Lutangilo Secondary School

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2. Project Overview

2.1 Project Title

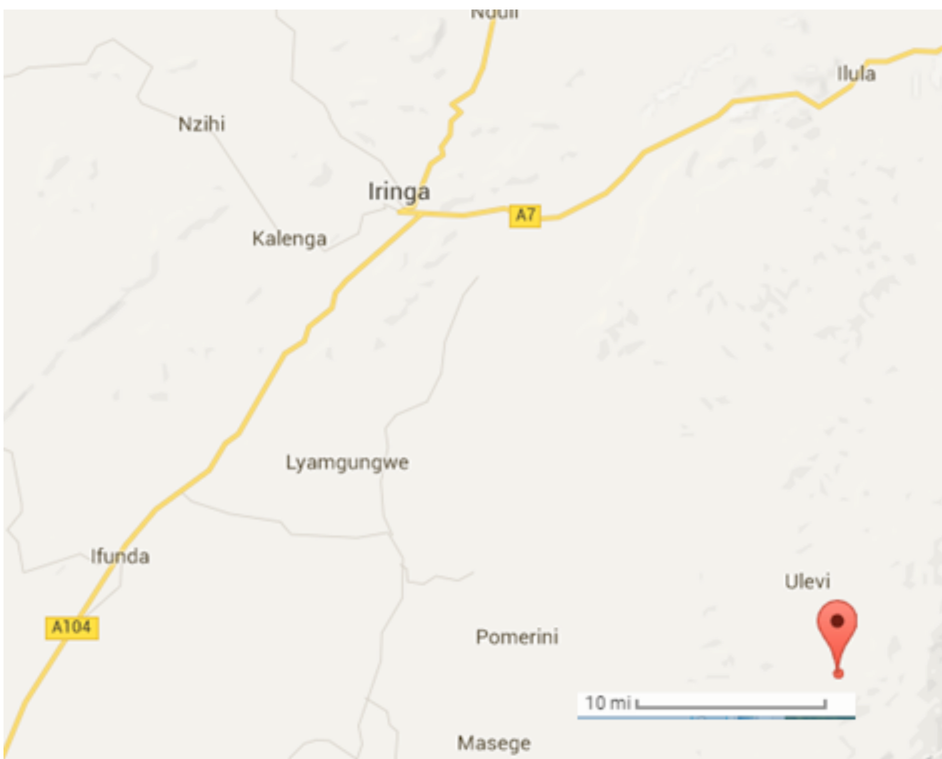
Lutangilo Secondary School solar-powered water distribution system.

2.2 Project Description

A submersible pump will supply water from an aquifer to (2) 10,000L sim tanks at the highpoint of the Lutangilo School campus. The system will have eight distribution points total - seven on-campus locations and one at a nearby dispensary about ½ km from the school grounds. Many of these distribution points will have multiple spigots in accordance to the demand at each location. The water sent to the dispensary will be stored in the two existing 5,000L sim tanks and distributed via outdoor spigots and two indoor sinks. The borehole will be air-hammered and the system will be solar-powered.

2.3 Location

Lutangilo Secondary School
Region: Iringa, Tanzania
GPS coordinates: 8° 8'15.84"S, 36° 1'1.32"E



(2.3-1)
Figure 2.3-1: Lutangilo school is approximately 55 km southeast of Iringa. The shortest drive is closer to 70 km.

2.4 In-Field Oversight

The St. Paul Partners local office in Iringa, TZ will be responsible for all in-field management and oversight regarding the implementation and progress of this system. The primary contact is Peter Simon, whose contact information is provided in Section 1.3 of this report.

2.5 Beneficiary Overview

This water distribution system is targeted to serve three groups of beneficiaries, which include (listed in order of descending priority): the patients at the nearby dispensary; the students, staff, and visitors of Lutangilo Secondary School; and lastly, the 600 people in the school's neighboring village.

2.6 Budget

Table 2.6-1: Overall project budget with air hammer option

Summarized Costs	Cost (Tsh)	Cost (USD)
Total Costs	55,983,084	26,658.61
In Kind Contribution	(5,400,000)	(2,571.43)
Contingency (10% Costs)	5,058,308	2,408.72
Total Donation Estimate	**55,641,392**	**26,495.90**

Table 2.6-2: Overall project budget with mud rotary option

Summarized Costs	Cost (Tsh)	Cost (USD)
Total Costs	50,820,584	24,200.28
In Kind Contribution	(5,400,000)	(2,571.43)
Contingency (10% Costs)	4,542,058	2,162.88
Total Donation Estimate	**49,962,642**	**23,791.73**

3. Executive Summary

3.1 Current Situation

(3.1-1)
Figure 3.1-1: School site map

3.1.1 School Logistics

- Student Population: 270
- Staff Population: 22
- Forms 1-4
- 2 Girls Dorms, 1 Boys Dorm (14-19/room)
- 8 Classrooms (all located in central 'quad')

3.1.2 Existing Amenities

- Hand Pump (clean water drawn from aquifer)
    - Installed Sept. 2014 - 24m. borehole
    - Pumps 1400 LPH (tested at max. pump rate for 30 min.)
    - Seals changed 3X in past 16 months
    - Used for: Drinking, dishes, *occasionally* bathing by female students
    - ~ 5 families also use pump

(3.1-2)
Figure 3.1-2: Elizabeth during instruction on hand pump use.

- On-Site Generator
    - Run time: 7pm - 10pm
    - Used for: Lighting
    - Sanma - single phase AC | 7.5kW | 230V
    - Fuel cost: 2500 Tsh/L
- Nearby River Water
    - Used for: Cooking, bathing (20L buckets), laundry
    - More appealing than multiple trips to the tap

(3.1-3)
Figure 3.1-3: River access point near boys' dorm

3.1.3 Nearby Dispensary

- Distance from Lutangilo School: ~½ km east of school grounds
- Patients/day: ~20 (*many* villagers accompany patients)
- Babies delivered/yr: ~60
- Nearby village population: 600
- 2 - 5000L rain-fed sim tanks behind dispensary
- 1 - 5000L rain-fed sim tank at Doctor's house near dispensary

(3.1-4)
Figure 3.1-4: One of (3) 5,000 L sim tanks at dispensary.

3.1.4 Future Plans (10-year Outlook)

- Student & Staff Population: 500
- New kitchen built near road (Completed February 2016)
- New boys' dorm south of main quad (current dorm will become admin. building)
- Additional girls' dorm due west of existing girls' dorm

3.2 St. Paul Partners Overview & Mission

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.

3.3 Project Objectives

1. Supply clean water to the dispensary and integrate current sim tanks into new system with added indoor sinks. The dispensary is critical in supporting the school and local village and would benefit greatly from improvements over its existing rain catchment system.

2. Supply clean drinking water across Lutangilo School and to the nearby village near the dispensary. A safe and reliable distribution system is central in supporting the school's expansion plan, which nearly doubles its current enrollment of 270 students.

3. Form a water committee containing members from each of the three beneficiaries. If the village of approximately 600 residents is to be supported, it is paramount that a committee is created to establish the responsibilities for each of the beneficiaries.

4. Instruct members from all three beneficiaries on proper maintenance of new system.

3.4 Deliverables

- Test drawdown of current borehole with temporary submersible pump
- Determine if current depth (24 m) has an aquafer capable of producing enough water
- Choose mud rotary or air hammer based on drawdown from existing borehole
- Size and install appropriate pump in new borehole
- Install appropriate solar system on roof of library
- Install concrete pads for (2) 10,000 L sim tanks
- Dig main pipe trench from borehole to sim tanks
- Dig and lay piping from sim tank to all distribution points
- Install spigots and pour concrete pads at distribution points
- Route water into 5000L sim tanks at dispensary and install piping supplying water to indoor sinks

3.5 Success Metrics

- Clean water to meet all patient/doctor needs at dispensary
- Accessible well water throughout entire school grounds
- Decrease reliance upon local river water

4. System Implementation

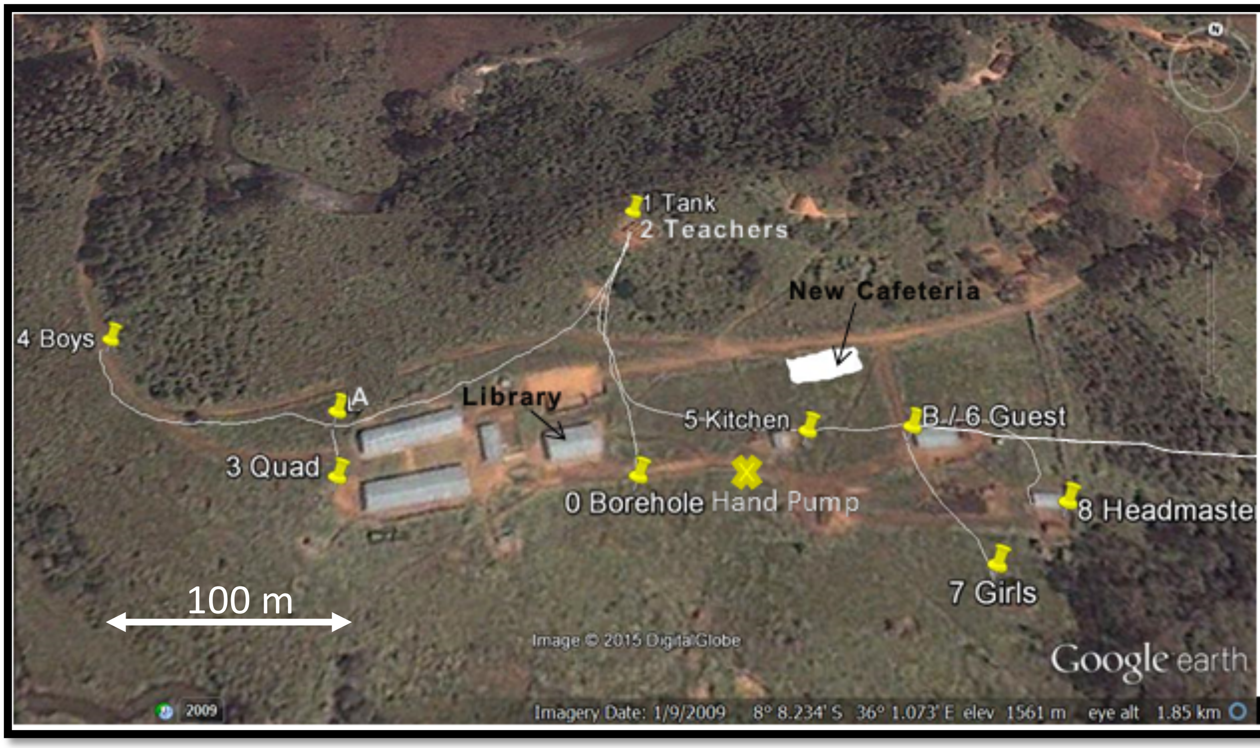
The base system will be installed on the Lutangilo School grounds. This will include a new borehole, a submersible pump, a solar panel power system, wiring, piping, and SIM tanks for storage. The distribution system is split into two main lines distributing to the eastern and western parts of the school campus. The eastern split will also have piping that will lead to the dispensary spigot location for use by the dispensary and villagers. The specific trench paths are outlined in Section 4.1 below.

The dispensary will have its own sub-system to deliver water around the dispensary. The water will flow from Lutangilo into the elevated tank behind the dispensary. Water will then flow into the dispensary for two sink and spigot combinations. There will also be a pipe leading to the two common spigots in front of the dispensary and an overflow pipe into the second tank. The layout can be seen in figure 4.2-2.

School and village ownership of the project is critical for long term sustainability. SPP will enable sustainability by leading village and school meetings, guiding water committee formation, conducting hygiene training, helping beneficiaries establish a maintenance bank account and provide initial funding for said account. Borehole drilling will be put out for bid to at least two vendors qualified to conduct air hammer drilling in this region. All things pump related will also be put out for bid to at least TransAfrica Water and Davis Shirtliff. Project planning and execution including system installation will be overseen by SPP. Trenches will be dug by school employees and villagers as an in-kind contribution for the project. Valves at the main storage tanks and at the dispensary will be utilized to meter flow going to the dispensary and village. The list of distribution points with number of spigots can be found in Table 4-1. Locations of the distribution points can be found in Figure 4-1. New system components to be installed are explained below.

Table 4-1: Distribution points

Distribution Point	Location	# spigots
2	Teacher's House	1
3	Classroom Quad	2
4	Boys' Dorm	3
5	Kitchen	2
6	Guest House	1
7	Girls' Dorm	3
8	Headmaster's house	1
9	Dispensary/Village	Tank



(4-1)

Figure 4-1: Trench runs on Lutangilo campus

4.1 Breaking Ground

Most groundbreaking work including the digging of trenches, laying of pipe, and building of concrete pads will be an in kind donation from the school and local village. The work will be supervised by SPP. A local plumber (fundi) will be hired to support the project.

All trenches shall be 1 meter deep. If the trench is to change direction or split from another trench, the radius of curvature shall not exceed the limit stated by the pipe manufacturer.

Before any ground is broken, the decision between mud rotary and air hammer drilling must be made. This decision will be based off the recharge rate of the existing borehole with temporary submersible pump. If the recharge rate is above the pumping rate, then the new borehole may be dug with a mud rotary drill as the hole does not need to go very deep to hit the same aquafer. If the recharge rate does not exceed the demand, then an air hammer may be used to drill through the bedrock to a more bountiful aquafer.

Before removing parts from the hand pump, ensure drinking water is stored for times when neither the hand pump or submersible pump used for testing, are producing water.

Existing Borehole

- The current hand pump parts shall be removed from the borehole
- A submersible pump shall be lowered into the borehole and used to test the recharge rate
- Ensure no debris falls into the borehole at any time

New Borehole

- An air hammer or mud rotary drill shall be used to drill a borehole just south of the path connecting the classroom quad to the girls' dorm. Final placement of the borehole will be defined by SPP staff working closely with the selected driller and school leaders.
- PVC casing and screen of at least 5-inch ID shall be used and backfilled with appropriate gravel pack.
- Draw down levels (dynamic water level) and the sustainable steady state water pumping yield (liters/hr) shall be determined using a temporary submersible pump
- The determined level shall be used to refine estimates for pump size and solar panel requirements

Trench Runs

- A main trench shall be dug from the borehole (0) to the main tank location (1) - cutting through the road just east of the parking lot. The two 10,000L SIM tanks will be placed on the hill near the teacher's house (2). Directly from the tank a short 4m line with a spigot will be for the teacher's water supply (no trench needed for this line).
- A western trench should tee off the main trench between the teachers' house and the parking lot, continuing on behind the north side of the quad classrooms to junction "A".
    - From junction "A" trenches shall be ran to the end of the quad at spigot location (3) as well as down the hill north of the science building foundations down to the front of the boys' dorm at spigot location (4).
- An eastern trench shall tee off of the main line east of the library and travel to the front of the new kitchen at spigot point (5) - then continue to junction "B" near the northwest corner of the guest house.
    - Near junction "B" will be a spigot location for the guest house (6). A short (~2m) trench from the junction may be needed for this spigot location.
    - Trenches shall be dug from junction "B" straight down to the girls' dorm spigot location (7)
    - The line to the headmaster's house (8) will run behind the guest house and down the short hill next to the banana tree.
    - A trench shall be dug from junction "B" through the gap in the trees, across the farm field, and up to the location of the current sim tank at the dispensary (9).

Dispensary

- A trench shall be dug from the elevated tank around the west side of the dispensary.
- Two holes shall be drilled through the wall of the dispensary for the sinks.

4.2 Component Installation

Pump

- 1-1.25HP submersible pump (still to be chosen) to be purchased from the selected solar power water system vendor. Final pump sizing will be rechecked based on finished bore hole dynamic water level and sustainable steady state water pumping yield.
- Required power estimated based on arbitrary draw-down depth, see Appendix 7.1. Power may be drastically less if a large enough recharge rate observed during current borehole testing.
- Probe sensor for detecting dry pumping situation
- The top of the bore hole shall be protected by a concrete and brick enclosure. The enclosure must have a removable lid and be large enough to provide maintenance access to the bore hole (to pull the riser pipe and pump, etc.)

Controller

- An appropriate controller matched to the submersible pump must be provided by the selected solar power water system vendor
- Install in safe location inside the library
- Run electrical cabling up to solar panels and underground to pump

Solar Panels

- (4) FDS 250W Polycrystalline solar panels to be installed on the library just southeast of the quad
- Fewer panels may be required if a smaller pump is chosen
- Panels shall be on the North-Northwest side of the building to maximize sun exposure

SIM Tanks

- A concrete pad for (2) 10,000 L SIM tanks shall be poured on the hill behind the teacher's house
- Tanks shall be connected at their bottoms by a large flexible pipe
- Steel pipe and fittings may be used to run water from the HDPE pipe up and into the top of one of the tanks

Pipes

- Black HDPE pipe shall be laid in trenches specified in Section 4.1
- Appropriate diameter and pressure ratings can be found in Figure 4.2-1

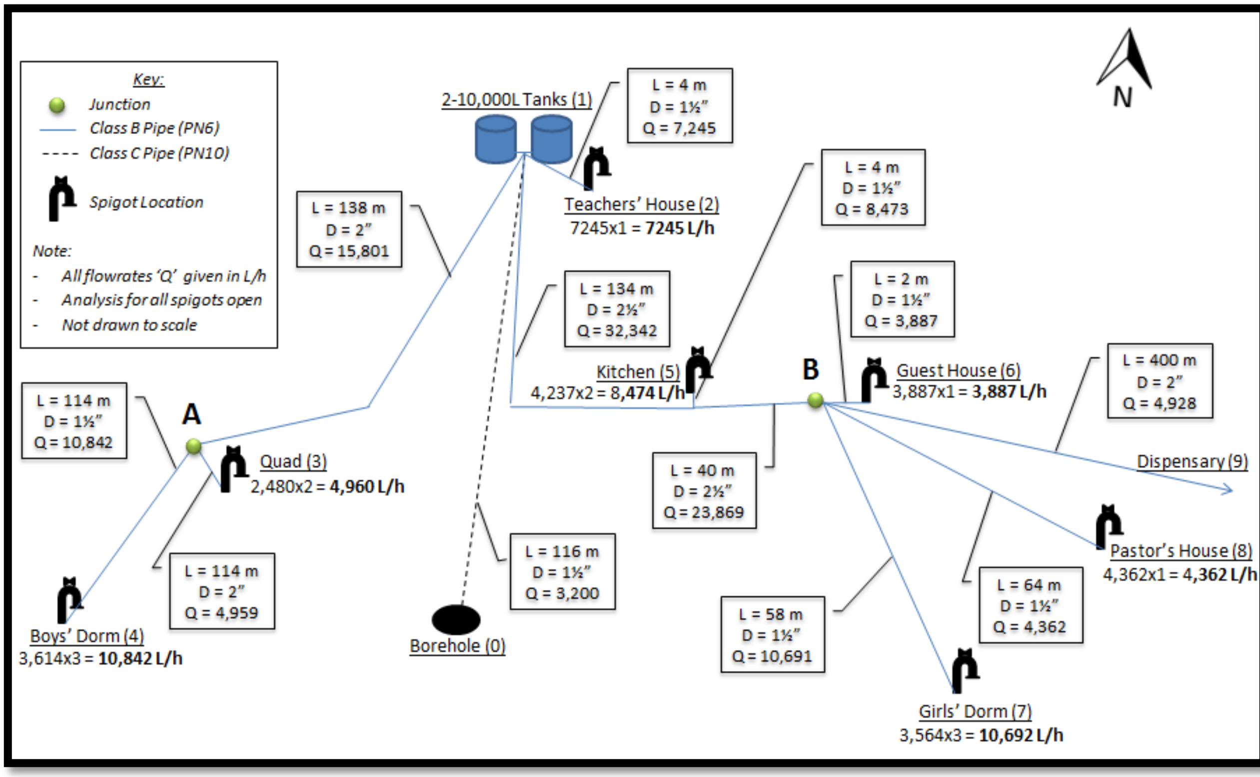


Figure 4.2-1: System layout containing pipe diameters, pressure ratings, and unrestricted flow rates

Distribution points

- The number of spigots specified in Figure 4.2-1 shall be installed at each distribution point
- The pipes supporting the spigots should be encased in a concrete base
- Reference Appendix 7.5 for photos of distribution points

Capped Pipes

- At the quad distribution site (3), the pipe shall be branched off and capped to allow for future building expansion south of the classrooms.
- At the girls' dorm distribution site (7), the pipe shall be branched off and capped to allow for future girls' dorm expansion nearer to the river
- Reference Appendix 7.3 for more detail about information about anticipated school growth

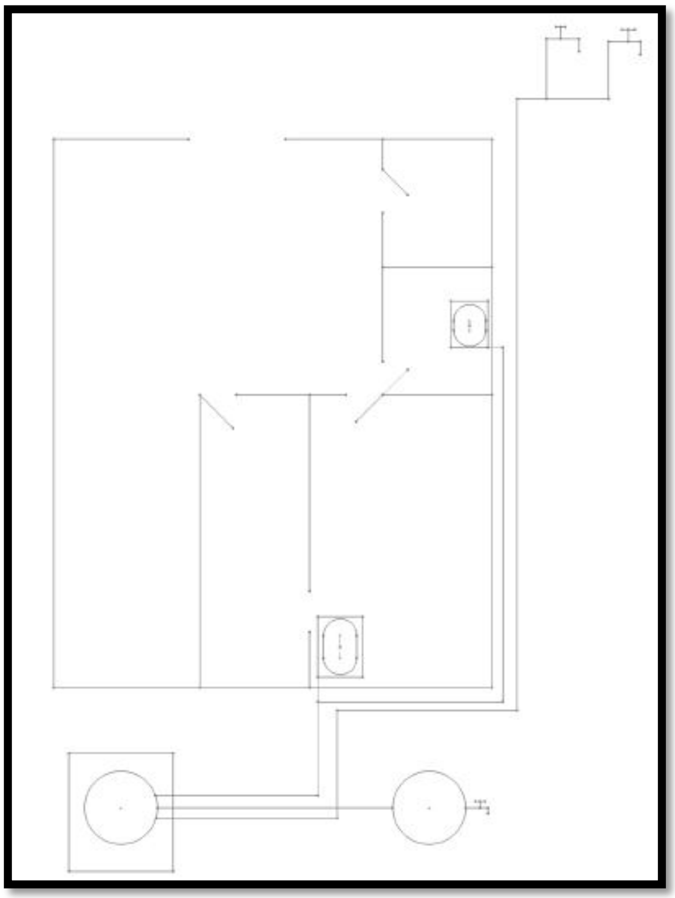
Valves

- A valve shall be located on each pipe exiting a junction to allow for leak isolation
- A valve shall be located underground in an easy to access box on the pipe heading to the dispensary

Dispensary

- Three rain collection tanks
  - The two tanks behind the dispensary will be used for clean water storage
  - The tank by the doctor's house will remain as is

- Pipes
    - The pipes from the school will go to the top of the elevated sim tank
    - There will be an overflow line from the top of the elevated tank to the lower tank
    - A pipe will flow from the elevated tank to a T and then to two sinks inside the dispensary
    - A pipe will flow from the middle of the elevated tank to two spigots in front of the dispensary for access for the villagers
    - Pipes will be one inch in diameter
- Distribution
    - The sinks will have spigots underneath so that dispensary staff can fill buckets without going outside
    - A spigot will be placed on the lower tank to replace the current corn cob plug



(4.2-2)
Figure 4.2-2: Layout of piping at dispensary

4.3 Project Site & System Layout

The highest distribution point in the system is the teacher's' house up on the hill. This dictates that the storage tanks be located higher than the house. The school lot line is 10 feet north of the house, leaving the area in between the most suitable location for the two sim tanks. Projected water demands are estimated at 38,000 L/day, therefore requiring (2) 10,000 L tanks. See Appendix 7.2 for more water demand and max/min system flow rate breakdowns. In order for the tanks to act as one large tank (both water levels equal at all times), the tank bottoms are connected by a semi-flexible pipe and valve. A flexible pipe is desirable to avoid potential strain at the connections if the tanks were to shift/deform when filled with water.

The existing hand pump on the school grounds tested to have a pump rate of about 1400 LPH with a relatively shallow borehole depth of 24 m; this proved the aquifer at this location to be somewhat sustainable and not far from the surface. An electric pump will be used to further test for the actual drawdown level and recharge rate of the existing hand pump borehole. Once the recharge rate is discovered, the decision to drill the new borehole with mud rotary or air hammer will be assessed by SPP. The new borehole location is suggested to be near to the hand pump, but final placement will again be decided by SPP.

Flow through the pipe supplying the dispensary and village can be controlled by a valve at the school just after junction "B" as well as at the dispensary near the sim tank. This allows the dispensary to shut off flow when they have enough water and the school to meter flow if the water level in the main tanks become low.

At the quad and girl's dorms, the line supplying the spigots will have an underground tee with a capped end. This is to supply the potential for building growth. The pipes leading to these areas are appropriately oversized to supply the potential growth. Reference Appendix 7.3 for specific building details.

The whole system is supplementary to the hand pump which will be untouched so that it can be used as a backup in the case of the main system being under repair.

5. System Sustainability

A water committee is recommended with representatives from all 3 beneficiaries: (2) school representatives, (1) dispensary representative, and (2) village representatives. This system, initially intended for the school, will now be providing to all three parties. The committee will be in charge of determining the means of gathering funds for any future maintenance costs, any possible in-kind contribution during the construction of the project, and ensuring timely maintenance if any problems occur. A water system maintenance bank account will be established with signatories from the water committee. Modest initial contributions from the school and villagers will be requested to provide initial funding for this account.

6. Budget

The budget shown in Table 6-1 and Table 6-2 reflect the funds needed to supply water to the Dispensary, Lutangilo, and the village near the Dispensary. The in kind contribution includes digging of the trenches, laying of piping, and concrete construction for the tank and spigot pads. A summary of how the costs were determined for the budget is located in Appendix 7.6.

Table 6-1: Budget for the water system with air hammer drilling option

	Item	Unit Price (Tsh)	Unit Price ($)	Unit	Quantity	Shipping Price (Tsh)	Shipping Price ($)	Total Price (Tsh)	Total Price ($)
1	10,000 L Sim Tank	2,400,000	1,142.86	-	2	800,000	380.95	5,600,000	2,666.67
2	Air Hammer Drilling	151,000	71.90	1 m	70	1,000,000	476.19	11,570,000	5,509.52
3	Well Development	2,650,000	1,261.90	-	1	-	-	2,650,000	1,261.90
4	Solar Panels (250 kW)	682,500	325.00	-	4				
5	Control Panel	1,907,588	908.38	-	1				
6	1 hp Pump (~700 W)	5,355,000	2,550.00	-	1	5,000,000	2,380.95	15,252,588	7,263.14
7	Borehole Cover Plate	160,000	76.19	-	1				
8	Safety Rope	100,000	47.62	-	1				
9	Electric Cable to Pump	12,668	6.03	1 m	72	-	-	912,096	434.33
10	HDPE Class B 2 inch	559,600	266.48	150 m roll	6				
11	HDPE Class B 2.5 inch	812,300	386.81	150 m roll	2	600,000	285.71	5,555,400	2,645.43
12	PVC 5 inch Class C	92,229	43.92	6 m	10				
13	Tank Fittings	107,000	50.95	-	4	-	-	408,000	194.29
14	Tap Fittings	107,000	50.95	-	14	-	-	1,428,000	680.00
15	2 Inch Pipe Coupling	22,000	10.48	-	5	-	-	225,000	107.14
16	2.5 Inch Pipe Coupling	31,000	14.76	-	2	-	-	270,000	128.57
17	Cement	16,000	7.62	Bag	66	600,000	285.71	1,656,000	788.57
18	Sand	105,000	50.00	Lorry	2	400,000	190.48	600,000	285.71
19	Gravel	105,000	50.00	Lorry	2	450,000	214.29	650,000	309.52
20	Ball Valve	66,000	31.43	-	3	-	-	198,000	94.29
21	Float Valve	179,000	85.24	-	2	-	-	358,000	170.48
22	Labor for Digging Trenches	4,500	2.14	1 meter	1200	-	-	5,400,000	2,571.43
23	SPP Oversight	2,100,000	1,000.00	-	-	-	-	2,100,000	1,000.00
24	Sinks	100,000	47.62	-	2	-	-	100,000	47.62
25	Plumber/Fundi	1,050,000	500.00	-	-	-	-	1,050,000	500.00
Total		**-**	**-**			**8,850,000**	**4,214.29**	**55,983,084**	**26,658.61**

Table 6-2: Budget for the water system with mud rotary drilling option

	Item	Unit Price (Tsh)	Unit Price ($)	Unit	Quantity	Shipping Price (Tsh)	Shipping Price ($)	Total Price (Tsh)	Total Price ($)
1	10,000 L Sim Tank	2,400,000	1142.86	-	2	800,000	380.95	5,600,000	2,666.67
2	Mud Rotary Drilling	6,090,000	2900.00	m	Up to 70	1,000,000	476.19	7,090,000	3,376.19
3	Well Development	2,650,000	1261.90	-	1	-	-	2,650,000	1,261.90
4	Solar Panels (250 kW)	682,500	325.00	-	3	5,000,000	2380.95	14,570,088	6,938.14
5	Control Panel	1,907,588	908.38	-	1				
6	1 hp Pump (~700 W)	5,355,000	2550.00	-	1				
7	Borehole Cover Plate	160,000	76.19	-	1				
8	Safety Rope	100,000	47.62	-	1				
9	Electric Cable to Pump	12,668	6.03	1 m	72	-	-	912,096	434.33
10	HDPE Class B 2 inch	559,600	266.48	150 m roll	6	600,000	285.71	5,555,400	2,645.43
11	HDPE Class B 2.5 inch	812,300	386.81	150 m roll	2				
12	PVC 5 inch Class C	92,229	43.92	6 m	10				
13	Tank Fittings	107,000	50.95	-	4	-	-	408,000	194.29
14	Tap Fittings	107,000	50.95	-	14	-	-	1,428,000	680.00
15	2 Inch Pipe Coupling	22,000	10.48	-	5	-	-	225,000	107.14
16	2.5 Inch Pipe Coupling	31,000	14.76	-	2	-	-	270,000	128.57
17	Cement	16,000	7.62	Bag	66	600,000	285.71	1,656,000	788.57
18	Sand	105,000	50.00	Lorry	2	400,000	190.48	600,000	285.71
19	Gravel	105,000	50.00	Lorry	2	450,000	214.29	650,000	309.52
20	Ball Valve	66,000	31.43	-	3	-	-	198000	94.29
21	Float Valve	179,000	85.24	-	2	-	-	358000	170.48
22	Labor for Digging	4,500	2.14	1 meter	1200	-	-	5,400,000	2,571.43

	Trenches								
23	SPP Oversight	2,100,000	1000.00	-	-	-	-	2,100,000	1,000.00
24	Sinks	100,000	47.62	-	2	-	-	100,000	47.62
25	Plumber/Fundi	1,050,000	500.00	-	-	-	-	1,050,000	500.00
Total			-	-		**8,850,000**	**4214.29**	**50,820,584**	**24,200.28**

Table 6-3: Overall project budget for airm hammer drilling

Summarized Costs	**Cost (Tsh)**	**Cost (USD)**
Drilling	14,220,000	6,771.43
Piping and Tank	14,042,400	6,686.86
Solar and Pump	16,164,684	7,697.47
Materials	3,006,000	1,431.43
Labor	5,400,000	2,571.43
SSP Oversight	2,100,000	1,000.00
Plumber/Fundi	1,050,000	500.00
In Kind Contribution	(5,400,000)	(2,571.43)
Contingency (10% Costs)	5,058,308	2,408.72
Total	**55,641,392**	**26,495.90**

Table 6-4: Overall project budget for mud rotary drilling

Summarized Costs	**Cost (Tsh)**	**Cost (USD)**
Drilling	9,740,000	4,638.10
Piping and Tank	14,042,400	6,686.86
Solar and Pump	15,482,184	7,372.47
Materials	3,006,000	1,431.43
Labor	5,400,000	2,571.43
SSP Oversight	2,100,000	1,000.00
Plumber/Fundi	1,050,000	500.00
In Kind Contribution	(5,400,000)	(2,571.43)
Contingency (10% Costs)	4,542,058	2,162.88
Total	**49,962,642**	**23,791.73**

7. Appendices

Appendix 7.1: Pump Sizing Calculations

Several assumptions were made in order to obtain an estimate of the required pump power. One, the borehole has not been drilled yet, so it is impossible to know how far down to drill for water. Two, until a temporary pump is lowered into the borehole, it is not possible to determine the drawdown depth. Given that the hand pump borehole contains water at 24m, we are confident water is not very far from the surface. A bore depth of 70 m and a drawdown of 50 m were assumed. The required power needed to be input into the water is 588 W. The pump would need to be slightly larger to account for electrical and pumping inefficiencies. If the drawdown is less than assumed, a less powerful pump may be used as the total head calculated from the well's water surface to the tank would be less. If the drawdown is deeper, a larger pump would be required.

This analysis also assumes that the well has a high enough recharge rate in order to supply 3200 L/hr. Other boreholes drilled by SPP have had recharge rates between 1400 to 2500 L/hr. The current hand pump borehole can produce 1500 L/hr at a depth of only 24 m. Given this, the team is hopeful that a new borehole in the area could push the upper recharge rates seen by SPP. If the borehole cannot produce 3200 L/hr, see Appendix 7.2 for contingency plan.

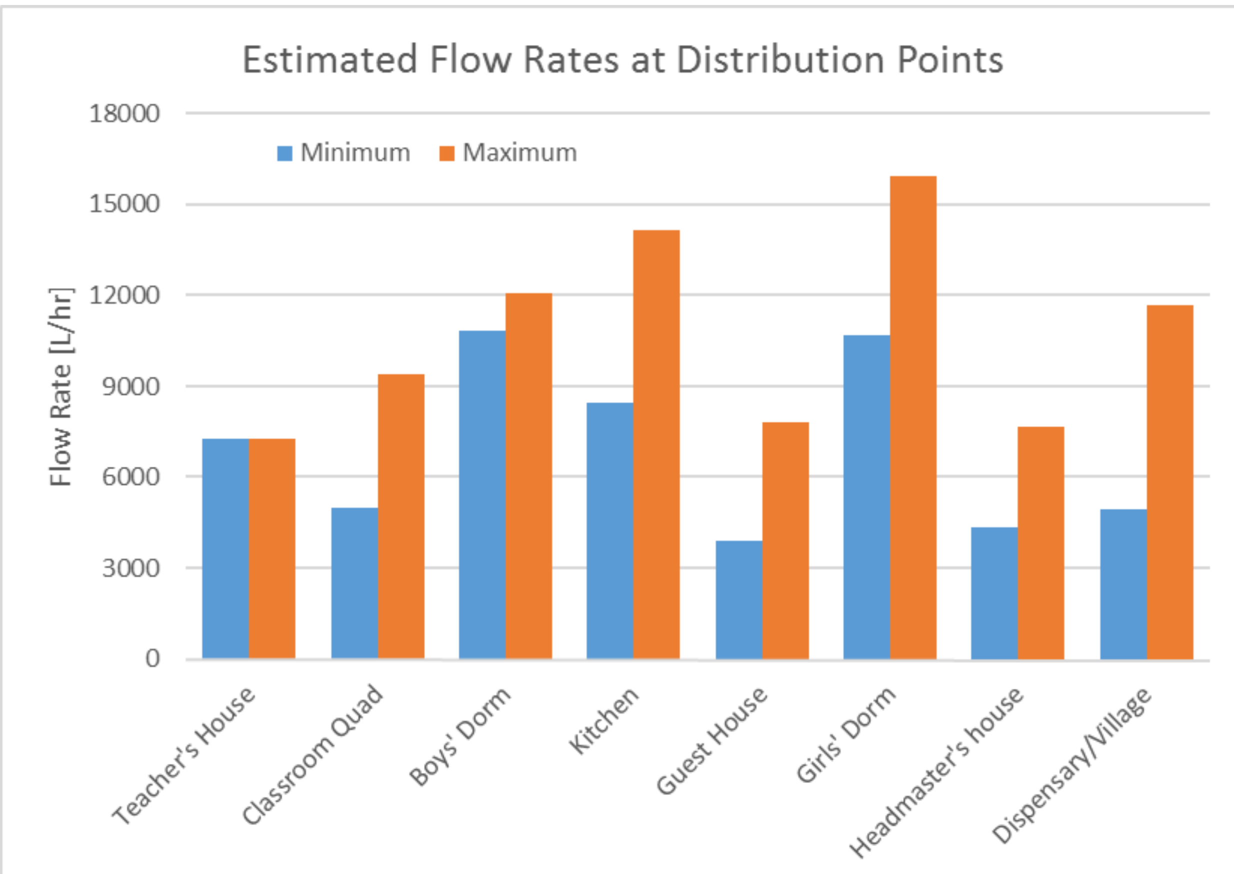
Appendix 7.2: Water Demand Calculations

The water calculation began with the current population estimates. For Lutangilo, the 10 year growth value was given by the headmaster as the predicted future population. The additional population estimates were determined using a 16 % growth over 10 years. The estimate for the amount of water used by a person in one day is 25 L. This was used to determine the average water need to be supplied by the system. The max usage or peak usage in a day was determined by tripling the average usage calculation.

Based on previous borehole sites overseen by SPP, 3200 L/hr is a large recharge rate and therefore requires a contingency plan if the borehole falls short of delivery. Out of the 25L of water per day per person quota, a large portion goes towards bathing. Bathing may be completed using river water while potable well water should be saved for drinking and cooking, thus drastically reducing water demand.

Table 7.2-1: Water Demand Calculations

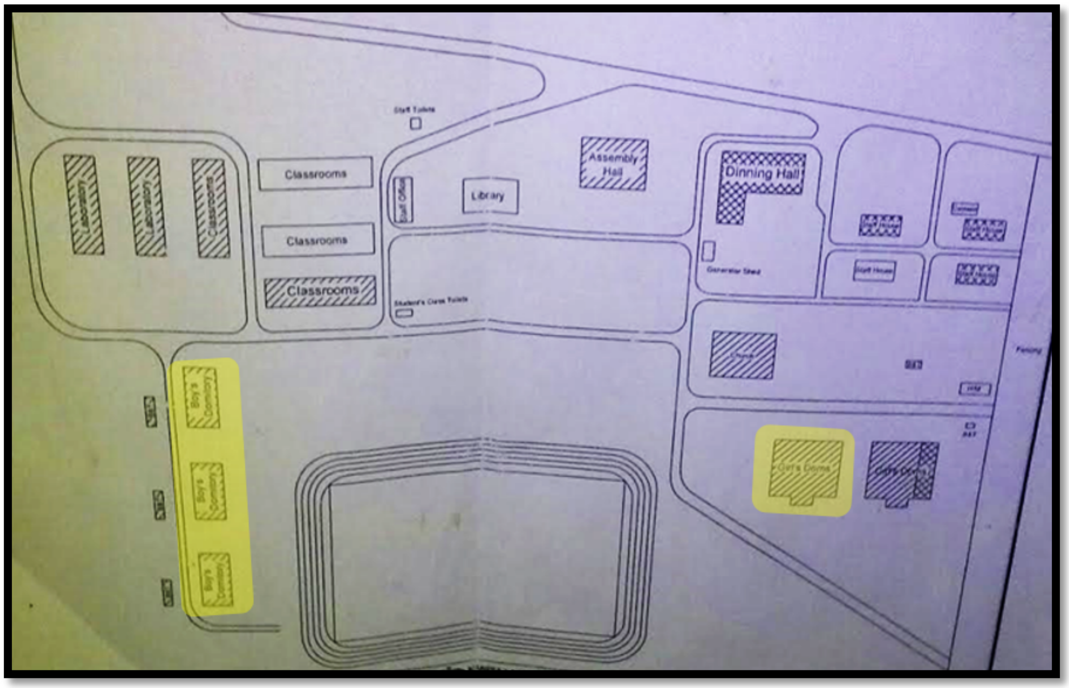
	Present	10 years (16%)	L/person/day	L/day	Average (L/hr)	Max Usage (L/hr)
Lutangilo	300	500	25	12500	1041.67	3125
Girls' Dorms	115	235	25	5875	489.58	1468.75
Boys' Dorms + Quad	115	235	25	5875	489.58	1468.75
Headmaster + Guests	25	30	25	750	62.50	187.5
Dispensary	21	25	25	1000	83.33	250
Village	600	696	25	17400	1450.00	4350
Water loss (25%)				7725	643.75	1931.25
Total		**1221**		**38625**	**3218.75**	**9656.25**



(7.2-1)

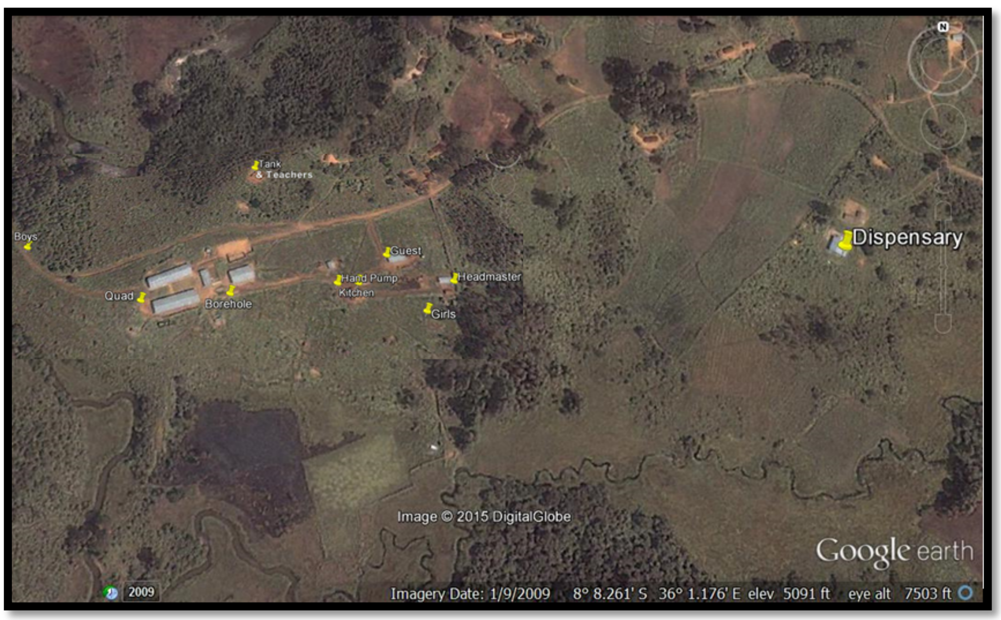
Figure 7.2-1: The maximum and minimum flow rates predicted for each distribution point

Appendix 7.3: School Future Growth



The map above shows the building additions for Lutangilo Secondary School. The buildings highlighted above are expected to be built within the next ten years and are considered in the placement of taps for the water system.

Appendix 7.4: Satellite View of Entire System



Google Earth Image of Lutangilo Secondary School

Appendix 7.5: Photos of Distribution Points

Tap location for headmaster's house

Tap location for teacher's house

Dispensary system

Taps location for girl’s dorm located between the two buildings

Tap location in front of the guest house

Tap location for quad

Appendix 7.6: Determination of Budget Costs

	Cost Determination
1	Price from Chemi & Cotex dated January 2016
2	Drilling, screen/casing, gravel pack from Freddie Hydro Rocks, January 2015 inflated by 10%.
3	Well flushing, determining dynamic water level at measured flow rate, water analysis from Freddie Hydro Rocks, January 2015 inflated by 10%.
4	TransAfrica Water August 2015 inflated by 5%
5	TransAfrica Water August 2015 inflated by 5%
6	TransAfrica Water August 2015 inflated by 5%
7	TransAfrica Water August 2015 inflated by 5%
8	TransAfrica Water August 2015 inflated by 5%
9	TransAfrica Water August 2015 inflated by 5%
10	Chemi & Cotex February 2016
11	Chemi & Cotex February 2016
12	Sita Steel Rollings LDT dated January 2015 inflated by 5%
13	From Ihemi Report inflated by 5%
14	From Ihemi Report inflated by 5%
15	From Ihemi Report scaled for pipe dimensions
16	From Ihemi Report scaled for pipe dimensions
17	From Hanael with Saint Paul Partners
18	From Mlangali report inflated by 5%
19	From Mlangali report inflated by 5%
20	From Ilula report inflated by 5%
21	From Ilula report inflated by 5%
22	From Hanael with Saint Paul Partners
23	From Ken Smith with Saint Paul Partners
24	From Ken Smith with Saint Paul Partners

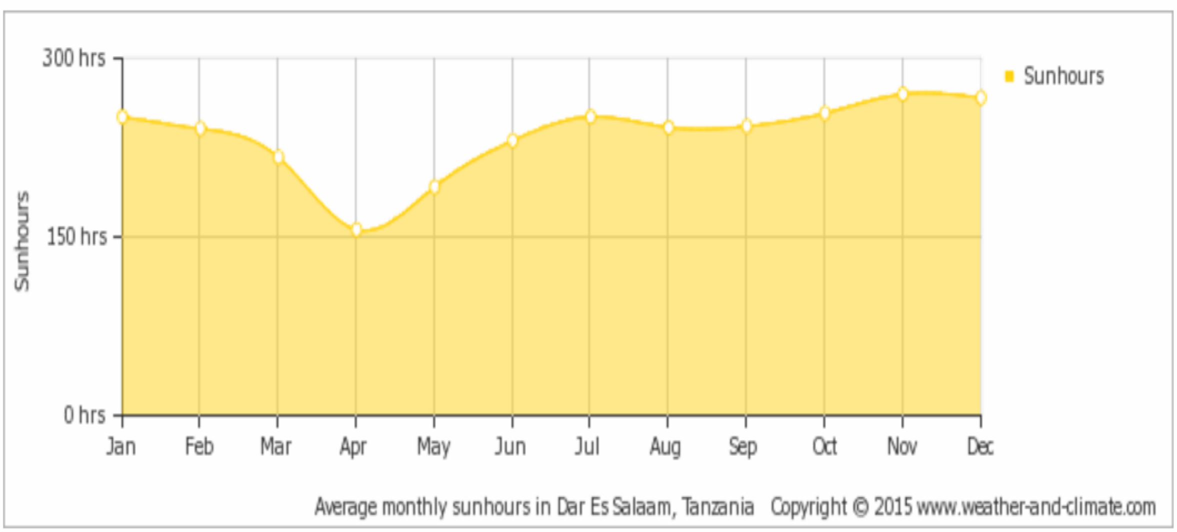
Appendix 7.7: Solar Irradiance for Iringa, Tanzania

The solar irradiance for Iringa, Tanzania was found from the Solar Electricity Handbook[1].

Table 7.7-1: Irradiation for panels that make a 82° angle with the vertical

Month	Solar Irradiation (kWh/m2)	Solar Irradiation (kWh/m2)
January	5.56	5.42
February	5.60	5.46
March	5.71	5.57
April	5.80	5.66
May	6.05	5.90
June	6.70	6.53
July	6.83	6.66
August	6.81	6.64
September	6.72	6.55
October	6.65	6.48
November	6.45	6.29
December	5.90	5.75
	Facing North	**Facing N-NW (22.5 degrees from N)**

The diagram below shows the average sunshine hours for each month in Dar es Salaam. The value ranges from 5 to 8 hours of sunshine each day depending on the month of the year[2]. The amount of solar panels needed for the system were determined by dividing the necessary power by 250 W, which is the power supplied by a single solar cell. The number of panels was determined to be 3 and an additional one was added to account for the variance in sunlight between months.



(7.7-1)

Figure 7.7-1: Monthly total of sun hours over the year in Dar es Salaam, Tanzania

1. http://solarelectricityhandbook.com/solar-irradiance.html
2. https://weather-and-climate.com/average-monthly-hours-Sunshine,Dar-Es-Salaam,Tanzania

Appendix 7.8: Generator and Solar Power Comparison

The cost analysis is compared below for a solar power system and a generator powered system over a ten-year period. The generator cost determination uses an 8-hour period of power to pump water because 8 hours is the upper bound that can be achieved by a solar powered system. The generator is currently used for 3 to 3.5 hours, so the generator would need to be run an additional 4.5 hours. The fuel cost per hour is used from the current fuel cost for running the generator at the school, so the cost may increase if used to power the pump in the water system. The cost analysis demonstrates that the solar system is more cost effective in the long term life of the water system.

Table 7.8-1: Solar powered system cost per day of operation over a ten-year period

Solar System	Quantity	Power (kW)/panel	Cost/unit (Tsh)	Total Cost (Tsh)	Total Cost (USD)	Cost/day over 10 yrs (Tsh)	Cost/day over 10 yrs (USD)
Solar Panels	4	250	700,000	2,800,000	$1,333.33	767.12	$0.37
Control Panel	1	-	1,907,558	1,907,558	$908.36	522.62	$0.25
Total			**2,607,558**	**4,707,558**	**$2,241.69**	**1,289.74**	**$0.61**

Table 7.8-2: Generator powered system cost per day of operation

Generator	Additional Run Time (hrs)	Cost/hr (Tsh)	Cost/day (tsh)	USD
Fuel	4.5	2500	11250	$5.36

Appendix 7.9: Main System EES Code + Solutions

```
function ff(Re,ed)
    if (Re>2200) then
      ff:=1/(-1.8*log10( (ed/3.7)^1.11 + 6.9/Re))^2 {turbulent flow}
    else
      if (Re=0) then
        ff:=0 {no flow}
      else
          ff:=64/Re    {laminar flow}
      endif
    endif
end

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

{Constants}
rho = 1000 {kg/m^3} {density of water}
mu = 0.0011 {N*s/m^2} {dynamic viscosity of water}
epsilon = 1E-5 {m} {inner pipe }
g=9.81 {m/s^2}
K_L=1.05 {unitless frictional losses}
Ds = 0.0226 {Diameter of spigot from ChemCotex 3/4" ClassB OD to ID calculation}
Ys = 1 {m} {height of spigot}

{Valve KV loss Values   ????RANGE????}
KV_2a = 10{dim}  {Teacher's house}
KV_3a = 10 {dim}  {Quad}
KV_3b = 10 {dim}
KV_4a = 10 {dim}  {Boy's Dorm}
KV_4b = 10 {dim}
KV_4c = 10 {dim}
KV_5a = 10 {dim}  {Kitchen}
KV_5b = 10 {dim}
KV_6a = 10 {dim}  {Guest House}
KV_7a = 10 {dim}  {Girl's Dorm}
KV_7b = 10 {dim}
KV_7c = 10 {dim}
KV_8a = 10 {dim}  {Headmaster's House}
KV_9a = 10 {dim}  {Dispensary}

{ Key
Borehole -> 0
Supply Tank ->1
Teachers' House -> 2
Quad (Classrooms) -> 3
Boys' Dorm ->4
Kitchen -> 5
Guest House ->6
Girls' Dorm -> 7
Headmaster's House -> 8
Dispensary -> 9
Quad Junction -> A
Guest House Junction -> B
Kitchen Junction -> K}
```

```
{Relative Elevations (Absolute Elevation - x) }
Y01 = -17  {m}  {Height from tank to top of borehole}
Y_dd = -50 {m}  {Draw down}
Y_p = -70 {m}  {Depth of pump from ground level}

Y1= 0 {m}
Y2= -1 {m}
YA= -11 {m}
Y3= -10 {m}
Y4= -21 {m}
YK=-17 {m}
Y5= -17 {m}
YB= -18 {m}
Y6=-18 {m}
Y7= -22 {m}
Y8= -20 {m}
Y9= -19 {m}

{Pipe Lengths}
L01 = 116 {m}
L12 = 4 {m}
L1A = 138 {m}
LA3 = 21 {m}
LA4 = 114 {m}
L1K = 134 {m}
LK5 = 4 {m}
LKB = 40 {m}
LB6 = 2 {m}
LB7 = 58 {m}
LB8 = 64 {m}
LB9 = 400 {m}

{Other Length Calculations}
Y_dd1 = Y01 + Y_dd {m}  {Total height from water free surface to tank}
L_pump = Y_p + L01 {m}  {Total length from pump to tank}


{Borehole to Tank, 0 to 1}
{Assume rechange rate of 1500 L/h}
Q01lph=4500 {L/h}
Q01=Q01lph*convert(l/h,m^3/s) {m^3/s}
Q01=V01*pi*D01^2/4
D01=0.0423 {m}
    {Pump Power}
    Re01 = rho*V01*D01/mu {dim}
    f01=ff(Re01,epsilon/D01) {dim}
    P01_Max=rho*g*(Y1-Y_dd1) + rho*V01^2/2*(f01*L_pump/D01)*K_L {Pa}
    W_dot=P01_Max*Q01 {W}

{Tank to Teachers, 1 to 2}
Q12=V12*pi*D12^2/4 {m^3/s}
Q12lph=Q12*convert(m^3/s,l/h) {L/h}
D12=0.0452 {m}
Re12 = rho*V12*D12/mu {dim}
f12=ff(Re12,epsilon/D12) {dim}
```

```
Y2-Y1=-V12^2/2/g*(  f12*L12/D12 + KV_2a)*K_L

{Tank to Quad/Boys}
    {Tank to Split-A, 1 to A}
    Q1A= QA3 + QA4
    Q1A=Q1Alph*convert(l/h,m^3/s) {m^3/s}
    D1A=0.057 {m}
    Q1A=V1A*pi*D1A^2/4
    Re1A = rho*V1A*D1A/mu {dim}
    f1A=ff(Re1A,epsilon/D1A) {dim}
    (PA)/rho/g+(YA-Y1)=-V1A^2/2/g*(f1A*L1A/D1A)*K_L

    {Split-A to Quad, A to 3} {3 to 3a/b}
      {A to 3}
      QA3=QA3lph*convert(l/h,m^3/s) {m^3/s}
      QA3=VA3*pi*DA3^2/4
      DA3=0.057 {m}
      ReA3 = rho*VA3*DA3/mu {dim}
      fA3=ff(ReA3,epsilon/DA3) {dim}
      (P3-PA)/rho/g + (Y3-YA)=-VA3^2/2/g*(fA3*LA3/DA3)*K_L

            QA3 = Q33a + Q33b

            {3 to 3a}
            Q33a=Q33alph*convert(l/h,m^3/s) {m^3/s}
            Q33a=V33a*pi*Ds^2/4
            (-P3)/rho/g + (Ys)=-V33a^2/2/g*(KV_3a)*K_L
            {3 to 3b}
            Q33b=Q33blph*convert(l/h,m^3/s) {m^3/s}
            Q33b=V33b*pi*Ds^2/4
            (-P3)/rho/g + (Ys)=-V33b^2/2/g*(KV_3b)*K_L



    {Split-A to Boys, A to 4} {4 to 4a/b/c}
       {A to 4}
       QA4=QA4lph*convert(l/h,m^3/s) {m^3/s}
       QA4=VA4*pi*DA4^2/4
       DA4=0.0452  {m}
       ReA4 = rho*VA4*DA4/mu {dim}
       fA4=ff(ReA4,epsilon/DA4) {dim}
       (P4-PA)/rho/g + (Y4-YA)=-VA4^2/2/g*(fA4*LA4/DA4)*K_L

            QA4 = Q44a + Q44b + Q44c

            {4 to 4a}
            Q44a=Q44alph*convert(l/h,m^3/s) {m^3/s}
            Q44a=V44a*pi*Ds^2/4
            (-P4)/rho/g + (Ys)=-V44a^2/2/g*(KV_4a)*K_L
            {4 to 4b}
            Q44b=Q44blph*convert(l/h,m^3/s) {m^3/s}
            Q44b=V44b*pi*Ds^2/4
            (-P4)/rho/g + (Ys)=-V44b^2/2/g*(KV_4b)*K_L
            {4 to 4c}
            Q44c=Q44clph*convert(l/h,m^3/s) {m^3/s}
            Q44c=V44c*pi*Ds^2/4
```

```
        (-P4)/rho/g + (Ys)=-V44c^2/2/g*(KV_4c)*K_L


{Tank to Kitchen/Guest/Girls/Headmaster/Dispensary}
  {Tank to Kitchen-split, 1 to K}
  Q1K=Q1Klph*convert(l/h,m^3/s) {m^3/s}
  Q1K=QKB+QK5
    D1K=0.0679 {m}
  Q1K=V1K*pi*D1K^2/4 {m^3/s}
  Re1K = rho*V1K*D1K/mu {dim}
  f1K=ff(Re1K,epsilon/D1K) {dim}
  (PK)/rho/g+(YK-Y1)=-V1K^2/2/g*(f1K*L1K/D1K)*K_L

  {Kitchen-split to Kitchen, K to 5}
  QK5=QK5lph*convert(l/h,m^3/s) {m^3/s}
  DK5=0.0452  {m}
  QK5=VK5*pi*DK5^2/4 {m^3/s}
  ReK5 = rho*VK5*DK5/mu {dim}
  fK5=ff(ReK5,epsilon/DK5) {dim}
  (P5-PK)/rho/g + (Y5-YK)=-VK5^2/2/g*(fK5*LK5/DK5)*K_L

        QK5 = Q55a + Q55b

        {5 to 5a}
        Q55a=Q55alph*convert(l/h,m^3/s) {m^3/s}
        Q55a=V55a*pi*Ds^2/4
        (-P5)/rho/g + (Ys)=-V55a^2/2/g*(KV_5a)*K_L
        {5 to 5b}
        Q55b=Q55blph*convert(l/h,m^3/s) {m^3/s}
        Q55b=V55b*pi*Ds^2/4
        (-P5)/rho/g + (Ys)=-V55b^2/2/g*(KV_5b)*K_L


  {Kitchen-split to Split-B, K to B}
  QKB=QB6+QB7+QB8 + QB9 {m^3/s}

  QKB=QKBlph*convert(l/h,m^3/s) {m^3/s}
  QKB=VKB*pi*DKB^2/4 {m^3/s}
    DKB=0.0679 {m}
  ReKB = rho*VKB*DKB/mu {dim}
  fKB=ff(ReKB,epsilon/DKB) {dim}
  (PB-PK)/rho/g+ (YB-YK)=-VKB^2/2/g*(fKB*LKB/DKB)*K_L

     {Split-B to Guest, B to 6} {6 to 6a}
     QB6=QB6lph*convert(l/h,m^3/s) {m^3/s}
     QB6=VB6*pi*DB6^2/4 {m^3/s}
     DB6=0.0452  {m}
     ReB6 = rho*VB6*DB6/mu {dim}
     fB6=ff(ReB6,epsilon/DB6) {dim}
     (P6-PB)/rho/g+ (Y6-YB)=-VB6^2/2/g*(fB6*LB6/DB6)*K_L

        QB6 = Q66a

        {6 to 6a}
        Q66a=Q66alph*convert(l/h,m^3/s) {m^3/s}
        Q66a=V66a*pi*Ds^2/4
```

```
    (-P6)/rho/g + (Ys)=-V66a^2/2/g*(KV_6a)*K_L

{Split-B to Girls, B to 7} {7 to 7a/b/c}
QB7=QB7lph*convert(l/h,m^3/s) {m^3/s}
QB7=VB7*pi*DB7^2/4 {m^3/s}
DB7=0.0452  {m}
ReB7 = rho*VB7*DB7/mu {dim}
fB7=ff(ReB7,epsilon/DB7) {dim}
(P7-PB)/rho/g+ (Y7-YB)=-VB7^2/2/g*(fB7*LB7/DB7)*K_L

    QB7 = Q77a + Q77b +Q77c

    {7 to 7a}
    Q77a=Q77alph*convert(l/h,m^3/s) {m^3/s}
    Q77a=V77a*pi*Ds^2/4
    (-P7)/rho/g + (Ys)=-V77a^2/2/g*(KV_7a)*K_L
    {7 to 7b}
    Q77b=Q77blph*convert(l/h,m^3/s) {m^3/s}
    Q77b=V77b*pi*Ds^2/4
    (-P7)/rho/g + (Ys)=-V77b^2/2/g*(KV_7b)*K_L
    {7 to 7c}
    Q77c=Q77clph*convert(l/h,m^3/s) {m^3/s}
    Q77c=V77c*pi*Ds^2/4
    (-P7)/rho/g + (Ys)=-V77c^2/2/g*(KV_7c)*K_L

{Split-B to Headmaster, B to 8} {8 to 8a}
QB8=QB8lph*convert(l/h,m^3/s) {m^3/s}
QB8=VB8*pi*DB8^2/4 {m^3/s}
DB8=0.0452  {m}
ReB8 = rho*VB8*DB8/mu {dim}
fB8=ff(ReB8,epsilon/DB8) {dim}
(P8-PB)/rho/g+ (Y8-YB)=-VB8^2/2/g*(fB8*LB8/DB8)*K_L

    QB8 = Q88a

    {8 to 8a}
    Q88a=Q88alph*convert(l/h,m^3/s) {m^3/s}
    Q88a=V88a*pi*Ds^2/4
    (-P8)/rho/g + (Ys)=-V88a^2/2/g*(KV_8a)*K_L

{Split-B to Dispensary, B to 9} {9 to 9a}
QB9=QB9lph*convert(l/h,m^3/s) {m^3/s}
QB9=VB9*pi*DB9^2/4 {m^3/s}
DB9=0.057 {m}
ReB9 = rho*VB9*DB8/mu {dim}
fB9=ff(ReB9,epsilon/DB9) {dim}
(P9-PB)/rho/g+ (Y9-YB)=-VB9^2/2/g*(fB9*LB9/DB9)*K_L

    QB9 = Q99a

    {9 to 9a}
    Q99a=Q99alph*convert(l/h,m^3/s) {m^3/s}
    Q99a=V99a*pi*DB9^2/4
    (-P9)/rho/g + (Ydisp)=-V99a^2/2/g*(KV_9a)*K_L
    Ydisp = 3 {m} {max height from ground to water level in tank @Dispensary}
```

Solutions

1. The first solution set was solved with all spigots turned on (KV=10). This will determine the minimum flow rates observed at the distribution points. These values were used to build the “predicted flow rates” figure in Appendix 7.2. The highlighted flow rates are those solely supplying all spigots at one distribution point. Take note that the differential pressures at times may be below the suggested 0.5 bar limit. The differential pressures are directly linked to the flow rates delivered at the distribution points, which are predicted to be more than adequate. Therefore, the low differentials are inconsequential.

Unit Settings: SI C kPa J mass deg

D01 = 0.0423 [m]	D12 = 0.0452 [m]	D1A = 0.057 [m]	D1K = 0.0679 [m]	DA3 = 0.057 [m]	DA4 = 0.0452 [m]
DB6 = 0.0452 [m]	DB7 = 0.0452 [m]	DB8 = 0.0452 [m]	DB9 = 0.057 [m]	DK5 = 0.0452 [m]	DKB = 0.0679 [m]
Ds = 0.0226 [m]	ε = 0.00001 [m]	f01 = 0.02317	f12 = 0.02125	f1A = 0.019	f1K = 0.0172
fA3 = 0.02407	fA4 = 0.0197	fB6 = 0.02424	fB7 = 0.01974	fB8 = 0.02362	fB9 = 0.02544
fK5 = 0.02061	fKB = 0.01809	g = 9.81 [m/s^2]	KV_{2a} = 10	KV_{3a} = 10	KV_{3b} = 10
KV_{4a} = 10	KV_{4b} = 10	KV_{4c} = 10	KV_{5a} = 10	KV_{5b} = 10	KV_{6a} = 10
KV_{7a} = 10	KV_{7b} = 10	KV_{7c} = 10	KV_{8a} = 10	KV_{9a} = 10	K_L = 1.05
L01 = 116 [m]	L12 = 4 [m]	L1A = 138 [m]	L1K = 134 [m]	LA3 = 21 [m]	LA4 = 114 [m]
LB6 = 2 [m]	LB7 = 58 [m]	LB8 = 64 [m]	LB9 = 400 [m]	LK5 = 4 [m]	LKB = 40 [m]
L_{pump} = 46 [m]	μ = 0.0011 [N*s/m^2]	$P01_{Max}$ = 667734 [Pa]	P3 = 25287 [Pa]	P4 = 42688 [Pa]	P5 = 54995 [Pa]
P6 = 47849 [Pa]	P7 = 41781 [Pa]	P8 = 57711 [Pa]	P9 = 30941 [Pa]	PA = 36454 [Pa]	PB = 48104 [Pa]
PK = 57056 [Pa]	Q01 = 0.00125 [m^3/s]	Q01lph = 4500 [l/h]	Q12 = 0.002012 [m^3/s]	Q12lph = 7245 [L/h]	Q1A = 0.004389 [m^3/s]
Q1Alph = 15801 [L/h]	Q1K = 0.008984 [m^3/s]	Q1Klph = 32342 [L/h]	Q33a = 0.0006888 [m^3/s]	Q33alph = 2480 [L/h]	Q33b = 0.0006888 [m^3/s]
Q33blph = 2480 [L/h]	Q44a = 0.001004 [m^3/s]	Q44alph = 3614 [L/h]	Q44b = 0.001004 [m^3/s]	Q44blph = 3614 [L/h]	Q44c = 0.001004 [m^3/s]
Q44clph = 3614 [L/h]	Q55a = 0.001177 [m^3/s]	Q55alph = 4237 [L/h]	Q55b = 0.001177 [m^3/s]	Q55blph = 4237 [L/h]	Q66a = 0.00108 [m^3/s]
Q66alph = 3887 [L/h]	Q77a = 0.0009899 [m^3/s]	Q77alph = 3564 [L/h]	Q77b = 0.0009899 [m^3/s]	Q77blph = 3564 [L/h]	Q77c = 0.0009899 [m^3/s]
Q77clph = 3564 [L/h]	Q88a = 0.001212 [m^3/s]	Q88alph = 4362 [L/h]	Q99a = 0.001369 [m^3/s]	Q99alph = 4928 [L/h]	QA3 = 0.001378 [m^3/s]
QA3lph = 4959 [L/h]	QA4 = 0.003012 [m^3/s]	QA4lph = 10842 [L/h]	QB6 = 0.00108 [m^3/s]	QB6lph = 3887 [L/h]	QB7 = 0.00297 [m^3/s]
QB7lph = 10691 [L/h]	QB8 = 0.001212 [m^3/s]	QB8lph = 4362 [L/h]	QB9 = 0.001369 [m^3/s]	QB9lph = 4928 [L/h]	QK5 = 0.002354 [m^3/s]
QK5lph = 8473 [L/h]	QKB = 0.00663 [m^3/s]	QKBlph = 23869 [L/h]	Re01 = 34205	Re12 = 51533	Re1A = 89130
Re1K = 153148	ReA3 = 27973	ReA4 = 77123	ReB6 = 27652	ReB7 = 76051	ReB8 = 31030
ReB9 = 22043	ReK5 = 60275	ReKB = 113024	ρ = 1000 [kg/m^3]	V01 = 0.8895 [m/s]	V12 = 1.254 [m/s]
V1A = 1.72 [m/s]	V1K = 2.481 [m/s]	V33a = 1.717 [m/s]	V33b = 1.717 [m/s]	V44a = 2.503 [m/s]	V44b = 2.503 [m/s]
V44c = 2.503 [m/s]	V55a = 2.934 [m/s]	V55b = 2.934 [m/s]	V66a = 2.692 [m/s]	V77a = 2.468 [m/s]	V77b = 2.468 [m/s]
V77c = 2.468 [m/s]	V88a = 3.021 [m/s]	V99a = 0.5364 [m/s]	VA3 = 0.5398 [m/s]	VA4 = 1.877 [m/s]	VB6 = 0.6729 [m/s]
VB7 = 1.851 [m/s]	VB8 = 0.7551 [m/s]	VB9 = 0.5364 [m/s]	VK5 = 1.467 [m/s]	VKB = 1.831 [m/s]	$\dot{W}$ = 834.7 [W]
Y01 = -17 [m]	Y1 = 0 [m]	Y2 = -1 [m]	Y3 = -10 [m]	Y4 = -21 [m]	Y5 = -17 [m]
Y6 = -18 [m]	Y7 = -22 [m]	Y8 = -20 [m]	Y9 = -19 [m]	YA = -11 [m]	YB = -18 [m]
Ydisp = 3 [m]	YK = -17 [m]	Ys = 1 [m]	Y_{dd} = -50 [m]	Y_{dd1} = -67 [m]	Y_p = -70 [m]

No unit problems were detected.

Calculation time = .0 sec.

2. The second solution set was solved when all valves were closed (KV=10^6). This simulates the no flow situation and was used to determine the maximum static pressures seen at the low points in the system. The maximum pressure in the pump to tank line is predicted to be 6.7 bar, therefore warranting a PN10 rated pipe. All other max pressures in the distribution system are below the 4.8 bar working pressure of a PN6 rated pipe.

Unit Settings: SI C kPa J mass deg

D01 = 0.0423 [m]	D12 = 0.0452 [m]	D1A = 0.057 [m]	D1K = 0.0679 [m]
DA3 = 0.057 [m]	DA4 = 0.0452 [m]	DB6 = 0.0452 [m]	DB7 = 0.0452 [m]
DB8 = 0.0452 [m]	DB9 = 0.057 [m]	DK5 = 0.0452 [m]	DKB = 0.0679 [m]
Ds = 0.0226 [m]	ε = 0.00001 [m]	f01 = 0.02317	f12 = 0.3603
f1A = 0.09362	f1K = 0.0389	fA3 = 0.303	fA4 = 0.1074
fB6 = 0.3496	fB7 = 0.1048	fB8 = 0.3307	fB9 = 0.09012
fK5 = 0.1802	fKB = 0.04543	g = 9.81 [m/s^2]	KV_{2a} = 1.000E+06
KV_{3a} = 1.000E+06	KV_{3b} = 1.000E+06	KV_{4a} = 1.000E+06	KV_{4b} = 1.000E+06
KV_{4c} = 1.000E+06	KV_{5a} = 1.000E+06	KV_{5b} = 1.000E+06	KV_{6a} = 1.000E+06
KV_{7a} = 1.000E+06	KV_{7b} = 1.000E+06	KV_{7c} = 1.000E+06	KV_{8a} = 1.000E+06
KV_{9a} = 1.000E+06	K_L = 1.05	L01 = 116 [m]	L12 = 4 [m]
L1A = 138 [m]	L1K = 134 [m]	LA3 = 21 [m]	LA4 = 114 [m]
LB6 = 2 [m]	LB7 = 58 [m]	LB8 = 64 [m]	LB9 = 400 [m]
LK5 = 4 [m]	LKB = 40 [m]	L_{pump} = 46 [m]	μ = 0.0011 [$N*s/m^2$]
$P01_{Max}$ = 667734 [Pa]	P3 = 98078 [Pa]	P4 = 205959 [Pa]	P5 = 166741 [Pa]
P6 = 176544 [Pa]	P7 = 215768 [Pa]	P8 = 196159 [Pa]	P9 = 186255 [Pa]
PA = 107889 [Pa]	PB = 176544 [Pa]	PK = 166741 [Pa]	Q01 = 0.00125 [m^3/s]
Q01lph = 4500 [l/h]	Q12 = 0.000006936 [m^3/s]	Q12lph = 24.97 [L/h]	Q1A = 0.00003366 [m^3/s]
Q1Alph = 121.2 [L/h]	Q1K = 0.00009652 [m^3/s]	Q1Klph = 347.5 [L/h]	Q33a = 0.000005202 [m^3/s]
Q33alph = 18.73 [L/h]	Q33b = 0.000005202 [m^3/s]	Q33blph = 18.73 [L/h]	Q44a = 0.000007754 [m^3/s]
Q44alph = 27.91 [L/h]	Q44b = 0.000007754 [m^3/s]	Q44blph = 27.91 [L/h]	Q44c = 0.000007754 [m^3/s]
Q44clph = 27.91 [L/h]	Q55a = 0.000006936 [m^3/s]	Q55alph = 24.97 [L/h]	Q55b = 0.000006936 [m^3/s]
Q55blph = 24.97 [L/h]	Q66a = 0.000007149 [m^3/s]	Q66alph = 25.74 [L/h]	Q77a = 0.000007945 [m^3/s]
Q77alph = 28.6 [L/h]	Q77b = 0.000007945 [m^3/s]	Q77blph = 28.6 [L/h]	Q77c = 0.000007945 [m^3/s]
Q77clph = 28.6 [L/h]	Q88a = 0.000007558 [m^3/s]	Q88alph = 27.21 [L/h]	Q99a = 0.0000441 [m^3/s]
Q99alph = 158.8 [L/h]	QA3 = 0.0000104 [m^3/s]	QA3lph = 37.45 [L/h]	QA4 = 0.00002326 [m^3/s]
QA4lph = 83.74 [L/h]	QB6 = 0.000007149 [m^3/s]	QB6lph = 25.74 [L/h]	QB7 = 0.00002384 [m^3/s]
QB7lph = 85.81 [L/h]	QB8 = 0.000007558 [m^3/s]	QB8lph = 27.21 [L/h]	QB9 = 0.0000441 [m^3/s]
QB9lph = 158.8 [L/h]	QK5 = 0.00001387 [m^3/s]	QK5lph = 49.94 [L/h]	QKB = 0.00008265 [m^3/s]
QKBlph = 297.5 [L/h]	Re01 = 34205	Re12 = 177.6	Re1A = 683.6
Re1K = 1645	ReA3 = 211.3	ReA4 = 595.7	ReB6 = 183.1
ReB7 = 610.4	ReB8 = 193.5	ReB9 = 710.2	ReK5 = 355.2
ReKB = 1409	ρ = 1000 [kg/m^3]	V01 = 0.8895 [m/s]	V12 = 0.004323 [m/s]
V1A = 0.01319 [m/s]	V1K = 0.02665 [m/s]	V33a = 0.01297 [m/s]	V33b = 0.01297 [m/s]
V44a = 0.01933 [m/s]	V44b = 0.01933 [m/s]	V44c = 0.01933 [m/s]	V55a = 0.01729 [m/s]
V55b = 0.01729 [m/s]	V66a = 0.01782 [m/s]	V77a = 0.01981 [m/s]	V77b = 0.01981 [m/s]
V77c = 0.01981 [m/s]	V88a = 0.01884 [m/s]	V99a = 0.01728 [m/s]	VA3 = 0.004077 [m/s]
VA4 = 0.0145 [m/s]	VB6 = 0.004455 [m/s]	VB7 = 0.01485 [m/s]	VB8 = 0.00471 [m/s]
VB9 = 0.01728 [m/s]	VK5 = 0.008645 [m/s]	VKB = 0.02282 [m/s]	$\dot{W}$ = 834.7 [W]
Y01 = -17 [m]	Y1 = 0 [m]	Y2 = -1 [m]	Y3 = -10 [m]
Y4 = -21 [m]	Y5 = -17 [m]	Y6 = -18 [m]	Y7 = -22 [m]
Y8 = -20 [m]	Y9 = -19 [m]	YA = -11 [m]	YB = -18 [m]
Ydisp = 3 [m]	YK = -17 [m]	Ys = 1 [m]	Y_{dd} = -50 [m]
Y_{dd1} = -67 [m]	Y_p = -70 [m]		

Appendix 7.10: Dispensary EES Code + Solutions

```
function ff(Re,ed)
    if (Re>2200) then
      ff:=1/(-1.8*log10( (ed/3.7)^1.11 + 6.9/Re))^2 {turbulent flow}
    else
      if (Re=0) then
        ff:=0 {no flow}
      else
          ff:=64/Re    {laminar flow}
      endif
    endif
end

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

{Constants}
rho = 1000 {kg/m^3} {density of water}
mu = 0.0011 {N*s/m^2} {dynamic viscosity of water}
epsilon =1E-5 {m} {inner pipe }
g=9.81 {m/s^2}
K_L=1.05 {unitless frictional losses}

{ Key
T1->Tank 1 (Close to school, elevated)
T2 ->Tank 2
S1->Sink 1 (by labour room)
S2->Sink 2
S3->Spigot (X2)
S4->Spigot on tank 2 (not calculated) }

KV_T1S1=10 {dim}
KV_T1S2=10 {dim}
KV_T1S3=10 {dim}
YT1=-19 {m}
YT2=-21 {m}
YS1=-21 {m}
YS2=-20 {m}
YS3=-20 {m}

LT1S1=3 {m}
LT1S2=15{m}
LT1S3=25 {m}

{Tank1 to Sink1, T1 to S1}
QT1S1=VT1S1*pi*DT1S1^2/4 {m^3/s}
QT1S1lph=QT1S1*convert(m^3/s,l/h) {L/h}
DT1S1=0.02 {m}
ReT1S1 = rho*VT1S1*DT1S1/mu {dim}
fT1S1=ff(ReT1S1,epsilon/DT1S1) {dim}
YS1-YT1=-VT1S1^2/2/g*(  fT1S1*LT1S1/DT1S1 + KV_T1S1)*K_L

{Tank1 to Sink2, T1 to S2}
QT1S2=VT1S2*pi*DT1S2^2/4 {m^3/s}
QT1S2lph=QT1S2*convert(m^3/s,l/h) {L/h}
```

```
DT1S2=0.02 {m}
ReT1S2 = rho*VT1S2*DT1S2/mu {dim}
fT1S2=ff(ReT1S2,epsilon/DT1S2) {dim}
YS2-YT1=-VT1S2^2/2/g*(  fT1S2*LT1S2/DT1S2 + KV_T1S2)*K_L

{Tank1 to Spigot 3, T1 to S3}
QT1S3=VT1S3*pi*DT1S3^2/4 {m^3/s}
QT1S3lph=QT1S3*convert(m^3/s,l/h) {L/h}
DT1S3=0.02 {m}
ReT1S3 = rho*VT1S3*DT1S3/mu {dim}
fT1S3=ff(ReT1S3,epsilon/DT1S3) {dim}
YS3-YT1=-VT1S3^2/2/g*(  fT1S3*LT1S3/DT1S3 + KV_T1S3)*K_L
```

Solutions

The following solution set was solved for with both dispensary sinks fully open (KV=10). Due to the local nature of the dispensary system, the max pressures at no flow do not approach the burst pressure of the weakest available pipe.

Unit Settings: SI C kPa J mass deg

DT1S1 = 0.02 [m]	DT1S2 = 0.02 [m]	DT1S3 = 0.02 [m]	ε = 0.00001 [m]
KV_{T1S1} = 10	KV_{T1S2} = 10	KV_{T1S3} = 10	K_L = 1.05
QT1S1 = 0.0005195 $[m^3/s]$	QT1S1lph = 1870 [L/h]	QT1S2 = 0.0002411 $[m^3/s]$	QT1S2lph = 867.8 [L/h]
ReT1S3 = 11328	ρ = 1000 $[kg/m^3]$	VT1S1 = 1.654 [m/s]	VT1S2 = 0.7673 [m/s]
YT1 = -19 [m]	YT2 = -21 [m]		

fT1S1 = 0.02446	fT1S2 = 0.02898	fT1S3 = 0.03051	g = 9.81 $[m/s^2]$
LT1S1 = 3 [m]	LT1S2 = 15 [m]	LT1S3 = 25 [m]	μ = 0.0011 $[N*s/m^2]$
QT1S3 = 0.0001957 $[m^3/s]$	QT1S3lph = 704.6 [L/h]	ReT1S1 = 30064	ReT1S2 = 13951
VT1S3 = 0.623 [m/s]	YS1 = -21 [m]	YS2 = -20 [m]	YS3 = -20 [m]