Expanding Water Distribution – Kising'a Village

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1.3 St. Paul Partners

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1.4 Kising'a Water Committee

2.0 Project Profile

2.1 Project Location

Region: Iringa, Tanzania
District: Iringa Rural Region
Place: Kising'a Village, 7°55' S, 35°59' E
Climate: Less than one inch of rain for half the year, temperatures reaching 90° F, humid.

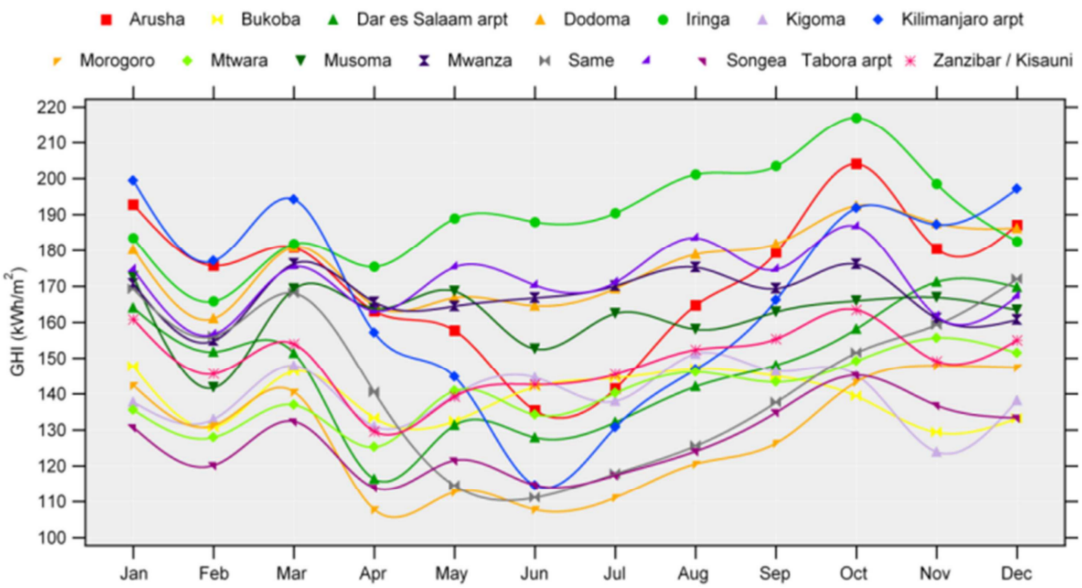


Figure 1 - Monthly means values of GHI measured by World Radiation Data Centre Stations in Tanzania.[1] The Green Circles near the top represent Iringa.

From Figure 1, the shortwave radiation in Iringa each month is plotted as green dots on the chart. The total radiation received in a year is around 2271kWh/m^2, which gives an average radiation of 189kWh/m^2 per month. Figure 2 confirms this, showing the yearly value at 2200 kWh/m^2. While Kising'a is only 23 miles from Iringa, Figure 2 shows yearly solar radiation drops to 1800 kWh/m^2, or 208W/m^2. This value will be used in calculating solar needs.

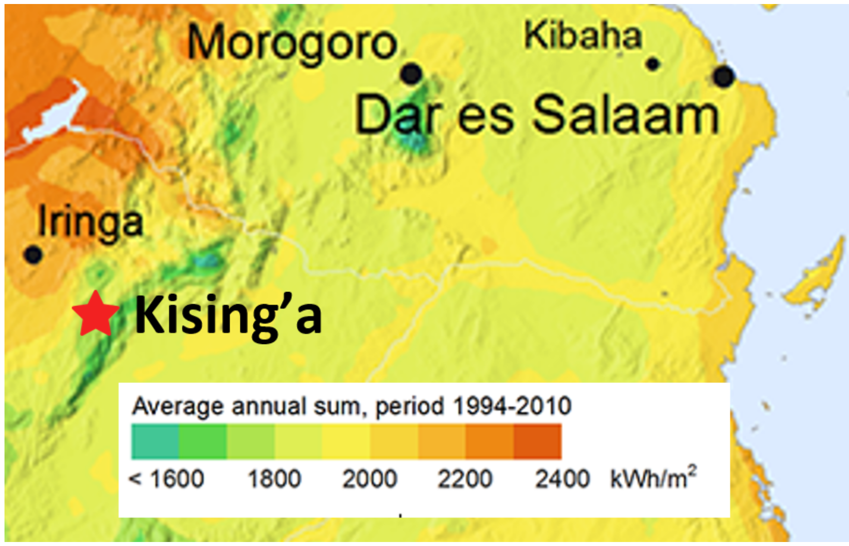


Figure 2 - The location of Kising'a and its annual GHI (Global Horizontal Irradiance)[2].

2.2 Implementing Organization.

Established in 2002, St. Paul Partners (SPP) is a 501c3 non-profit organization that provides drinking water to the people of Tanzania, specifically in the Iringa Region. The vision of SPP is to "assist and enable the Tanzanian people to obtain universal access to safe water, community by community." To accomplish this vision, SPP works with other organizations to help implement projects in Tanzania. Some partner organizations include H2O for Life, Bega Kwa Bega, Winter Wheat Foundation and Water to Thrive. More information can be found on their website, http://stpaulpartners.org.

2.3 Beneficiaries Information

The total population of Kising'a is over 3,500, and grew at an average rate of 6.2% between 2008 and 2014[3][4]. The village is split into 8 hamlets[3]. The largest, Kibaoni, is home to over 600 villagers and the location of the village's dispensary, primary school and secondary school. Additionally, it is the site of a gravity fed system water system designed in 2014 by University of Minnesota students and St. Paul Partners. The system proposed in this report will benefit the dispensary, primary school, and to more populations of Kising'a by expanding water access to these areas.

2.4 Project Duration

2.5 Project Budget

Table 1 -- Project Budget

	TSH	USD
Phase I	TZS 30,450,000	$14,500
Phase II	TZS 7,350,000	$3,500
Total	TZS 37,800,000	$18,000

3.0 Executive Summary

3.1 Kising'a Village

Kising'a Village is located approximately 2 hours by car southwest of Iringa. It is home to over 3,000 people and hosts a dispensary, primary school, and secondary school. Below, Figure 3 show an overview of Kising'a Village and major landmarks.

Figure 3 – Location of Village Landmarks with GPS coordinates and elevations.

The primary school enrolls 665 and 13 teachers. The secondary school has an enrollment of 110 students and 7 teachers. Both schools are seeing consistent growth rate equaling approximately that of the village's. The dispensary sees over 3000 patients a year, about 1/3 of which are children. In addition, there are on average 12 births per month delivered at this dispensary.

3.2 Existing System

In January of 2014, a team from the University of Minnesota designed a water distribution system fed from a mountain spring source 1.6km northeast of the village center. This source had been discovered a few year prior and a temporary system was put in by the local villager, Sajeni. However, due to the large elevation changes, the pipe was consistently bursting and unreliable. The team's design included containing and protecting the source, running class E piping into a 10k polytank located on the edge of town, and creating 5 spigots for public water distribution at this point. The location is denoted in Figure 3 as "Current Tank". Figure 4 shows this tank and spigots.

This source delivers consistent clean water year round at a rate of 1200L/hr during the wet season and 1100L/hr during the dry season. However, the supply is larger than current demand and much of the water overflows out of the tank and into a nearby ravine. Even during the dry season, the tank is never less than 1/3 of the way full according to Sajeni.

This is currently the primary source the village's water, including for the primary school and nurses at the dispensary despite both being located approximately a kilometer away. There is a permanent tank located at the dispensary which collects rain water; however, there is a crack in the side which allows water to leak out of it. Since the current tank's installation the village has seen a decline in water-related illnesses leading the village to consider this a source of 'clean' water; this was confirmed by water testing conducted during the site visit. As a result, it is believed by the water committee that the use of this source is increasing as more of the village sees the benefits of using its clean water.

Figure 4 - Current Tank and 5 Spigots installed in University of Minnesota Student Designs in 2014.

Prior to this source's discover, the primary source was a spring, shown in Figure 5, located between the village center and secondary school. This source is not well developed or protected and considered 'unclean' by the village. This verdict cannot be confirmed, as water from this source was not tested. Despite this, it is still used by many residents who live closer to this source than the new tank. The old source provides water at a much slower rate, approximately 250L/hr, and excess water is not contained for future use, leading to long lines during peak demand. According to those we spoke to in the village, it is also subject to larger variation depending on time of year, leading to much lower supply in the dry season. The source is located in a local ravine with agriculture on either side. It is protected by boards that prevent large debris from entering, but is unprotected from runoff and smaller contaminants.

Figure 5 – Old Water Source. The spring bubbles up under the boards and flows out through the pipe denoted in the picture.

Some in the village still use surface water sources as their primary source, including the students at the secondary school who are a few kilometers away from both the current and old sources. This is seen more often the further away from the two other sources discussed, as these surface sources are closer to their homes and reduce the time for the women and children to collect water. During the dry season, demand at the current system has been seen to increase, as it is expected these surface sources dry up.

3.3 Program Goals

In conversations with the water committee, their primary goal is to provide clean water to the dispensary, primary school, and provide easier access to clean water for residents living further away from the current tank. Currently, nurses walk over 1 kilometer to the tank to fill buckets several times during the day, taking approximately 30 minutes of their time away from patients on each trip. By bringing water to the dispensary, the time commitment is removed, allowing better care to the village's sick. Primary school students travel about the same distance 2-3 times throughout their day to meet the water demands of the school. With 600 children fetching water from 5 spigots, this causes a large gap in the instruction time each day. Additionally, the longs lines at the tank leads some children to collect water from open surface sources. Being able to deliver water to the school would reduce this interruption and help ensure the children are actually collecting clean water.

With this in mind, the primary objectives of this project are as follows:

1. **Bring Clean Water to Dispensary** – This is the water committee's primary goal, therefore making it this project's primary goal. By bringing clean water to the dispensary, patient care can be improved.
2. **Bring Clean Water to Primary School** – By bringing water to the school, the children will be able to spend less time fetching water, and more time learning and playing.
3. **Increase the Storage Capacity of the Current Tank –** Currently, it is estimated the current tank is overflowing 15 hours per day, meaning upwards of 20,000L of water is not being collected each day. By expanding capacity, more water will be available as the system expands and less water will be wasted.
4. **Expand Public Access to Clean Water** – Kising'a has already seen a decline in water-related illnesses. By expanding access of clean water to more village residents, this trend should continue.

3.4 Program Deliverables

This project is split into two phases to help limit complexity and disperse costs over a greater period of time. Figure 6 shows an overview of the proposed sites and paths for system components. A simplified version this map with distances and elevations is provided in Appendix B.

Figure 6 – Overview of the Proposed System. The purple route shows the proposed pipeline from the current tank to the new tank. The orange route shows pipeline from the new tank to the primary school.

3.4.1 Phase I

The objectives for Phase I are outlined below.

1. Placing a 10,000L polytank at the dispensary to expand capacity. This will be placed on top of a permanent tank located on the premises. This tank will be used as the supply source for the dispensary, primary school, and public taps. Figure 7 shows this tank with Ce for reference.
2. Placing a solar powered submersible pump into the current tank, to supply water to the new dispensary tank.
3. Pole-mounted solar panels placed at the current tank to power the pump. Included on the pole will be the electronics to control the pump, security light, and battery. This will all be enclosed within a cage on top of the tower.
4. Two outside spigots at the dispensary and plumbing two sinks inside the southern office building. The exterior spigots would be for dispensary use only until Phase II is completed. Figure 7 shows this building on the left. A concrete base will be needed for the exterior spigots.
5. A 5000L polytank connected to the current tank to expand the system capacity and reduce water waste. A tower will also need to be built to elevate this to the same level as the current tank
6. Rock and gravel filler for the permanent tank at the dispensary to provide structural stability for the new tank.

Figure 7 – Proposed site for new tank at the dispensary. Show on the left is the permanent tank that will act as the base for the new tank. The building on the left is to be plumbed during Phase I, and the building to the right is to be plumbed during Phase II.

3.4.2 Phase II

The objectives for Phase II are outlined below.

1. Placing 3 taps at the western edge of the primary school. These would be supplied by the tank placed at the dispensary. It is expected three spigots will be enough if classes take turns fetching water. A concrete base will be needed for these spigots.
2. Adding another 5000L poly tank at the current tank to expand capacity further. Two 5000L tanks are preferred to one 10,000L tank to maintain water depth when limited water is contained. Figure 8 illustrates this.
3. Plumbing the northern dispensary building with 3 sinks. This would increase access of water to nurses and patients. This is the right most building in Figure 7.
4. Placing 3 taps at the village center for public use. Again, these would be supplied by the dispensary tank. A concrete base will be needed for these spigots.

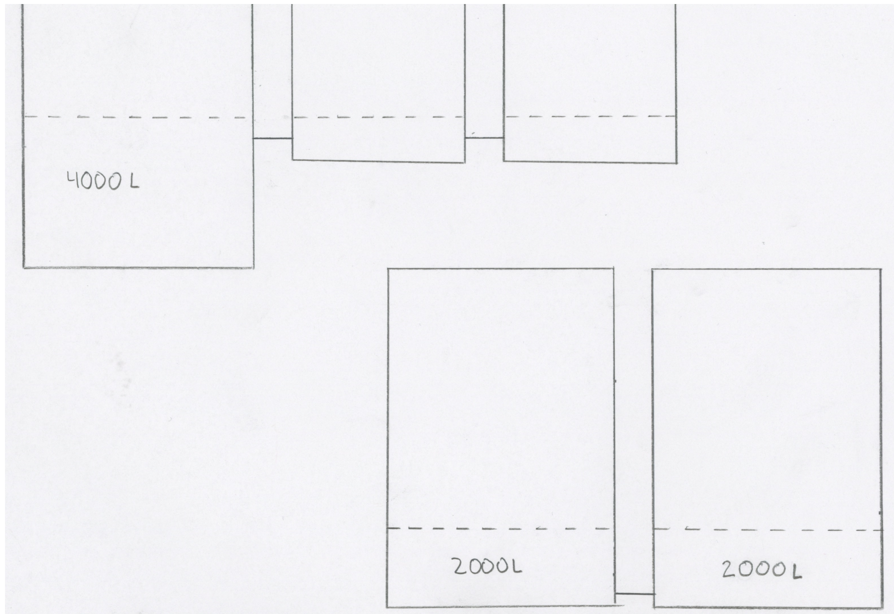


Figure 8 – The effect of using two 10,000L polytanks versus one 10,000L and two 5000L polytanks on water height.

3.5 Economic Impact and Sustainability

Currently, no money is collected for use of the system and taps nor is the village's use documented. It was understood by the water committee that before any new system was to be built, the village must set up a water tax to pay for system improvements and maintenance. Similar systems charge TZS 10-50 per 20L bucket. Someone will also need to be hired to maintain a record of water used and enforce this tax.

Table 2 shown below gives a simple cost analysis to support this tax, including long-term costs and estimated water usage. It is recommended that a tax of at least TZS 25 be placed on each bucket of water gathered from the system, with at least TZS 9 per bucket going towards long-term maintenance costs. With the estimates made, this allows a surplus of over $3,500 to be put towards this system, allowing the village help to own the system and make it their own. It is assumed additional surplus will be collected to go towards future expansion of the system.

Table 2 : Basic Cost Analysis for Water Tax			
Population	750		
Number of 20L Buckets/Person	1.5		
Total 20L Buckets/day	1125		
Total 20L Buckets/yr	410625		
Costs to System	**Costs**	**Life Time (yrs)**	**Cost/Yr**
Pump	$2,000	8	$250
Guards/Maintenance (2 at $400 each)	$800	1	$800
Spigots	$200	10	$20
Piping System	$1,000	15	$67
	US Dollars	**TSH**	
Minimum Cost/Bucket ($)	$0.0028	5.81	
Cost / Bucket (TSH)	$0.0119	25	
Surplus / Year (TSH)	$3,751.73	$7,878,625.0	
Cost / Bucket (TSH)	$0.0071	15	
Surplus / Year (TSH)	$1,796.37	$3,772,375.0	

3.6 Additional Considerations

Currently, the water supply rate is an estimate based up reported times in takes to fill the current tank from empty. However, if these numbers are not accurate, the estimates for the amount of water available to distribute throughout the village will no longer be valid and design changes will need to be implemented to reflect this.

Additionally, we are unsure of the structural stability of the permanent tank at the dispensary. The goal of filling this tank with gravel is to provide support for the new tank placed on top. However, if this proves to be unsuccessful, a new tower will need to be built to provide enough water head to reach the primary school.

4.0 Project Analysis and Construction

4.1 Overview

Two phases are proposed in this project. Phase I encompasses bringing water from the current tank to the dispensary, while Phase II seeks to expand access to clean water from the dispensary to key village sites.

Engineering Equation Solver (EES) was used to model and analyze the proposed system. The code used and a printout of the results are proved in Appendix C. This will be referenced throughout this section in selecting and sizing component for the system.

Under both phases, trenches can be dug by village. During the build process of the system designed in 2014, the mile-long trench was dug in 2 days. Therefore, this should be no problem for the village to contribute. Additionally, it is asked that the village contribute money and resources for all towers needed to be built for water tanks. Additionally, it is expected that the village can aid in making the concrete slabs for the spigots.

For all main distribution lines (current tank to dispensary, to village center and primary school), HDPE piping will be used. Galvanized steel pipe will be needed for spigots and piping entering and exiting the tanks to protect against damage.

Below, each phase is described in detail.

4.2 Phase I

The primary concern of this design is providing clean water to the dispensary. This goal will be achieved by placing a pump in the current 10,000L tank and running a pipeline to a second 10,000L tank at the dispensary. This main run of the proposed system is 1km long and up-hill 40m. To provide enough water to meet needs all day long, a pumping rate of 2500 L/hr is recommended to provide a filling time of 4 hours. To accomplish this, pump work was found to be approximately 0.4 HP for inner pipe diameters 1.5-2". Further analysis of pipe diameters, maximum pressures, and their material costs determined 50mm Class B HDPE pipe should be used for this line. In comparison to 40 mm Class C HDPE piping, the larger Class C piping is 30% less expensive while both have safety factors around 1.5 with regards to burst pressure.

A Grundfos SQF 2.5-2 submersible water pump is recommend for this system. This pump is also used to a bore-hole well water system in the village of Lukani, also made possible by St. Paul Partners. For longer term maintenance, it is a desire of the organization to use similar pumps in all applications possible to provide continuity across the projects. This way, in case of pump failure, a stock pump can be kept on hand and quickly installed for short-term repair. The pump curve to this model is provided in Appendix D, along with the approximate operating point of the system. A pump stand will also be purchased to secure the pump inside the tank and ensure good water flow into the pump.

It was established in Section 2.1 that the average solar radiation received by Kising'a is approximately $208W/m^2$. With most solar panels used for this purposed measuring approximately 1m x 1.5m, a minimum of 5 panels will needed to power the 2hp pump. These will be mounted on a steel pole at least 6m tall for safety, along with a light and battery. Figure 9 below shows a sample of this type of assembly. The light will provide security for the solar panels as well as to villagers who may need to fetch water at night. A battery system similar to a solar street light will be used.

Figure 9 –The Solar Panel Assembly

For the new 5000L tank, a concrete base will need to be built next to the current tank. It should be 0.889 meters tall to put the top of both tanks at the same height. The tanks will be connected with a galvanized steel pipe joining the bottom of both tanks. The area of this base should be large enough for two 5000L tanks so an additional base will not need to be built for Phase II implementation.

4.3 Phase II

The pipe that connects dispensary and primary school will be of the diameter 40mm. Class B piping will be used to as the maximum pressure predicted by the model is less than 0.5 bar. There will be 3 spigots installed at the school for washing and cooking at the school. An additional 5000L polytank will be placed at the current tank on the same level as the other 5000L. Reason for having smaller tank on a higher level is to ensure a decent pumping head in dry season (when the water level is low). Additionally, it increases storage capacity while not lowered water levels when the system is not full. For the pipe from the dispensary to the nurse's building, it is recommended that Class B 32mm OD pipe be used. The village center, an outer diameter of 40mm class B pipe should be used. The model suggests that the maximum pressure at both sites will be less than one bar.

5.0 Project Budget
5.1 Phase I

Table 3 -- Phase I Budget						
1	**Piping**					
	Item	**Quantity**	**Price (TZS)**	**Total (TZS)**	**Total (USD)**	**Rounded Total (USD)**
1.1	GS Pipe (2”)	1	TZS 176,000.00	TZS 176,000.00	$83.81	$90
1.2	GS Elbow (2”)	4	TZS 16,000.00	TZS 64,000.00	$30.48	$35
1.3	1.5 in (50 mm) Piping (HDPE) Class B	8	TZS 346,600.00	TZS 2,772,800.00	$1,320.38	$1,325
1.4	PVC Pipe (1.5”)	1	TZS 10,000.00	TZS 10,000.00	$4.76	$5
1.5	PVC Elbow (1.5”)	2	TZS 4,000.00	TZS 8,000.00	$3.81	$5
1.6	PVC Tee (1.5")	1	TZS 3,000.00	TZS 3,000.00	$1.43	$5
1.7	Check Valve	1	TZS 8,500.00	TZS 8,500.00	$4.05	$5
1.8	Taps	2	TZS 126,000.00	TZS 252,000.00	$120.00	$120
1.9	PVC Connector	9	TZS 34,000.00	TZS 306,000.00	$145.71	$150
1.10	PVC Cement	5	TZS 3,500.00	TZS 17,500.00	$8.33	$10
1.11	Sinks	2	TZS 50,000.00	TZS 100,000.00	$47.62	$50
1.12	Shut Off Valve	1	TZS 8,500.00	TZS 8,500.00	$4.05	$5
2	**Tank and Pump**					
2.1	5 kL Sim Tank	1	TZS 922,000.00	TZS 922,000.00	$439.05	$450
2.2	10 kL Sim Tank	1	TZS 2,400,000.00	TZS 2,400,000.00	$1,142.86	$1,200
2.3	Pump (GRUNDFOS SQF 2.5-2, 1.4m3/h)	1	TZS 5,310,000.00	TZS 5,310,000.00	$2,528.57	$2,550
2.4	Electrical Control Panel	1	TZS 1,776,750.00	TZS 1,776,750.00	$846.07	$850
2.5	Pump Stand*	1	TZS 210,000.00	TZS 210,000.00	$100.00	$100
3	**Solar Panels**					
3.1	Solar Panel	5	TZS 650,000.00	TZS 3,250,000.00	$1,547.62	$1,600
3.2	Tower	1	TZS 1,150,000.00	TZS 1,150,000.00	$547.62	$550
3.3	Battery*	1	TZS 210,000.00	TZS 210,000.00	$100.00	$100
3.4	Light*	1	TZS 105,000.00	TZS 105,000.00	$50.00	$50
3.5	Electronics	1	TZS 1,810,750.00	TZS 1,810,750.00	$862.26	$900
3.6	Cage Surrounding Solar Pannels*			TZS 0.00	$0.00	$100
4	**Construction**					
4.1	Cement for New Tanks and Taps (In Kind)	40	TZS 16,000.00	TZS 640,000.00	$304.76	$310
4.2	Filling in Tank at Dispensary (gravel) (In-Kind)	1	TZS 450,000.00	TZS 450,000.00	$214.29	$230
4.3	Dispensary Plumbing	1	TZS 50,000.00	TZS 50,000.00	$23.81	$25
4.4	SPP Oversight and Training ($500 per day)	2	TZS 1,050,000.00	TZS 2,100,000.00	$1,000.00	$1,000
4.5	Digging Trenches ($3 per person/day, In-Kind)	30	TZS 6,300.00	TZS 189,000.00	$90.00	$100
5	**Totals**					
5.1	Subtotal			TZS 24,110,800.00	$11,481.33	$11,920
5.2	20% Materials/Shipping Cost			TZS 4,822,160.00	$2,296.27	$2,384
5.3	In-Kind Contribution			TZS 1,050,000.00	$500.00	$500
	Phase I, Total			TZS 30,038,400.00	$13,777.60	$14,304
	Phase I, Requested Donor Total			TZS 27,644,400.00	$12,668.55	$13,164

5.2 Phase II

Table 4 -- Phase II Budget						
1	**Piping**					
	Item	**Quantity**	**Price (TZS)**	**Total (TZS)**	**Total (US Dollars)**	**Rounded Total (US Dollars)**
1.1	GS Pipe (2”)	1	TZS 176,000.00	TZS 176,000.00	$83.81	$85
1.2	GS Elbow (2”)	2	TZS 16,000.00	TZS 32,000.00	$15.24	$20
1.3	1.5 in (50 mm) Piping (HDPE) Class B	4	TZS 346,600.00	TZS 1,386,400.00	$660.19	$665
1.4	Taps	6	TZS 126,000.00	TZS 756,000.00	$360.00	$360
1.5	PVC Connector (1.5")	5	TZS 34,000.00	TZS 170,000.00	$80.95	$85
1.6	PVC Tee (1.5")	5	TZS 3,000.00	TZS 15,000.00	$7.14	$10
1.7	PVC Cement (1.5")	5	TZS 3,500.00	TZS 17,500.00	$8.33	$10
1.8	Sinks	3	TZS 50,000.00	TZS 150,000.00	$71.43	$75
1.9	Shut Off Valve	1	TZS 8,500.00	TZS 8,500.00	$4.05	$5
2	**Tank**					
2.1	5 kL Sim Tank	1	TZS 922,000.00	TZS 922,000.00	$439.05	$440
3	**Construction**					
3.1	Dispensary Plumbing*	1	TZS 50,000.00	TZS 50,000.00	$23.81	$25
3.2	SPP Oversight and Training ($500 per day)	2	TZS 1,050,000.00	TZS 2,100,000.00	$1,000.00	$1,000
3.3	In-Kind Contribution ($3 per day) (In Kind)	30	TZS 6,300.00	TZS 189,000.00	$90.00	$100
4	**Totals**					
4.1	Subtotal			TZS 5,972,400.00	$2,754.00	$2,880
4.2	20% Materials/Shipping Cost			TZS 1,194,480.00	$550.80	$576
4.3	In-Kind Contribution			TZS 630,000.00	$300.00	$300
Phase II, Total				TZS 7,166,880.00	$3,304.80	$3,456
Phase II, Requested Donor Total				TZS 6,536,880.00	$3,004.80	$3,156

5.3 Total

Table 5 -- Total System Budget			
	Phase I	**TZS**	**USD**
1.0	Piping	TZS 3,790,500	$1,805
2.0	Tank and Pump	TZS 10,815,000	$5,150
3.0	Solar Panels	TZS 6,930,000	$3,300
4.0	Construction	TZS 3,496,500	$1,665
	20% Added for Shipping	TZS 5,006,400	$2,384
5.0	Total	TZS 30,038,400	$14,304
	Phase II		
1.0	Piping	TZS 2,761,500	$1,315
2.0	Tank and Pump	TZS 924,000	$440
3.0	Construction	TZS 2,362,500	$1,125
	20% Added for Shipping	TZS 1,209,600	$576
4.0	Total	TZS 7,257,600	$3,456
	In-Kind Contributions		
1.0	Phase I	TZS 2,394,000	$1,140
2.0	Phase II	TZS 840,000	$400
3.0	Total	TZS 3,234,000	$1,540
Total System Cost		TZS 37,296,000	$17,760
Requested Donor Total		TZS 34,062,000	$16,220

All prices comes from TZS and is converted into USD using the current exchange rate, 2100 TZS/USD.

Appendix A – References

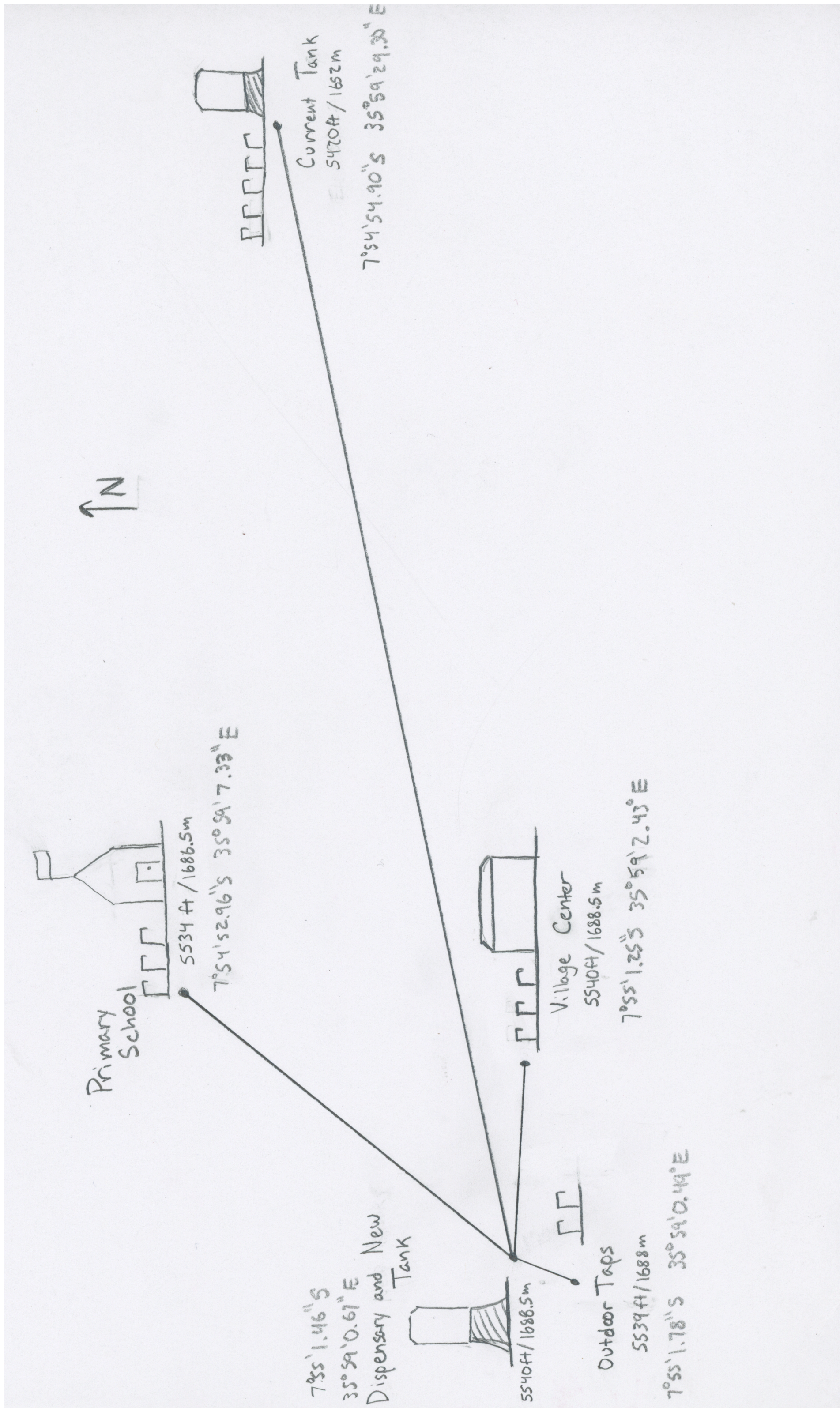
[1] Bernardos, Ana et al. *Solar Resource Mapping in Tanzania Solar Modeling Report*. The World Bank Group, 2015. Print. Renewable Energy Resource Mapping and Geospatial Planning.

[2] Google Images for Radiation Map

[3] Byemerwa, Amos. *Kising'a Water Supply Project Preliminary Design Document*. N.p., 2008. Print

[4] Klarich, Kathryn et al. *Potable Water Supply for Kising'a Village*. University of Minnesota, 2014. Print.

Appendix B – Village Landmarks



Appendix C – Engineering Equation Solver Model

```
{Kising'a code}

{-----------------------------------------------------------------}
{friction factor function}

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} {kinematic viscosity of water}
epsilon = 0.00001  {m} {inner pipe wall roughness}
g = 9.81 {m/s^2}

patopsi = 14.7 / 101325 {psi/Pa} {Conversion from Pascals to psi}

{Point 1 is at top of existing tank}
{Point 2 is beyod the pump at the beginning of the new pipe}
{Point 3 is at the top of the dispensary tank}
{Point 4 is inside the dispensary}
{Point 5 is outside the dispensary}
{Point 6 is the primary school}
{Point 7 is the village center}
{Pump is between points 1 and 2}

{Elevations}
z_1 = H_platform1 + H_sim {m} {elevation of top of current tank}
z_2 = H_platform1 {m} {elevation of bottom of current tank}
z_3 = 36 + H_sim + H_platform3 {m} {elevation of the top of the dispensary tank}
z_4 = z_3 - H_sim - H_platform3 + 1/3 {m} {elevation of the pipe going into the dispensary}
z_5 = z_3 - H_sim {m} {elevation of the pipe outside the dispensary}
z_6 = 34 {m} {Primary school elevation}
z_7 = 35 {m} {Village center elevation}

{Distances}
L_12 = 0 {m}
L_23 = 1000 {m} {Distance from current tank to dispensary}
L_4 = 1 {m}
L_5 = 5 {m}
L_6 = 370 {m} {Dispensary to primary school}
L_7 = 65 {m} {Dispensary to village center}

{Heads}
H_sim = 4 {m}
H_platform1 = 1/3 {m}
H_platform3 = 2.5 {m}
H_spigot = 1 {m}
H_pipe = -1 {m}

{Pressures, gage}
P_1 = 0 {Pa}
P_3 = 0 {Pa}
P_A = 0 {Pa}
P_B = 0 {Pa}
P_C = 0 {Pa}
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P_D = 0 {Pa}
P_E = 0 {Pa}
P_F = 0 {Pa}
P_G = 0 {Pa}
P_H = 0 {Pa}
P_I = 0 {Pa}
P_J = 0 {Pa}

{Convert Pressures from Pascals to pounds per square inch}
P_2psi = patopsi * P_2 {psi}

{Times to Fill}
t_fill = 120 [s] {time to fill a 20 liter bucket}
t_A = .02 / Q_A {s}
t_B = .02 / Q_B {s}
t_C = .02 / Q_C {s}
t_D = .02 / Q_D {s}
t_E = .02 / Q_E {s}
t_F = .02 / Q_F {s}
t_G = .02 / Q_G {s}
t_H = .02 / Q_G {s}
t_I = .02 / Q_G {s}
t_J = .02 / Q_G {s}

{Flow rates}
Q_23 = 2.5 {m^3/s}
Q_4 = V_4 * A_4 {m^3/s}
Q_4 = 2 * Q_spigot {m^3/s}
Q_A = V_A * A_A {m^3/s}
Q_B = V_B * A_B {m^3/s}
Q_5 = V_5 * A_5 {m^3/s}
Q_5 = 2 * Q_spigot {m^3/s}
Q_C = V_C * A_C {m^3/s}
Q_D = V_D * A_D {m^3/s}
Q_6 = V_6 * A_6 {m^3/s}
Q_6 = 3 * Q_spigot {m^3/s}
Q_E = V_E * A_E {m^3/s}
Q_F = V_F * A_F {m^3/s}
Q_G = V_G * A_G {m^3/s}
Q_7 = V_7 * A_7 {m^3/s}
Q_7 = 3 * Q_spigot {m^3/s}
Q_H = V_H * A_H {m^3/s}
Q_I = V_I * A_I {m^3/s}
Q_J = V_J * A_J {m^3/s}
Q_spigot = .02 / t_fill {m^3/s}

{Velocities}
V_23 = Q_23 / 3600 / A_23 {m/s}
{V_4 = 0.5 {m/s}
V_5 = 0.5 {m/s}
V_6 = 0.5 {m/s}
V_7 = 0.5 {m/s}}

{Pipe Inner Diameters}
d_23 = 0.046 {m}
d_4 = 0.028 {m}
d_5 = 0.028 {m}
d_6 = 0.0365 {m}
d_7 = 0.0365 {m}
d_spigot = 0.01905 {m}

{Internal Area of Pipes}
A_23 = d_23^2 * pi/4 {m^2}
A_4 = d_4^2 * pi/4 {m^2}
A_5 = d_5^2 * pi/4 {m^2}
A_6 = d_6^2 * pi/4 {m^2}
A_7 = d_7^2 * pi/4 {m^2}
A_A = d_spigot^2 * pi/4 {m^2}
A_B = d_spigot^2 * pi/4 {m^2}
A_C = d_spigot^2 * pi/4 {m^2}
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A_D = d_spigot^2 * pi/4 {m^2}
A_E = d_spigot^2 * pi/4 {m^2}
A_F = d_spigot^2 * pi/4 {m^2}
A_G = d_spigot^2 * pi/4 {m^2}
A_H = d_spigot^2 * pi/4 {m^2}
A_I = d_spigot^2 * pi/4 {m^2}
A_J = d_spigot^2 * pi/4 {m^2}

{Relative roughnesses}
ed_23 = epsilon/d_23
ed_4 = epsilon/d_4
ed_5 = epsilon/d_5
ed_6 = epsilon/d_6
ed_7 = epsilon/d_7

{Reynolds numbers}
Re_23 = rho * V_23 * d_23 / mu
Re_4 = rho * V_4 * d_4 / mu
Re_5 = rho * V_5 * d_5 / mu
Re_6 = rho * V_6 * d_6 / mu
Re_7 = rho * V_7 * d_7 / mu

{Friction Factors}
f_23 = ff(Re_23,ed_23)
f_4 = ff(Re_4,ed_4)
f_5 = ff(Re_5,ed_5)
f_6 = ff(Re_6,ed_6)
f_7 = ff(Re_7,ed_7)

{KV values}
fun = 1000
KV_A = fun
KV_B = fun
KV_C = fun
KV_D = fun
KV_E = fun
KV_F = fun
KV_G = fun
KV_H = fun
KV_I = fun
KV_J = fun


{Main Lines, major losses}
{From Point 1 to Point 2, Through Pump (Work used)}
(P_2-P_1) / (rho*g) + (z_2-z_1) = W_dot / (rho*Q_23/3600*g) - V_23^2 / (2*g) * (f_23*L_12/d_23*1.05)

{From Point2 to Point3, After Pump to Dispensery Tank}
(P_3-P_2) / (rho*g) + (z_3 - z_2) = - V_23^2 / (2*g) * (f_23*L_23/d_23*1.05)

{From Point3 to Point4, Inside dispensary}
(P_4-P_3) / (rho*g) + (z_4 - z_3) = - V_4^2 / (2*g) * (f_4*L_4/d_4*1.05)

{From Point3 to Point5, Outside dispensary}
(P_5-P_3) / (rho*g) + (z_5 - z_3) = - V_5^2 / (2*g) * (f_5*L_5/d_5*1.05)

{From Point3 to Point6, From dispensary to primary school}
(P_6-P_3) / (rho*g) + (z_6 - z_3) = - V_6^2 / (2*g) * (f_6*L_6/d_6*1.05)

{From Point3 to Point7, From dispensary to village center}
(P_7-P_3) / (rho*g) + (z_7 - z_3) = - V_7^2 / (2*g) * (f_7*L_7/d_7*1.05)


{Spigots, minor losses}
{Branch to SpigotA inside dispensary}
(P_A-P_4) / (rho*g) + (H_spigot) = - V_A^2 / (2*g) * (KV_A)

{Branch to SpigotB inside dispensary}
(P_B-P_4) / (rho*g) + (H_spigot) = - V_B^2 / (2*g) * (KV_B)
```

{Branch to SpigotC outside dispensary}
(P_C-P_5) / (rho*g) + (H_spigot) = - V_C^2 / (2*g) * (KV_C)

{Branch to SpigotD outside dispensary}
(P_D-P_5) / (rho*g) + (H_spigot) = - V_D^2 / (2*g) * (KV_D)

{Branch to SpigotE at primary school}
(P_E-P_6) / (rho*g) + (H_spigot) = - V_E^2 / (2*g) * (KV_E)

{Branch to SpigotF at primary school}
(P_F-P_6) / (rho*g) + (H_spigot) = - V_F^2 / (2*g) * (KV_F)

{Branch to SpigotG at primary school}
(P_G-P_6) / (rho*g) + (H_spigot) = - V_G^2 / (2*g) * (KV_G)

{Branch to SpigotH at village center}
(P_H-P_7) / (rho*g) + (H_spigot) = - V_H^2 / (2*g) * (KV_H)

{Branch to SpigotI at village center}
(P_I-P_7) / (rho*g) + (H_spigot) = - V_I^2 / (2*g) * (KV_I)

{Branch to SpigotJ at village center}
(P_J-P_7) / (rho*g) + (H_spigot) = - V_J^2 / (2*g) * (KV_J)

Trial	d_23 (m)	Q_23 (m^3/hr)	P_2 (Pa)	P_2psi (psi)
1	0.03	1.5	579168	84.02
2	0.035	1.5	493370	71.58
3	0.04	1.5	456017	66.16
4	0.045	1.5	437923	63.53
5	0.05	1.5	428405	62.15
6	0.03	2	687224	99.7
7	0.035	2	545221	79.1
8	0.04	2	483481	70.14
9	0.045	2	453608	65.81
10	0.05	2	437912	63.53
11	0.03	3	971509	140.9
12	0.035	3	681439	98.86
13	0.04	3	555536	80.6
14	0.045	3	494712	71.77
15	0.05	3	462798	67.14
16	0.046	2.5	466750	67.72
17	0.044	3	503847	73.1

Appendix D – Grundfos 2.5-2 Pump Curve

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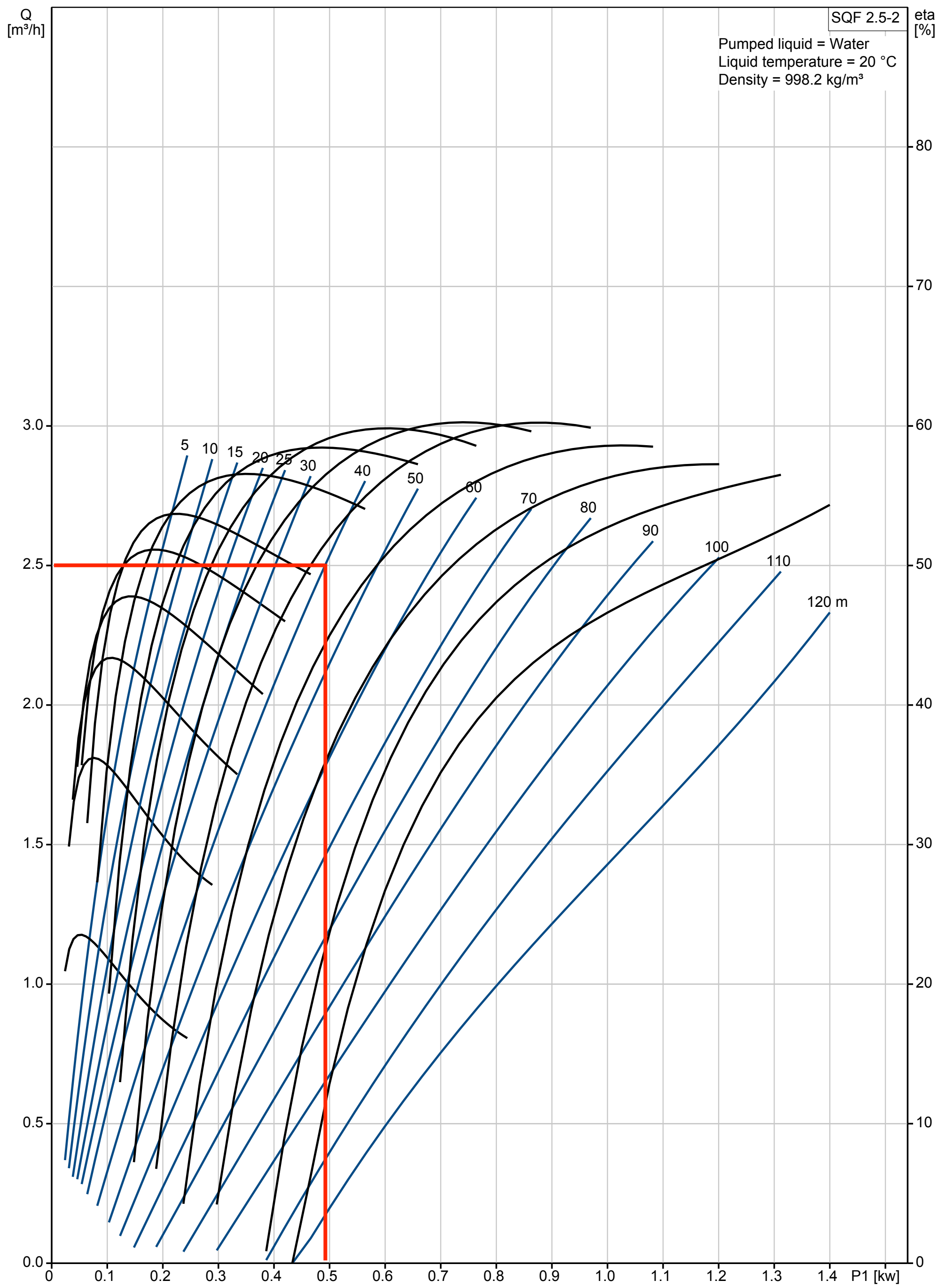

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