Designing a Gravity-fed Water Distribution System for Lukani, Tanzania

Design for Life: Water in Tanzania, 2018

Andrew Lindquist
Patrick Olson
Sam Sheibley
Trent Woodcock

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

From left to right: Samuel Sheibly, Andrew Lindquist, Clement M. Kanumi (Interpreter), Kululetela (Kulu) Lukandiga (Iringa Student), Trenton Woodcock, Patrick Olson.

Executive Summary

The goal of this project was to design a system capable of distributing water to a majority of the population in the village of Lukani in Tanzania. Lukani has a population of 2,954 people distributed between seven different sub-villages. The existing system in Lukani is a solar powered pump that directly supplies the dispensary and a public tap nearby. There are two storage tanks, one sized at 10,000L and the other 2,000L. The 1315 liters/hour output of this system is approximately large enough to fill the larger tank over the course of the day using solar energy. There are other surface sources where citizens currently draw water as well as broken hand pumps in Mjemwema, Ipogoro, and another currently under maintenance near the peak of Kilimahewa. Based on field water tests, many of the surface water sources around the village are not safe and the water must be boiled to be used as safe drinking water. Many of the hand pumps don't produce water during the dry season because of the decreasing water table. The dispensary is the only clean water source year round and it does not produce nearly enough water to supply the entire village.

The focus for this project is to supply water to the main ridge of the village which presently has 1,400 residents out of the 2,954 total population as well as the primary school and main Lutheran church. Phase one of the project involves drilling a borehole in a large valley that is constantly saturated with groundwater and supports a year-round surface source for the villagers. After initial ground surveying, it can be assumed that an air-hammer bored well will produce an output similar to that of the existing borehole near the dispensary. The recent installment of grid power to the village of Lukani will allow the system to run for 24 hours a day. From the borehole, water will be pumped 0.7 km to the top of Kilimahewa filling two 10,000 L tanks. A gravity main will run down the gradual slope of the ridge for approximately 1.5 km supplying 1,400 villagers, the Lutheran church, and a primary school with potable water. Seven public distribution points will be spread out along this region along with one private tap for the primary school. There is an option for a second phase of the project that would extend the gravity main to supply the secondary school. This would require purchasing a 5,000 L tank that would act to break the pressure, and an additional km of piping.

The village of Lukani was more than grateful for the opportunity to potentially have further access to potable water. The water committee and village leaders were well prepared with agreement on locations of water priorities and a plan of how to help fund the project. Currently, the villagers will collect 2,000 TSH from each household a month for safe water. This will eventually help fund any repairs and extra costs required by the system. The villagers did not hesitate to acknowledge the hard work that would be put into digging trenches for pipes and building platforms for the borehole and holding tanks. The village of Lukani is ready to better the lives of their community and are ready to help in any way possible.

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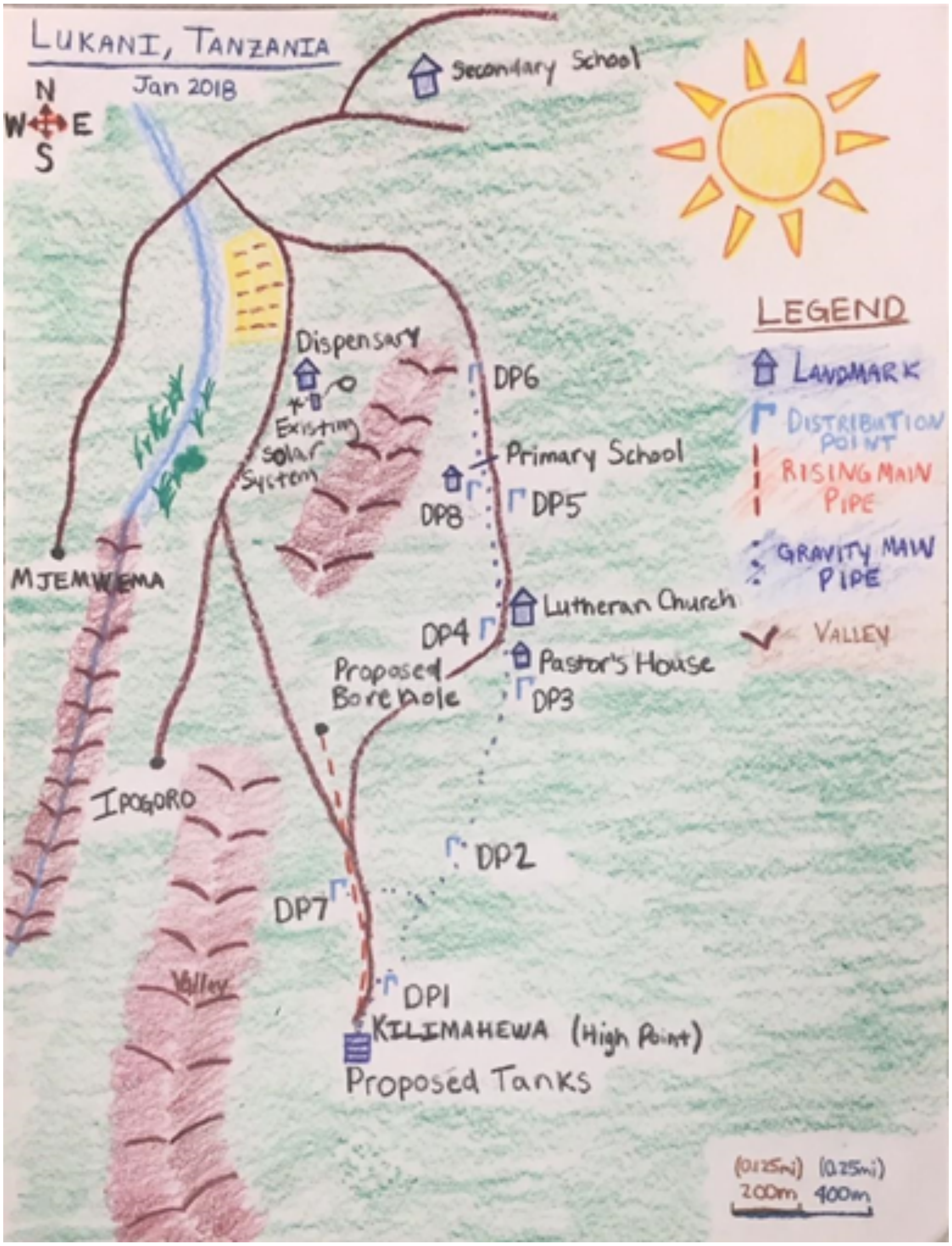

Figure 1.0 Hand-drawn map of Lukani, Tanzania

1.0 Background

1.1 Lukani, Tanzania

Fifty kilometers southeast of Iringa lies the village of Lukani. Visiting during the rainy season, we were unusually fortunate to have an easy safari (journey) to the village as the roads were in good shape. The drive into the village brought us along a ridgeline that gave us a good idea for the layout of the village. We were greeted at the city hall by members of the village government, water committee and other leaders from various sub villages. We immediately had a brief meeting to introduce everyone and get information on populations, current water source locations, a map of the village, and the villages priorities. We were pleasantly surprised by the preparation the village had already done regarding where they would like water to be distributed. After the meeting we drove to Kilimahewa, the highest point in the village where water would ideally be pumped for storage. Our tour was cut short by a storm that led to us racing back down the hill to the pastors house. Upon arrival we were welcomed with tea and had our first meal in the village. The rest of the first night we took time to talk about our initial thoughts and ideas for potential water delivery systems.

Figure 1.1 A view of the valley in Lukani surrounded by populations of people along ridge lines.

After a wonderful breakfast in the morning we took a hike to Kilimahewa to begin taking elevations and laying out the purposed gravity main. The villagers were certain of the area they would like to have the water fed and it was just a matter of properly locating the proposed distributions points to ensure all the villagers were within suitable range. The weather changed a couple times throughout the course of the day, so we were sure to take multiple measurements to eliminate any inconsistencies from pressure changes. We took the opportunity to visit each of the documented hand pumps around Lukani, observing the many broken and dried up wells. After lunch we decided to go test the surface water where we observed many people filling up buckets and washing their clothes. We conducted a field water test[1] by taking a sample of the surface source and adding extra proteins to promote accelerated bacteria growth. We would soon find out, as seen in figure 1.2, after a long 24 hours of human incubation that the water was full of bacteria. On our walk back to the pastor's house we joined a game of soccer. Figure 1.3 shows the large crowd of children that had a great time laughing at us as we tried to compete.

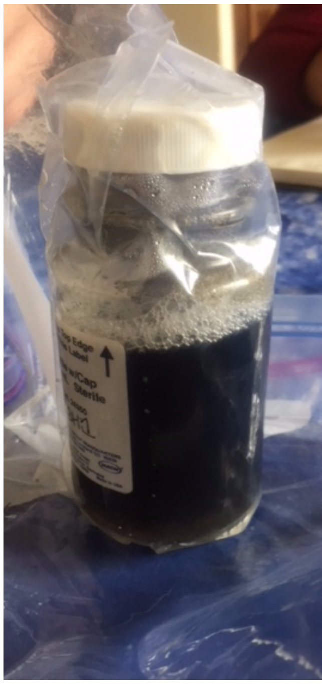


Figure 1.2 & 1.3 The water test proved to be full of bacteria as the bottle turned from amber to an almost black color in 24 hours. On the right, Patrick, Sam, and Peter with all the village kids.

We were grateful to have the opportunity to attend a church service on our last morning in the village. Men, women, and children all joined in to make a wonderful experience.


Figure 1.4 & 1.5 show the large church that has recently been built and still being finished. Singing and dancing to traditional HeHe rhythms, the church service was a blast. The church alone was an amazing sight to see. It was such a large building that required an extensive amount of engineering. Shaped like a cross, the architecture added to the amazing building

Lukani provided for its people. After the singing, praying, and dancing was through, an auction full of eggs, beans, rice, vegetables, chickens and a goat followed the service. A few members of the group ended up walking away with some livestock.

Figure 1.6 & 1.7 On the left, Clement, the group translator, and student, Trent, won chickens at the auction. Pictured on the right, Dr. Ken Smith holding the goat he was almost out bid for during the church auction.

The women's group of Lukani were quite gracious to accept our donations. After the auction we presented the gifts we brought including cooking utensils for the Mamas, shirts for the pastor and other village leaders, and candy and stickers for the children - and some elders who haven't outgrown their sweet tooth. It was a good reminder that not a whole lot changes even halfway around the world. We said our goodbyes, expressed our gratitude for letting us stay in their village and headed back to Iringa to meet back up with the other groups.

2.0 Current System

Current systems are defined here as any pre-existing and utilized water sources in the village. These include the dispensary borehole, 4 - 6 private hand dug wells, a surface source to the east, and a surface source to the west. There are hand pump well sites that have fallen into disrepair which have potential to contribute to the current system if repaired and developed.

Figure 2.1. Overview map of sources. Current sources are shown in relation to population centers, Kilimehewa, and public buidlings.

2.1 Dispensary Borehole

The first St. Paul Partners water project in Lukani was completed in 2015 to provide potable water to the dispensary and some water for residents to use. The project scope included a new borehole, storage tanks, a single line to dispensary taps, a single public distribution point, and a solar system to run the borehole pump. Figure 2.2 provides an image of the current system.

Figure 2.2 Dispensary System. The 2,000 and 10,000 L tanks are seen at right. The solar panel on the roof of the dispensary could be replaced by nearby power lines.

The borehole was air-hammer drilled to 100 m to find a water table at a depth of 50 m. The well produces 1,300 L/h at full capacity, and the current solar system allows for seven hours of pumping to provide 9,200 L/day. The well has not run dry in its current operation. Two storage tanks totalling 12,000 L provide water reserves for the dispensary and the villagers. The 2,000 L tank reserves water solely for the dispensary while the public as well as the dispensary can access water from the 10,000 L tank through a public tap. The solar system was built before electricity was brought to the dispensary, however power lines have since been built. There is potential to switch the borehole pump to grid power and increase the hours of operation, however the capacity of 1,300 L/h would remain the same.

2.2 Private Wells

Private wells provided daily water to 10 - 15 households according to owners, and were located next to private homes. Wells were all hand-dug, reached depths up to 40 feet, and fed water to storage tanks nearby. Though each well has not been tested for pathogens, it is likely the water is unsafe based on previous SPP testing. A typical well is depicted in Figure 2.3.

Figure 2.3. Private Hand-dug Well. This was a deeper well of the four to six private wells providing water to some surrounding households.

2.3 Surface Sources

A surface source to the east of Kilimahewa and the major population center was located next to a crop field in a small depression collecting runoff. Water appeared clouded and there was some concern for animal and human fecal matter contamination. Approximately 50 households could access this water as a daily source, depicted in Figure 2.4 and 2.5. The source appears as “East Surface Source” in Figure 2.1

Figure 2.4. East Surface Source. This surface source collected runoff near agricultural land.

Figure 2.5. Local villagers may walk more than half a kilometer to the east source.

The surface water to the west of Kilimahewa and the population center is in a designated water reserve away from agricultural fields and homes. The water sits in a saturated flat marshy area in a valley descending towards the dispensary. Approximately 70 households have convenient access. The west source is depicted in Figure 2.6 and is “West Surface Source” in FIgure 2.1. This water tested positive for coliform bacteria and E. Coli.

Figure 2.6. West Surface Source. The west source in the crease between two hills is saturated with water year round and allows tall grasses and trees to thrive in this protected water area.

2.4 Hand Pump Wells

Near the east surface source, a defunct hand pump from a mud-rotary borehole has been left unused for two years. Before falling to disrepair, the well produced water year-round without running dry.

Figure 2.7. East Hand Pump Well (Broken) The borehole has been covered and abandoned until the village decides to repair.

There is an additional hand pump well in the Ipogoro sub-village which also requires repair, depicted in Figure 2.8.

Figure 2.8. Hand Pump Well (Broken), Ipogoro

3.0 Village Needs

Upon our arrival in Lukani, we were immediately greeted by members of the village government and the water committee. After a short introduction, the water committee gave us their first water report in which they told us about their current water situation. They informed us that the system previously installed at the dispensary was working well and was able to be used by a majority of the village, but that there was still water shortages. There were several other current water sources that are being used but upon further inspection and after a water quality test was conducted, it was found that all the current water sources being used outside of the dispensary were unclean and not safe for consumption. They informed us that half of the population lives between Kilimahewa and the Primary School, and that the new system should focus on producing water for those 1,400 people. After the meeting was concluded, we traveled to the top of Kilimahewa in order to get a better understanding of what the committee wanted. It was here we learned that not all of the sub villages, such as Ipogoro, would be able to have easy access to either of the water systems. Each of those sub-villages, however, have hand pump wells that are both currently disabled (See Section 2.4). Therefore the water committee has promised the residents of these sub-villages that the money raised from the current and possible new water system would be used to help fix those hand pump wells.

4.0 Tanzanian Water Code

The Tanzanian water code was used to help develop this project. The full list of requirements can be found in Appendix B. The system was designed for a design period of 10 years, which leads to an increased population of 1.5% per year, and with everybody receiving 25 liters per day, and students receiving an additional 10 L/day during attendance.

Figure 4.1. Walking the Gravity Main.

5 Proposed System: Overview

The potential supply system covers the highly populated central-Lukani area described in the Needs section. The source is a new borehole air-hammer drilled near the West Surface Source and within the protected water area. The proposed well is 240m from power lines for electricity.

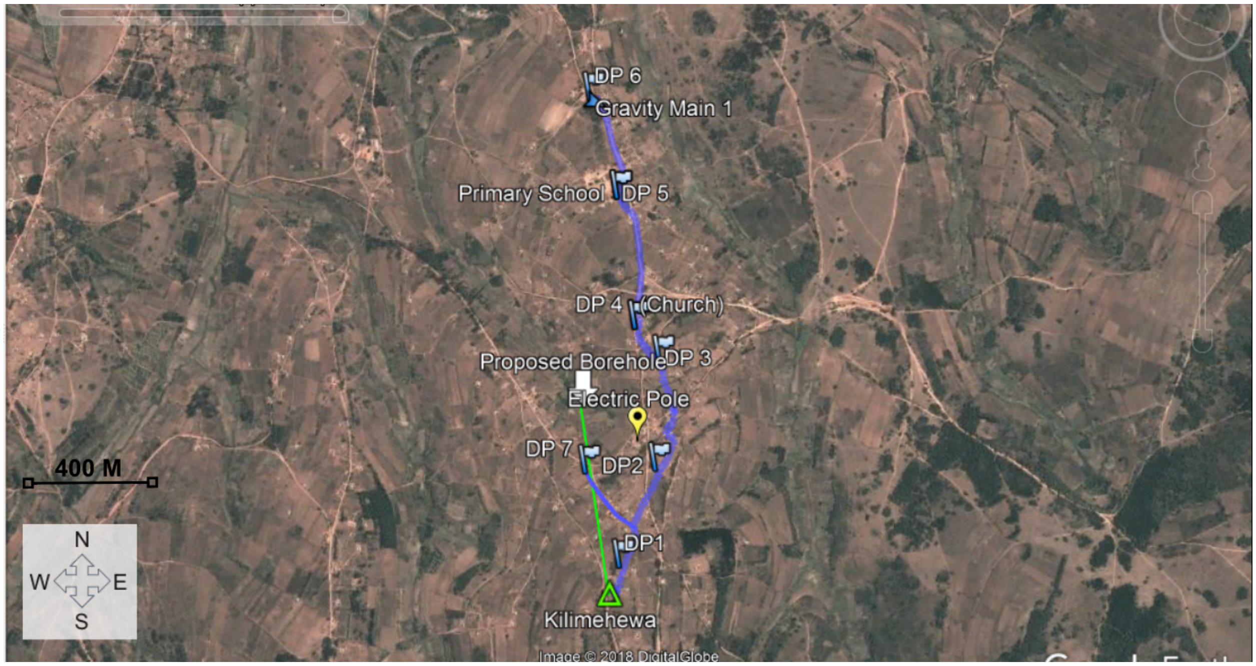

Figure 5.1. Proposed System Overview. The rising main is represented in green, the gravity main in blue, and the power source in yellow. "DP" indicates distribution points, of which there are seven plus one private tap at the Primary School.

Figure 5.1 provides a map of the proposed system. The rising main brings water to the crest of Kilimahewa where it will be stored in two tanks. From these tanks, a gravity main will snake down the mountain near roads through mostly crop fields. The main will be designed to reach seven distribution points which are approximately 400 m apart and are recommended locations by the water committee. These include important nodes such as the church and the primary school. An eighth distribution point (labeled DP7) was added by our group to allow for future population growth. The system gives freshwater access within 400m to all 1,400 people in the central area with a daily consumption of 18-25 liters per person per day and 10 liters per student per day.

5.1 Rising Main Design

As mentioned before, the current system in place utilizes the borehole drilled in 2015 and is pumped via the solar system which supplies the dispensary as well as a public tap immediately adjacent to the dispensary. The new borehole location will be 616m away from the desired tank location, Kilimahewa, and only 240m away from the current power line. The elevation change from the borehole location to Kilimahewa is 73m along with an assumed 50m water level within the borehole, giving a total of 123m for the pump to raise the water. Given the output of the dispensary borehole, it is reasonable to suggest that the output of the new location will produce a similar flow rate, around 1300 L/hr. We will plan running the pump 22 hours of the day to preserve the integrity of the system and allow for some down time in the system, and also to provide a low estimate for the total water we will be able to pump per day.

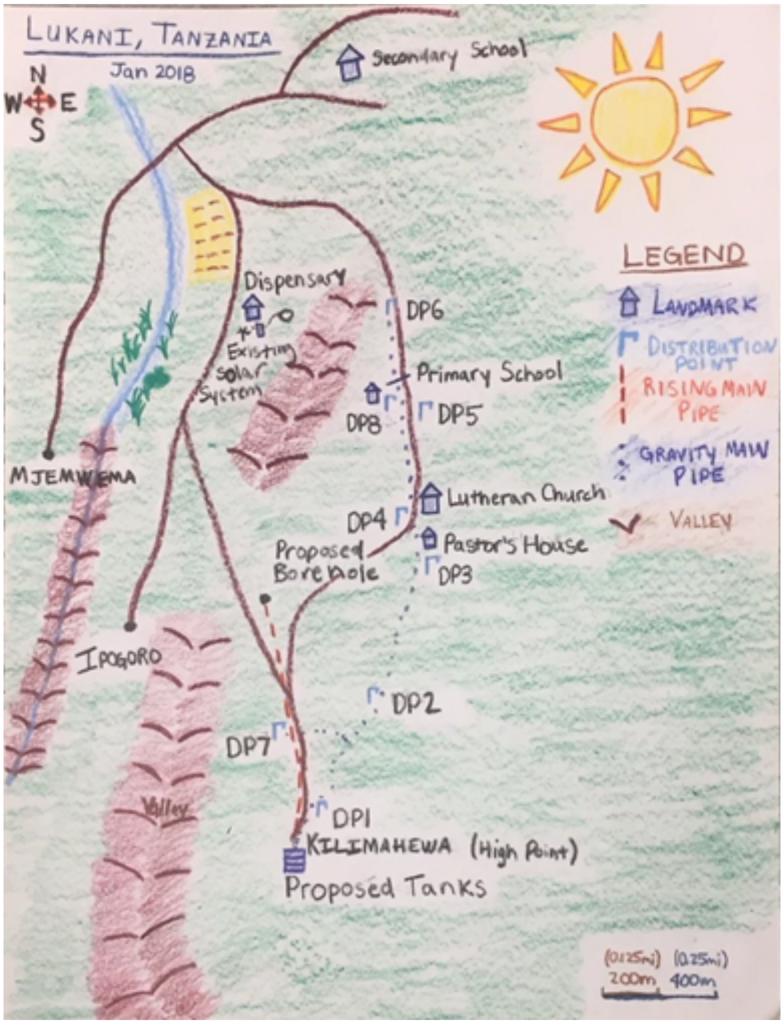

Figure 5.2. Hand Drawn Map. The overview of the design is included in the sketch of the village.

The rising main will pump water to two 10,000 L water storage tanks located at the top of the hill, Kilimahewa (elev: 1989m), denoted as point K in figure 5.2. The tanks will be connected near the top to allow for one tank to be the main supply and the other to serve as an overflow. The two tanks will reside on a 1 m concrete pad in order to elevate the tanks off the ground and create more overall head in the system to push the water simpler via gravity. The proposed design will provide 20 L/day/person to the 1400 residents of Lukani. Given the expected rate of 1.5% growth per year, in 10 years the system will supply 17.6 L/day/person to the same territory of Lukani. While this is below the 25 L/day/person guideline suggested for this work, we were more focused on getting water to as many people as possible. Also, during the meetings we had with the water committee of Lukani we were told the citizens plan to use to new water system only for domestic use (cooking, drinking, washing), not for tasks such as washing clothes or if they plan to boil the water they use. This number is also subject to change based on the water flow rates that will be measured when the borehole is drilled and developed.

5.2 Gravity Distribution System

5.2.1 Storage Tanks

The highest point in Lukani was identified to us as Kilimahewa is located at the very south of the village of Lukani. Kilimahewa is identified in Figure 5.2 at the far right of the map. The water storage system will consist of two 10,000 L Poly tanks as previously mentioned. Poly tanks are simple, easier to install, clean and they offer plenty of similarity with regard to maintenance and replacement tanks. We also are leaving room at the 6th distribution point, identified as DP6 in Figure 5.2, to build two storage tanks which will hold water to possibly be delivered to the secondary school in the future. This allows us to store water for solely the secondary school and it serves to break the pressure in the gravity main and save cost on the long pipe connecting the 6th distribution point and the Secondary School. All of this is for future consideration and likely will not be executed in this stage of the distribution system.

5.2.2 Distribution Points

The distribution points were carefully chosen by our team with the input of the water committee of Lukani who indicated high priority areas where they would like a tap placed. We were able to mark the locations they chose and then design the system to route the gravity main to those points to save pipe and create less labor for the Lukani citizens who will one day dig the paths for the pipe to be laid. Our main priorities in choosing distribution points were making sure there was a tap every 400m as we walked down the hill and also to provide a tap for the Church and a private tap for the primary school which was approximately 1 km down the hill from Kilimahewa. Each supply line location will receive two standard solid bronze valves and a concrete pad to allow the water to flow away from the user and keep the surrounding area free of mud. We will not need to install meters on each of the taps given the current payment system in place in Lukani which requires a flat rate for each adult citizen to pay 1,000 TZS (about $.50) per month to contribute to the water system fund that is controlled by 3 different members of the water committee. If Lukani changes their system for collecting money from the citizens and they are unable to accurately monitor the amount of water being used by their citizens, we will absolutely consider and likely implement water meters into our design.

A globe valve will act as a flow restrictor and will be installed to reduce static pressure prior to the tap which will reduce the possibility of tap failure. The height of the taps will be 1 m above ground to allow for filling of large containers.

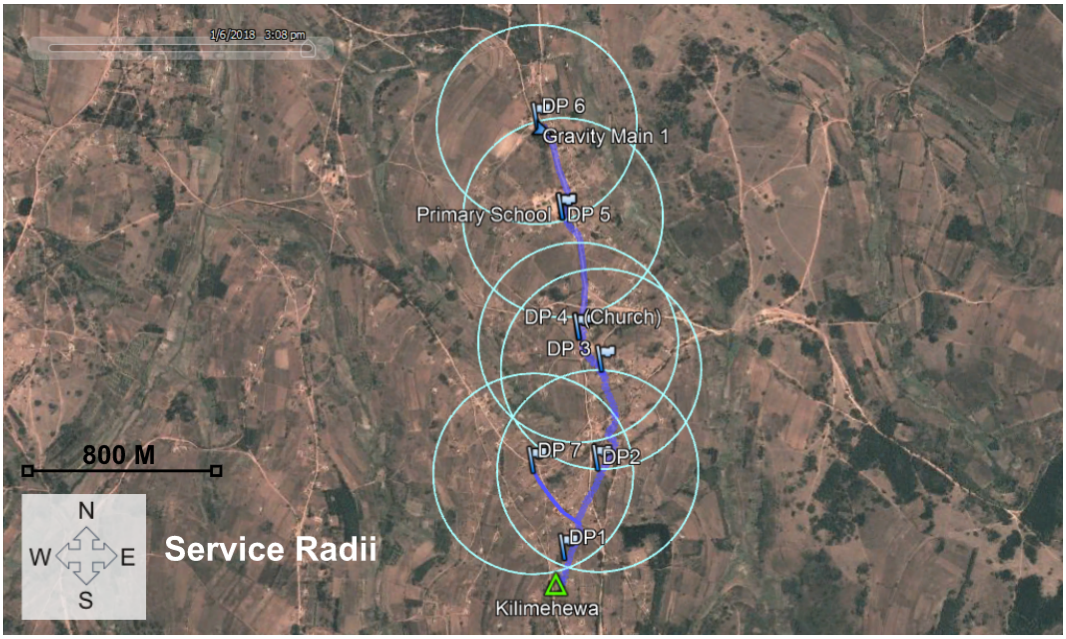

Figure 5.3. Distribution Point Radii. The radii of service provided by each distribution point is shown with circles. Nearly all households appear to fall within the radii.

5.2.3 Pipe Selection

The materials and diameters of the pipes for the pipeline needed to be determined in order for the new system to meet the Tanzanian Guidelines, while also being cost effective and efficient for the village of Lukani. The needs of the village, along with the guidelines, led our group to choose HDPE as our pipe material. There were two sets of diameters that needed to be calculated for the pipes, the rising main and the gravity main. The rising main was found to require an inner diameter of 28 mm and the gravity main was found to have an inner diameter of 50 mm. With the inner diameters in mind, we then focused on the type of static pressures that the pipes would incur to determine the grade of pipe that would be needed.

For the rising main, it was found that the pipe needed to support 9.84 atm with 80% of its rating included, found in the Tanzanian guidelines. This means that PN10 pipe will be used for at least the first 19 meter of elevation rise, with PN8 taking over for the rest of the 53 meters of elevation rise.

The gravity main has a much higher elevation change to deal with and therefore the grades of the pipes were found to be higher. The total elevation difference between the top of Kilimahewa and DP6 is found to be 92 meters, which leads to a maximum static pressure of 12.58 atm gauge pressure, with the 80% of rating for the pipe being taken into account. This means that a pipe grade of PN14 will be at the base of the gravity main, starting at DP6. After 9.14 meters of elevation increase, a PN12 pipe will then be placed. At the 27.42 meter mark in elevation rise a PN10 pipe will then be placed, followed by a PN8 pipe going all the way to the top at the 45.7 meter mark.

5.2.4 Elevation Profiles

Figure 5.4 below shows all of the relevant elevations and distances for each distribution point, the location of the tanks (Kilimahewa) and the proposed bore hole. The entire system covers an elevation span of 92 m and requires a total distance of approximately 2,880 km in pipe. The gradual slope of the gravity main will allow for sufficient vertical head from the holding tanks to each distribution point.

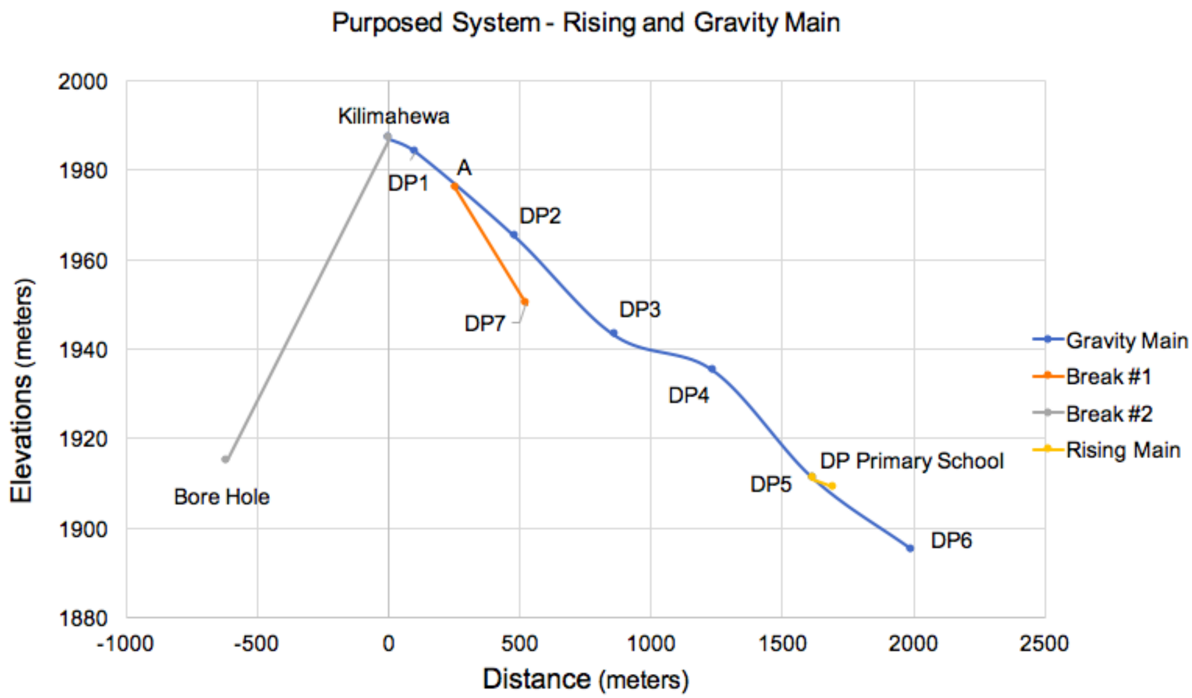

Figure 5.4. Elevation graph of proposed system with key locations and distribution points.

Elevation from Kilimahewa to the last distribution point follows a nearly linear fit. Point A to DP7 will be a break off from the gravity main to distribute water to a small cluster of villagers. The distribution point at the primary school will also be a branch off of the main gravity main to allow for a tap within the school grounds. All other distribution points will lie within a few meters of the gravity main.

5.3 Design Concerns

One of the largest design concerns that this project has is the air hammer well that will need to be drilled. There is no way of knowing how much water this well will produce. The site was chosen because it has a current water source around it and the geography of the area makes it favorable to have a rich water table. A professional will come out and survey the area in order to make sure that the area that was chosen is favorable for all the reasons stated above. With money being a large concern, the well depth to be drilled is also a concern. The water table seems to be favorable in the area but with a cost of 155,000 TZS/meter, the depth of the well becomes a financial concern.

5.4 Impact of Design

5.4.1 Health Impact

The quality of life for Lukani citizens will be drastically improved from this water distribution system if implemented. For example, When the solar powered system was introduced in early 2016 the waterborne illnesses in Lukani decreased by 50% from about 360/year to 180/year given the statistics we received from the dispensary in Lukani. This gives us great hope that the citizens who still find it challenging to stay healthy given their current water source options will be able to find clean drinking water and maintain good health. The dispensary was very far for some citizens to regularly get water from and was not feasible as a consistent water source for all residents in Lukani. We are hoping to make clean water easier to obtain for all residents and provide the opportunity to provide health for as many families as we can.

5.4.2 Economic Impact

Our goal for the implementation of the water distribution system is to be able to entirely fund the drilling, piping, and distribution point costs to supply the water system to the Lukani residents. With that being said, to ensure the Lukani community takes full responsibility of the water system we have asked that they pay for the cost of power for the submersible pump each month. They have enacted a by-law to require each of the adults in their village to pay 1,000 TZS per month which will be placed in a village account dedicated to water system costs. The approximate cost of supplying power to the proposed system will cost be 205,000 TZS per month. This will make up about 20% of the monthly collection of money from the citizens given there are approximately 1,000 adults in the village.

A concern we had regarding the monthly collection of money from the village was they are collecting money from every resident, while when we implement the system, it will be much easier to collect water for half the village than for the sub villages farther west in the village. The water committee assured us that they will be able to maintain the collection of money from all citizens because when they implemented the by-law, all citizens agreed that all water solutions are the responsibility of the entire village. If this does seem to be an issue for Lukani, we also have suggested a collection system that is dependent on the amount of buckets of water that are taken by each individual as opposed to a flat rate for each to pay. We have great confidence that Lukani is committed to the water distribution system and they will wholeheartedly take responsibility for the system and the costs associated with the upkeep as well as the labor necessary to lay the piping and construct the system.

6.0 Implementation of Budget

The budget for the chosen system is described below. This includes: estimated materials and their costs based on prices from past years, the estimated labor and transportation costs required to get the parts to Lukani, and the in-kind contribution from the village to help dig trenches, put pipe in the ground, and help build bases and housing for essential components of the system. A 10% contingency is added to the system to account for a 10-year lifecycle cost of the project.

Table 1: Estimated Material Costs

Item	Price (TZS)	Price (USD)	Unit basis	Qty.	Total Price (USD)
28 mm PN8 Pipe	107,966.10	$49.53	Per roll (150m)	4	$198.12
28 mm PN10 Pipe	228,390.10	$102.78	Per roll (150m)	7	$719.46
50 mm PN8 Pipe	665,735	$299.58	Per roll (150m)	2	$599.16
50 mm PN10 Pipe	786,159	$351.91	Per roll (150m)	3	$1,055.73
50 mm PN12 Pipe	906,583	$405.82	Per roll (150m)	3	$1,217.46
50 mm PN14 Pipe	1,027,007	$462.15	Per roll (150m)	2	$924.30
Air Hammer Well	4,000,000	$1,800.00	Per each	1	$1,800.00
1 m of Air Hammer	155,000	$69.75	Per meter	100	$6,975.00
10,000 L Tank	2,640,000	$1,181.22	Per each	2	$2,362.44
Concrete Materials (for tank base)	1,100,000	$488.89	Per each	2	$977.78
Grundfos Submersible Pump 1.85 kW	5,605,600	$2,491.38	Per each	1	$2491.38
6.00mm^2x4 Core Drop Cable	13,512	$6.05	Per meter	100	$600.53
6.00mm^2x4 Core Surface Cable	11,500	$5.11	Per meter	20	$102.22
ARJE 2 (1.5mm^2-4.0mm^2)	40,000	$17.78	Per each	1	$17.78
Control Panel	2,250,000	$1,000	Per each	1	$1,000
Borehole cover plate (7”)	176,000	$78.22	Per each	1	$78.22
LT Line Extension	1,425,375	$633.50	Per 250m	1	$633.50
Tank Fittings	143,880	$63.95	Per each	2	$127.90
Spigot Taps	143,880	$63.95	Per each	16	$1023.16
Fitting, 25mm to 25mm PN8	8,720	$3.87	Per each	3	$11.63
Fitting 25mm to 25mm PN10	10,000	$4.44	Per each	6	$26.67
Fitting 50mm to 50mm PN10	15,000	$6.67	Per each	3	$20.00
Fitting 50mm to 50mm PN12	16,000	$6.67	Per each	3	$20.00
Fitting 50mm to 50mm PN14	17,000	$6.67	Per each	3	$20.00
Fitting 50mm PN8 to PN10	13,000	$5.78	Per each	1	$5.78
Fitting 50mm PN10 to PN12	13,000	$5.78	Per each	1	$5.78

Fitting 50mm PN12 to PN14	13,000	$5.78	Per each	1	$5.78

Table 2: Estimated Labor and Transportation Costs

Item	Price (TZS)	Price (USD)	Unit basis	Qty.	Total Price (USD)
Transportation/Shipping to Lukani	400,000	$177.78	Per trip	5	$888.89
Trenches/Pipe	4,500	$2.00	Per meter	3150	$6,300
Housing Construction	2,250,000	$1,000	Per each	1	$1,000
Tank Fondation	1,323,000	$588.00	Per each	2	$1176
Distribution Point	400,000	$177.78	Per each	8	$1422.24
Service Line Cost	387,000	$172	Per 250m	1	$172
In-kind Village Contributions	16,425,000	$7,300			$7,300

Conversion rate 1 USD = 2,250 TSH

Transportation to Lukani includes 5 trips. One trip for each sim tank, two trips for all the necessary piping, and one trip for the pump and all the accessories. The in-kind village contributions include helping build the housing for the pump controller and digging the trenches for all the pipes. Additional village contributions may include helping build the tank foundations and helping to extend the electricity line.

Table 3: Budget Summary

Estimated Material Costs	$23,019.78 USD
Estimated Net Labor/Transportation Costs	$3,659.13 USD
Total Estimated Cost (with 10% contingency)	$29,346.80 USD

7.0 Summary and Conclusions

Our experience in Lukani is one that will never be forgotten. From the initial drive in, to the moment we left, the people of Lukani made us feel at home and treated us with the utmost respect. Their drive and determination to better the lives of their community will suit them well with an opportunity to provide clean, running water to over 1400 people. A system such as the one proposed will ease families' concern about access to potable water each day. It will provide a safe alternative to bacteria-contaminated surface sources they have used for so long to drink, bathe, wash clothes, and cook food. It will take away the burden of walking over a kilometer each day for a bucket of water and put a fresh source for many within a quarter of that distance.

The village leaders and water committee members of Lukani are ready to take on a new challenge and bring it upon themselves and the village to make this project successful.

8.0 Appendix

Add EES, Tanzania guidelines, maps, figures, and additional information

Appendix A

EES Code

```
Function ff(Re, ed)
If (Re > 2300) Then
        ff:= 1/(1.8*log10( (ed/3.7)^1.11 + 6.9/Re))^2
Else
        ff:= 64/Re
Endif
End

{------------------------------------------}

{Constants}
rho = 1000      {kg/m^3}    {density of water}
mu = 0.0011    {Ns/m^2}    {dynamic viscosity of water}
epsilon = 0.2/1000    {m}   {inner pipe wall roughness}
g = 9.81     {m/s^2}

{System Characteristics}
LK1 = 103;    {LBK = 616;}    {Length of pipe runs, [m] Kilimahewa to DP1 and Borehole to
Kilimahewa}
L1A = 151;    LA2 = 227;    LA7 = 270;    L23 = 445;    L34 = 154;    L45 = 506;    L5P = 80;
LP6 = 414;
L1aa = 2; L2a = 2;  L3a = 2; L4a =2;  L5a = 2; L6a = 2; LPa = 2;
dK1 = 0.050;
d1aa = 0.020; d2a = 0.020; d3a = 0.020; d4a = 0.020; d5a = 0.020; d6a = 0.020; d7a = 0.020;
dPa = 0.020;   {Diameters of pipe from gravity main to DP}
d1A = 0.050;  {Diameter of gravity main from DP1 to T intersection A}
```

```
dA2 = 0.050;
d23 = 0.050;
d34 = 0.050;
d45 = 0.050;
d5P = 0.050;
dP6 = 0.050;
{relative roughnesses}
ed1aa = epsilon/d1aa;
ed2a = epsilon/d2a;
ed3a = epsilon/d3a;
ed4a = epsilon/d4a;
ed5a = epsilon/d5a;
ed6a = epsilon/d6a;
ed7a = epsilon/d7a;
edPa = epsilon/dPa;
edK1 = epsilon/dK1;
ed1A = epsilon/d1A;
edA2 = epsilon/dA2;
ed23 = epsilon/d23;
ed34 = epsilon/d34;
ed45 = epsilon/d45;
ed5P = epsilon/d5P;
edP6 = epsilon/dP6;
{area of pipe cross-section; internal}
A1aa = pi*d1aa^2/4    {m^2}
A2a = pi*d2a^2/4    {m^2}
A3a = pi*d3a^2/4    {m^2}
A4a = pi*d4a^2/4    {m^2}
A5a = pi*d5a^2/4    {m^2}
A6a = pi*d6a^2/4    {m^2}
A7a = pi*d7a^2/4    {m^2}
APa = pi*dPa^2/4    {m^2}
AK1 = pi*dK1^2/4    {m^2}
A1A = pi*d1A^2/4    {m^2}
AA2 = pi*dA2^2/4    {m^2}
A23 = pi*d23^2/4    {m^2}
A34 = pi*d34^2/4    {m^2}
A45 = pi*d45^2/4    {m^2}
A5P = pi*d5P^2/4    {m^2}
AP6 = pi*dP6^2/4    {m^2}
{known elevations}
zK = 1987    {m}    {Kilimahewa}
z1 = 1984    {m}    {DP1}
zA = 1972    {m}    {Pipe T-location}
```

```
z7 = 1950    {m}    {DP7}
z2 = 1965    {m}    {DP2}
z3 = 1943    {m}    {DP3}
z4 = 1935    {m}    {DP4}
z5 = 1911    {m}    {DP5}
zP = 1909    {m}    {Primary School Location}
z6 = 1895    {m}    {DP6}
{ Volumetric Flow Rates }
QK1 = Q1aa + Q1A;
Q1A = Q7a + QA2;
Q1aa = 0.333/1000;
Q2a = 0.333/1000;
Q3a = 0.333/1000;
Q4a = 0.333/1000;
Q5a = 0.333/1000;
Q6a = 0.333/1000;
Q7a = 0.333/1000;
QPa = 0.333/1000;
QA2 = Q2a + Q23;
Q23 = Q3a + Q34;
Q34 = Q4a + Q45;
Q45 = Q5a + Q5P;
Q5P = QPa + QP6;
QP6 = Q6a;
{Average Velocities in Pipe Sections}
V1aa = Q1aa / A1aa      {m/s};
V2a = Q2a / A2a      {m/s};
V3a = Q3a / A3a      {m/s};
V4a = Q4a / A4a      {m/s};
V5a = Q5a / A5a      {m/s};
V6a = Q6a / A6a      {m/s};
V7a = Q7a / A7a      {m/s};
VPa = QPa / APa      {m/s};
VK1 = QK1 / AK1     {m/s};
V1A = Q1A / A1A     {m/s};
VA2 = QA2 / AA2     {m/s};
V23 = Q23 / A23     {m/s};
V34 = Q34 / A34     {m/s};
V45 = Q45 / A45     {m/s};
V5P = Q5P / A5P     {m/s};
VP6 = QP6 / AP6     {m/s};

{Reynolds numbers}
Re1aa = rho*V1aa*d1aa/mu;
```

```
Re2a = rho*V2a*d2a/mu;
Re3a = rho*V3a*d3a/mu;
Re4a = rho*V4a*d4a/mu;
Re5a = rho*V5a*d5a/mu;
Re6a = rho*V6a*d6a/mu;
Re7a = rho*V7a*d7a/mu;
RePa = rho*VPa*dPa/mu;
ReK1 = rho*VK1*dK1/mu;
Re1A = rho*V1A*dK1/mu;
ReA2 = rho*VA2*dK1/mu;
Re23 = rho*V23*dK1/mu;
Re34 = rho*V34*dK1/mu;
Re45 = rho*V45*dK1/mu;
Re5P = rho*V5P*dK1/mu;
ReP6 = rho*VP6*dK1/mu;

{Call Friction Factor Routine}
f1aa = ff(Re1aa, ed1aa);
f2a = ff(Re2a, ed2a);
f3a = ff(Re3a, ed3a);
f4a = ff(Re4a, ed4a);
f5a = ff(Re5a, ed5a);
f6a = ff(Re6a, ed6a);
f7a = ff(Re7a, ed7a);
fPa = ff(RePa, edPa);
fK1 = ff(ReK1, edK1);
f1A = ff(Re1A, ed1A);
fA2 = ff(ReA2, edA2);
f23 = ff(Re23, ed23);
f34 = ff(Re34, ed34);
f45 = ff(Re45, ed45);
f5P = ff(Re5P, ed5P);
fP6 = ff(ReP6, edP6);

{Boundary Conditions}
PK = 0
P1aa = 0
P2a = 0
P3a = 0
P4a = 0
P5a = 0
PPa = 0
P6a = 0
P7a = 0
```

```
{K1aa, K2a, K3a, K4a, K5a, K6a, K7a, and KPa are variable loss coefficients, which will act as
valves to throttle the flows to the DPs}
{Neglect Kinetic Energy terms within each pipe system}

{K1aa = 10;
K2a = 10;
K3a = 10;
K4a = 10;
K5a = 10;
K6a = 10;
K7a = 10;
KPa = 10;}


{Governing Equations...need to check for unit consistency}
(P1-PK)  /  (rho*g)  +  z1  -  zK  =  -VK1 ^ 2 / (2 * g) * (fK1 * LK1 / dK1)
(PA-P1)  /  (rho*g)  +  zA  -  z1  =  -V1A ^ 2 / (2 * g) * (f1A * L1A / d1A)
(P2-PA)  /  (rho*g)  +  z2  -  zA  =  -VA2 ^ 2 / (2 * g) * (fA2 * LA2 / dA2)
(P3-P2)  /  (rho*g)  +  z3  -  z2  =  -V23 ^ 2 / (2 * g) * (f23 * L23 / d23)
(P4-P3)  /  (rho*g)  +  z4  -  z3  =  -V34 ^ 2 / (2 * g) * (f34 * L34 / d34)
(P5-P4)  /  (rho*g)  +  z5  -  z4  =  -V45 ^ 2 / (2 * g) * (f45 * L45 / d45)
(PP-P5)  /  (rho*g)  +  zP  -  z5  =  -V5P ^ 2 / (2 * g) * (f5P * L5P / d5P)
(P6-PP)  /  (rho*g)  +  z6  -  zP  =  -VP6 ^ 2 / (2 * g) * (fP6 * LP6 / dP6)

(P1aa-P1)  /  (rho*g)   =  -V1aa ^ 2 / (2 * g) * (f1aa * L1aa / d1aa + K1aa)
(P2a-P2)  /  (rho*g)   =  -V2a ^ 2 / (2 * g) * (f2a * L2a / d2a + K2a)
(P3a-P3)  /  (rho*g)   =  -V3a ^ 2 / (2 * g) * (f3a * L3a / d3a + K3a)
(P4a-P4)  /  (rho*g)   =  -V4a ^ 2 / (2 * g) * (f4a * L4a / d4a + K4a)
(P5a-P5)  /  (rho*g)   =  -V5a ^ 2 / (2 * g) * (f5a * L5a / d5a + K5a)
(P6a-P6)  /  (rho*g)   =  -V6a ^ 2 / (2 * g) * (f6a * L6a / d6a + K6a)
(P7a-PA)  /  (rho*g) + z7 - zA   =  -V7a ^ 2 / (2 * g) * (f7a * LA7 / d7a + K7a)
(PPa-PP)  /  (rho*g)   =  -VPa ^ 2 / (2 * g) * (fPa * LPa / dPa + KPa)

{
(P1aa-P1)  /  (rho*g)   =  -V1aa ^ 2 / (2 * g) * (f1aa * L1aa / d1aa + 10)
(P2a-P2)  /  (rho*g)   =  -V2a ^ 2 / (2 * g) * (f2a * L2a / d2a + 10)
(P3a-P3)  /  (rho*g)   =  -V3a ^ 2 / (2 * g) * (f3a * L3a / d3a + 10)
(P4a-P4)  /  (rho*g)   =  -V4a ^ 2 / (2 * g) * (f4a * L4a / d4a + 10)
(P5a-P5)  /  (rho*g)   =  -V5a ^ 2 / (2 * g) * (f5a * L5a / d5a + 10)
(P6a-P6)  /  (rho*g)   =  -V6a ^ 2 / (2 * g) * (f6a * L6a / d6a + 10)
(P7a-PA)  /  (rho*g) + z7 - zA   =  -V7a ^ 2 / (2 * g) * (f7a * LA7 / d7a + 10)
(PPa-PP)  /  (rho*g)   =  -VPa ^ 2 / (2 * g) * (fPa * LPa / dPa + 10)
}
```

Appendix B

Tanzania Design Guidelines

- The design period should be for a minimum of 10 years. Recent population data should be inflated at a rate of 1.5% per year. This means that all designs should design for a 16% population growth, i.e. $(1.015)^{10}$.

- Water demand should be based on 25 liters per person per day. For schools the design should be for 10 liters per student per day.

- The system should be designed to accommodate 2.5 times the average rate of demand. Hourly water demand is bimodal, with the largest peak in the morning, followed by a lull around noon, and a second peak in the late afternoon.

- The system should have a minimum water storage capacity equal to 50% of the average daily demand

- The minimum capacity of each 'spigot' should be 10 liters/min. Each DP (distribution point) should be designed with a T having 2 spigots, so each DP should be able to provide 20 liters/min.

- The pipe surface roughness: PVC and HDPE 0.01 mm; galvanized steel 0.15 mm (relative roughness epsilon/d is roughness divided by internal pipe diameter)

- The maximum working pressure for a pipe should be approximately 80% of rating. For example: a HDPE pipe is rated at PN8. PN8 stands for 8 bars or 116 psig. Therefore, it shouldn't be used in environments where the pressure exceeds 0.8*116 psig, or 93 psig.

- Design for a total water loss of 20-25% (leaks, valves left open, etc.)

- Washout valves and air bleed valves may be required for undulating pipe layouts, low points and high points, respectively.

- Isolation valves need to be used at all branches and at 3 km intervals on straight sections.

- One DP can serve a maximum of 250 people. Maximum walking distance to a DP is 400 m.

- The velocity of water in a pipe should typically be in the range of 0.5 – 1.5 m/sec. Slower than 0.5 m/sec usually means you pipe is too large, larger may lead to water hammer.

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

- All minor losses should be modeled at 5% of major losses. Treat valves separately

- Add 15% to pipe costs for fittings; add 20% to supply costs (pipe/tank/concrete) for shipping