) must be increased by 8 meters from their Google Earth reading. That is, in the profile above, the “End” elevation is 1393 m rather than 1385 m. This is used in the equation $\Delta z = (z_{end} + \Delta h) - z_{start}$ where Δz is the change in absolute elevation in meters between the start and end of the path and z_{start} and z_{end} are the elevations at the endpoints.