Ilula Hospital Water System

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Project Summary:

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ABOUT THE HOSPITAL:

- Only hospital in 100-mile stretch
- Water system built in 1969
- Patients/Day: 100
- Total Staff: 90
- Doctors: 7
- Buildings requiring water: 28

CURRENT SITUATION:

- Many buildings do not receive water from the current system
- Water is contaminated
- Complex system with many valves and tanks
- Pipes are exposed to environment
- City does not supply water during the dry season

PROPOSAL:

- Create new piping system on top of the old
  - Allows for a non-interfering transition
  - Divided into 4 zones for anticipated multi-phase funding
- Decrease dependency on city water
- Clean piping near sinks
- Place 3 10kL SIM tanks on top of the preexisting concrete tank
- Add level switches to communicate between tanks and pump

PROJECT BUDGET:

	MIN	MAX
Up-Front	$1,660.00	$5,260.00
Patient Zone	$3,080.00	$3,080.00
Urgent Care Zone	$2,220.00	$2,220.00
Housing Zone	$3,830.00	$3,830.00
School Zone	$1,520.00	$1,520.00
Pipe Discount	$ (850.00)	$ (850.00)
Total Cost	**$11,460.00**	**$15,060.00**

*These numbers reflect a possible 20% contribution from the hospital

OUTCOME:

- Supply water to all buildings on the hospital campus
- Ensure clean and safe water for all hospital procedures

Background and History:

The Ilula Hospital is a government supported hospital located within the city of Ilula, in the Iringa region of the Kilolo district in Tanzania (see figure 1). The hospital is the only major medical center between the city of Iringa and Morogoro, roughly a 100 mile stretch of road. The city of Ilula has around 30,000 residents and the hospital treats about 100 patients per day, in addition to housing 7 doctors, 90 staff, and numerous visiting guess. The hospital is growing every year and is currently planning to add on a nursing school complete with dormitories and a kitchen for up to 64 students at a time. The complex currently consists of 27 buildings within a fenced off area from the rest of the city of Ilula.

Figure 1: Maps of Ilula, Tanzania

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The existing water system, built in 1969, is extensive and complicated. As the hospital expanded over the years, piping was added on wherever it was needed. The basic structure of the water system consists of a 1 horse power pump, a large 32 kL concrete tank located at the highest point in the complex, and a series of branching pipes leading away from the tank toward the hospital buildings below. These pipes are made of both plastic and metal of various sizes.

In addition to the well water supplied by the 1 hp pump, several of the buildings rely on a combination of rainwater collection and water supplied by the city. This city/rainwater system consists of its own 1 hp pump, a small 5 kL water tower, and it serves several buildings on the west side of the complex. In the summer months, city water and rainwater is not available, and water is then trucked in to supply these buildings. A map of the complex with its current piping (city/rainwater=red, well water=green, any tank=blue) is shown in Figure 2.

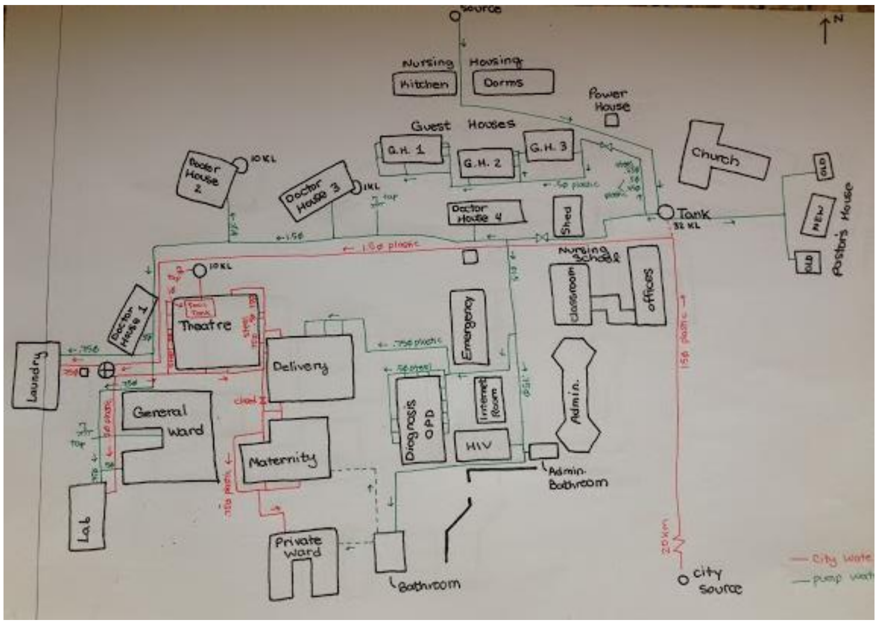

Figure 2: Ilula hospital's existing water system

Challenges:

Currently, the hospital's water supply is experiencing a variety of challenges. Lack of water to key buildings, contaminated water, poor piping, an old tank, an unsophisticated control system, and an unreliable city source are amongst the most important to address. While not as high priority, there is some preference of soft water over hard water when cleaning surgical equipment because hard water can accelerate corrosion of the tools.

Many buildings are either not connected to the current system at all or they are offline due to poor water pressure or clogged piping. The General Ward, the Private Ward, Diagnosis, and the Consent to Treatment and Care (CTC) buildings are all connected to the water system but do not have water access. We believe this is due to clogged piping in many of the sinks. The sinks are currently built of thin metal piping that has been scaling over the years; this is a process that is accelerated by metal pipe over the smoother plastic compounds. This has led to a neglect of the system in these buildings, and implies that the internal plumbing has not been properly cleaned in a very long time. Guest House 3, the guest house furthest east, also receives little to no water, but this time it is due to insufficient pressure. As there is not much of a height difference between the guest house and the tank (and the piping is actually run back uphill), this specific guest house does not have enough gravitational head to supply proper flow. The Nursing Dormitories and Kitchen, which are under construction but due to be completed in the next year, are two major buildings that are not yet connected to any water supply.

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These two buildings alone will be hosting up to 64 nursing students at a time beginning as soon as this fall. There is a sense of urgency involved in providing water to these buildings as soon as possible.

Contaminated water is another concern in Ilula. Currently there are two water sources as previously mentioned. The well water is believed by many of the people in the complex to be too salty to drink. This presumption is due in part to the fact that the old well, which was recalled to be very salty, was dug right beside the new one, but at a much shallower depth. While the new well's water is less salty (see the mineral test in Appendix B); it is difficult to convince the hospital staff it can be used in tool-cleaning applications. This water was also tested for bacteria by incubating the test sample shown in Figure 3 In this test, a light orange color indicates clean water and as the color gets darker, there is more bacteria present. It appeared as though there was very little bacteria in the water meaning it is safe to drink. On the other hand, the city water was found to have a lot more bacteria in it which is unfortunate because this is the water that is currently used for drinking on the complex. The one advantage the city water has is its lack of salt in its water. This makes it ideal for cleaning tools as it will not rust them.

Figure 3: Water Quality Tests from the City Source (Left) and Well Source (Right)

Poor piping remains one of the largest challenges at the hospital and may be the cause of a variety of the other issues occurring on the complex. As mentioned before, the complex piping has been added onto multiple times over the years. Piping of a variety of different diameters and materials has been used to connect the system from point A to B. Each expansion, not only adds to the confusion of the system, but also compromises the flow properties leading to more losses. Further, there are a variety of valves and sub tanks located throughout the system. The valves are used to manually control the system but when they are left inadvertently closed for too long some buildings are left without water. The sub tanks located throughout the complex are used as buffer tanks but they could be used more efficiently. Also, many pipes are left exposed or unburied which leads to corrosion and possible external damages.

The old 32 kL concrete tank located at the top of the hill provides another concern to the hospital. Due to its age and quality, a crack has propagated around the entire wall of the tank as shown in Figure 4. Located approximately 4 feet from the ground, the crack only allows the tank to hold 20 kL of water at a time. The pipe outlet for the pastor's house is located above this crack thus preventing any water from flowing there. On another note, the tank is exposed to the environment through small holes which allow insects and reptiles to get into the water stored there.

Figure 4: 32kL Concrete Tank with Large Crack

Lastly, the hospital relies on the city water for a large amount of their water needs. The problem is that the city shuts off the supply during the dry season which spans approximately half the year. During this time water must be shipped in by truck for most of these procedures to take to place. The buildings reliant on the city water supply include the Theatre, Delivery, and Maternity -- all of which are high priority buildings that have legitimate need of a consistent water supply, as well as a drinking water tank used by the locals.

Water Needs by Building:

To help identify how much water was needed, and which regions used how much relative to one another, a list of water usage estimates was compiled. These estimates are based on the number of people affected, the nature of the activity, etc. For all of the calculations, an overestimate of what they are currently using was recorded so that the hospital would not need to worry about inconsistencies. This also allows for future expansion of the complex. Table 1 shows a table of the calculated water usage estimates by building.

Table 1: Water Usage Estimates, by Building

Name	L/person	people/day	L/day total
Pastor South House	50	4	200
Pastor Middle House	50	4	200
Pastor North House	50	4	200
Nursing Dorms	30	50	1500
Nursing Kitchen	30	10	300
Guest House 1	50	4	200
Guest House 2	50	4	200
Guest House 3	50	4	200
Admin Bathrooms	10	20	200
Emergency	50	10	500
CTC	30	20	600
Diagnostics	1	100	100
General Bathrooms	10	40	400
Dr. House 1	50	4	200
Dr. House 2	50	4	200
Dr. House 3	50	4	200
Dr. House 4	50	4	200
Dr. House 5	50	4	200
Private Ward	30	10	300
Maternity Ward	25	30	750
Delivery East	10	10	100
Delivery West	50	10	500
Theatre	60	10	600
General Ward	30	30	900
Lab	20	4	80
Laundry	100	4	400
Washing Spigot	10	20	200
Drinking Spigot	100	5	500
Total			**10,130 L/day**

The total estimated water usage was just over 10 kL per day. To see if the current 1 hp pump in the well would be able to supply this, the flow rate provided by the pump under these conditions was calculated (see Appendix C for details). The pump was found to be able to provide this amount of water to the hospital by running for about 4 hours per day.

Proposed Plan Overview:

Our plan to address all of these issues is to supply the entire complex with well water from a combination of three 10 kL tanks placed on top of the concrete tank using new HDPE pipe. This would allow the pump to give clean, drinkable water to the entire hospital complex which would eliminate the reliance on city and rainwater. Placing the three tanks on top of the concrete tank allows for more pressure to be available, ensuring that every building receives a sufficient flow rate. A stress test was also performed (see Appendix D), and it indicates that the concrete tank would be able to safely support the 30 kL of water that is being suggested.

The distribution plan would consist of four main lines, each servicing an area of buildings based on a mixture of geographical location and relative need. These four areas, referred to as "zones" from here on out, are broken up in Figure 5. Each zone is entirely disconnected from the other zones because they each have their own pipe coming out of the tanks. Because of this, each zone could be implemented independently or with other zones.

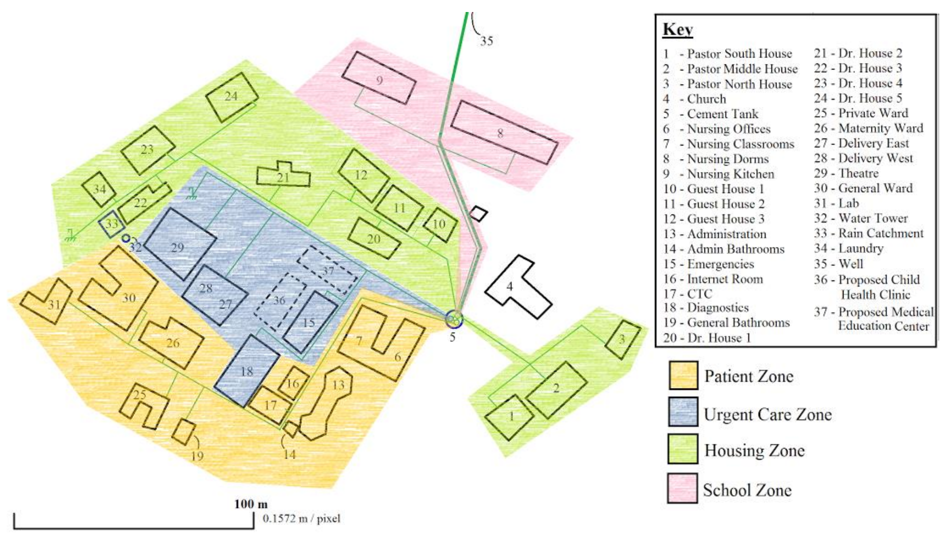


Figure 5: Ilula Hospital Complex Broken Down by Zones

These zones are broken up as follows:

- **Patient Zone:** General Ward, Private Ward, Lab, Maternity, Admin Bathrooms, General Bathrooms, CTC

- **Urgent Care Zone:** Emergency, Diagnosis, Delivery, Theatre, Drinking Water Spigot

- **Housing Zone:** All Guest Houses, All Dr. Houses, Laundry, Laundry Spigot, All Pastor Houses

- **School Zone:** Nursing Dorms, Nursing Kitchen

Upfront Needs and Costs:

Each zone has unique costs related to it, depending on how far a trench needs to be dug, how much pipe is needed, and any other components the system requires. However, there are upfront costs that would need to be implemented along with the first zone to be approved. These special upfront costs are one time investments that will be needed for any of the four zones. These costs include the tanks themselves, level switches to automatically turn the pump on and off when the water level needs to be adjusted, and paying St Paul Partners employees to assist in the management of the project. The entire upfront budget estimate is shown in Table 2.

Table 2: Upfront Cost Estimate

Item No.	Description	Qty	Unit	Cost/Unit	Total Cost
1	10 kL SIM Tank	3	# of Tanks	$1,200.00	$3,600.00
2	Ball Valve	2	# of Valves	$30.00	$60.00
3	Pipe Components	5	# of Components	$20.00	$100.00
4	SPP Oversight/Training	2	Days	$500.00	$1,000.00
5	Level Switch/Wiring	1	System	$500.00	$500.00
*	Less Possible In-Kind Contribution	3	# of Tanks	$ (1,200.00)	$ (3,600.00)
				Upper Estimate	$5,260.00
				Lower Estimate	$1,660.00

In the cost estimate above, there is a price range given. This price range is dependent on how many of the 10 kL SIM tanks that the hospital complex already has are in good, working order. The hospital complex currently has four 10 kL tanks scattered around, so the price would likely be closer to the lower estimate than the upper one.

Patient Zone:

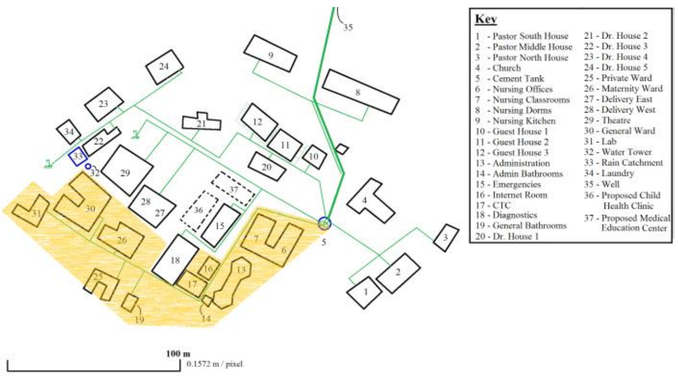


Figure 6: Patient Zone Overview Map

Overview

The patient zone was named such because it contains all the wards in the hospital. Currently the wards in use are the general ward, the maternity ward, and the CTC ward. The CTC ward, which stands for "Consent to Treatment and Care", is where sufferers of HIV are treated and cared for. This zone has a private ward which is under construction, and has plans for men's and women's wards in the future. In addition to the wards, the zone also includes the bathrooms for administration, the bathrooms for general patients, and the laboratory building because of their nearby geographical location.

Challenges

Access to water in the patient zone in the current system is shown in Table 3.

Table 3: Patient Zone Map

Building	City Water Connection	Pump Water Connection	Is there water?
Admin Bathrooms	No	Yes	No
General Bathrooms	No	Yes	No
CTC	No	Yes	No
Maternity	Yes	No	No
Private Ward	Yes	No	No
General Ward	No	Yes	No
Lab	Yes	Yes	Yes

Proposed Solution

We propose a main pipe coming off one of the three tanks at the top of the hill. A 2-inch main pipe will carry the water down the complex and branch into various 0.75 inch pipes for each building. The general layout and the distances are in Figure 7.

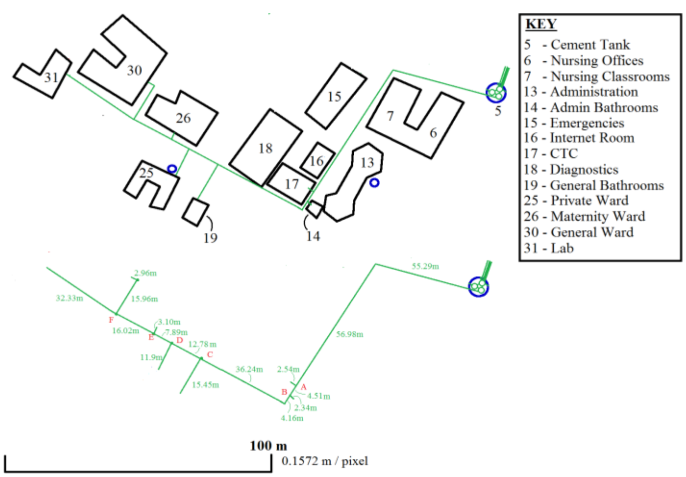
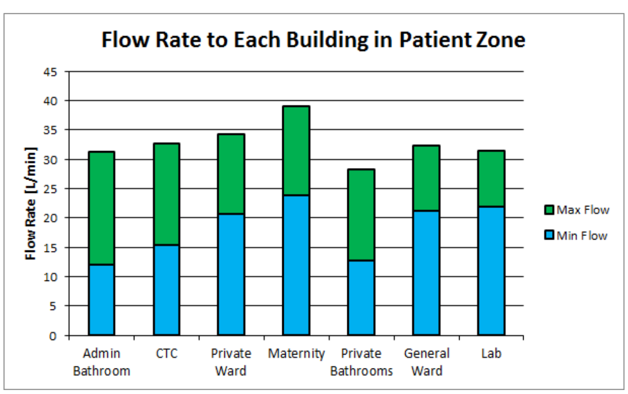


Figure 7: Patient Zone Map

In order to model the feasibility of this system, we used a program called EES to solve all the Bernoulli equations simultaneously. Each building was modeled as having one sink connected to the pipe where it ended at the building. For a worse case flow scenario, all the sinks were turned on simultaneously. Through our analysis we found that even in this situation, each building would have enough flow for even a few sinks.



Projected Budget

Figure 8: Patient Zone Projected Flow Rates

The materials needed for this zone can be broken down into three main topics: pipe, piping components, and labor. The labor includes digging, burying the pipe, inspecting and cleaning sinks, and transportation of the pipe. An overall 20% contribution from the hospital was assumed when making this estimate. The cost estimate for this zone is shown in Table 4.

T*able 4: Patient Zone Projected Budget*

Item No.	Description	Qty	Unit	Cost/Unit	Total Cost
1	2" HDPE pipe (63 mm)	2	150m Roll	$750.00	$1,500.00
2	0.75" HDPE pipe (25 mm)	1	150m Roll	$100.00	$100.00
3	Transport for pipe	1	Trip	$190.00	$190.00
4	Ball valve	1	Quantity	$30.00	$30.00
5	Pipe Components	40	Quantity	$15.00	$600.00
7	Labor for plumbing	7	Building	$100.00	$700.00
8	Labor for digging trenches	310	Meter	$2.19	$720.00
	Patient Zone Sub-Total				**$3,840.00**
9	Less In-Kind Contribution (20%)				$ (760.00)
	Patient Zone Donor Sub-Total				**$3,080.00**

Urgent Care Zone:

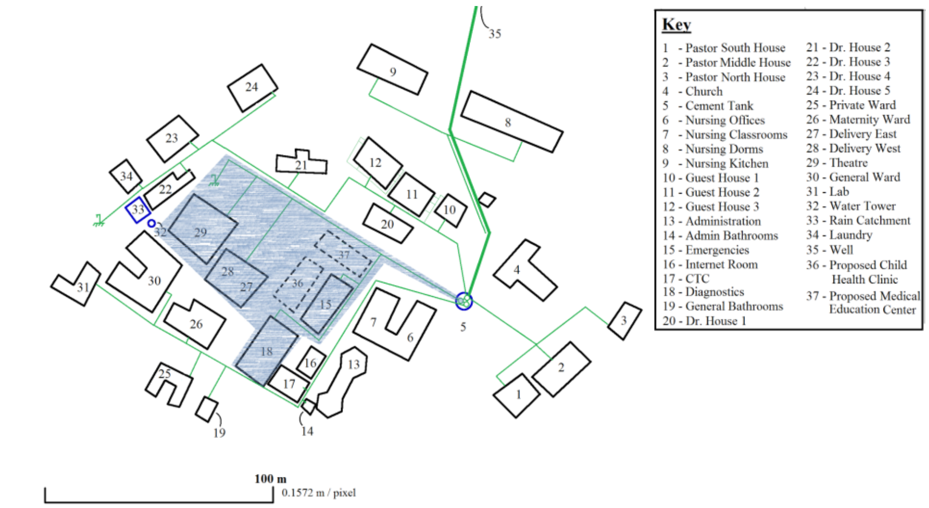


Figure 9: Urgent Care Zone Overview Map

Overview

The urgent care zone was named such because it contains all of the buildings used for very serious treatment. This includes the theatre (surgery), emergency building, diagnosis, and delivery. Because this is where locals go to currently get their water, the drinking water spigot is also in this zone.

Challenges

Access to water in the urgent care zone in the current system is shown in Table 5.

Table 5: Urgent Care Zone Water Situation

Building	City Water Connection	Pump Water Connection	Is there water?
Drinking Water Tap	Yes	No	Inconsistent
Emergency	No	No	No
Delivery	Yes	Yes	Yes
Theatre	Yes	No	Inconsistent

Proposed Solution

We propose a main pipe coming off one of the three tanks at the top of the hill. A 2-inch main pipe will carry the water down the complex and branch into various 0.75 inch pipes for each building. The general layout and the distances are shown in Figure 10.

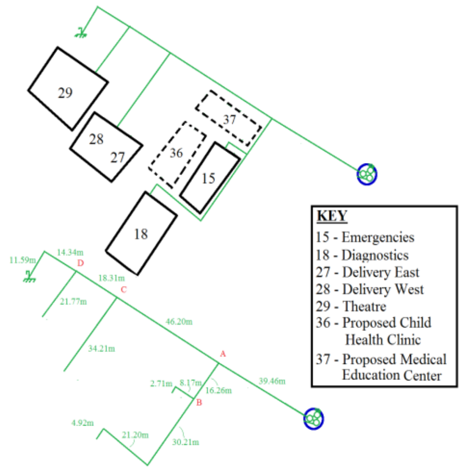


Figure 10: Urgent Zone Proposed Solution

Using a similar method to that described in the Patient Zone, we found that each building would have plenty of flow for even a few sinks at a time. Because this system has relatively few buildings, each building is also hardly impacted by the open/closed position of the others, making it a robust system capable of expansion. The flow rates are shown in detail in Figure 11.

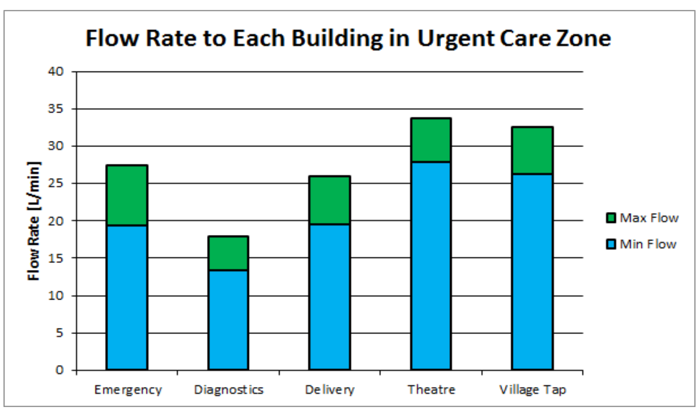


Figure 11: Urgent Care Zone Projected Flow Rates

This is also the only zone that would have a use for soft water to clean their medical equipment. At the moment, our plan would be to leave the city/rainwater system hooked up to one or two sinks in each building so that they can still get soft water for cleaning their metal surgery equipment. The city and rainwater mixture was found to have lots of bacteria in it, but this isn't an issue for cleaning the tools because the hospital uses an autoclave for this purpose (which would kill all of the bacteria either way). Our system would provide water for all other uses in these buildings such as washing hands, cleaning off surgery tables, drinking, etc.

Projected Budget

The materials needed for this zone are the same as the other zones – pipe, piping components, and labor. An overall 20% contribution was assumed when making this estimate. The cost estimate for this zone is shown in Table 6.

Table 6: Urgent Care Zone Projected Budget

Item No.	Description	Qty	Unit	Cost/Unit	Total Cost
1	2" HDPE pipe (63 mm)	1	150m Roll	$750.00	$750.00
2	0.75" HDPE pipe (25 mm)	2	150m Roll	$100.00	$200.00
3	Transport for pipe	1	Trip	$190.00	$190.00
4	Ball valve	1	Quantity	$30.00	$30.00
5	Pipe Components	30	Quantity	$15.00	$450.00
7	Labor for Plumbing	5	Building	$100.00	$500.00
8	Labor for digging trenches	295	Meter	$2.19	$650.00
	Urgent Care Zone Sub-Total				**$2,770.00**
9	Less In-Kind Contribution (20%)				$ (550.00)
	Urgent Care Zone Total				**$2,220.00**

Housing Zone:

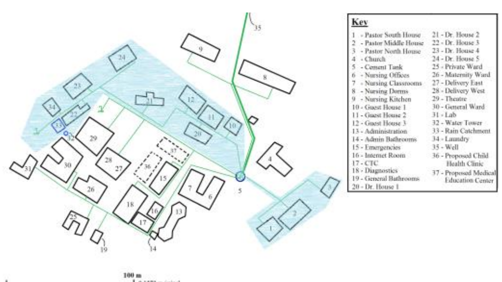


Figure 12: Urgent Care Zone Overview Map

Overview

The "Housing Zone" is a grouping of all the living quarters on the hospital grounds except for the new nursing school. This includes the doctor housing where the physicians live, the guest housing, and the houses for the pastor.

Challenges

Access to water in the patient zone in the current system is shown in Table 7.

Table 7: Housing Zone Water Situation

Building	City Water Connection	Pump Water Connection	Is there water?
Guest House 1	No	Yes	No
Guest House 2	No	Yes	Yes
Guest House 3	No	Yes	Yes
Dr. House 1	No	Yes	Inconsistent
Dr. House 2	No	Yes	Inconsistent
Dr. House 3	No	Yes	Inconsistent
Dr. House 4	No	Yes	Inconsistent
Dr. House 5	No	No	No
Pastor House North	No	Yes	No
Pastor House Middle	No	Yes	No
Pastor House South	No	Yes	No

The first guest house doesn't get enough pressure through a combination of being highest on the hill and the complicated small metal piping system that leads to it. The other 2 guest houses have a more direct piping system as well being lower on the hill and have water. The doctor's houses are able to get water but are often shut off in order to increase system pressure elsewhere. The pastor's houses have piping directly to the concrete tank at the top but are connected at the same level as a large crack around the tank. Because the water can't remain above the crack for long due to leakage, the pastor's houses rarely have water.

Proposed Solution

We propose a main pipe coming off one of the three tanks at the top of the hill. A 2-inch main pipe will carry the water down the complex and branch into various 0.75 inch pipes for each building. The general layout and the distances are shown in Figure 13.

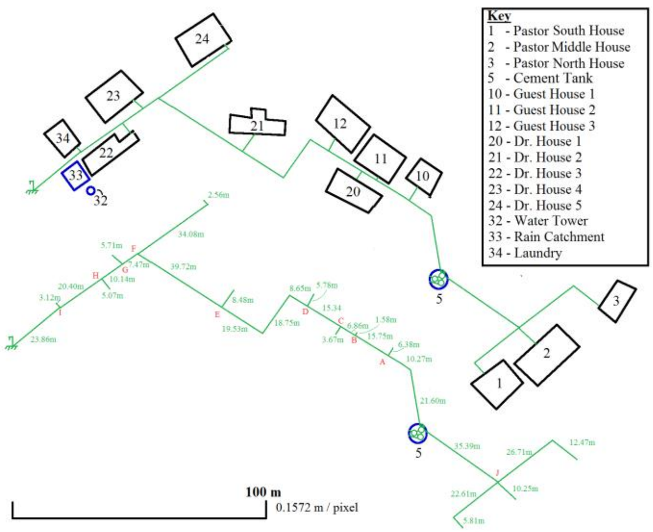


Figure 13: Housing Zone Proposed Solution

In order to model the feasibility of this system, we used a program called EES to solve all the Bernoulli equations simultaneously. Each building was modeled as having 1 sink connected to the pipe where it ended at the building. For a worse case flow scenario, all the sinks were turned on simultaneously. Through our analysis we found that even in this situation, each building would have enough flow for even a few sinks. The flow rates for worst and best case scenario are shown in Figure 14.

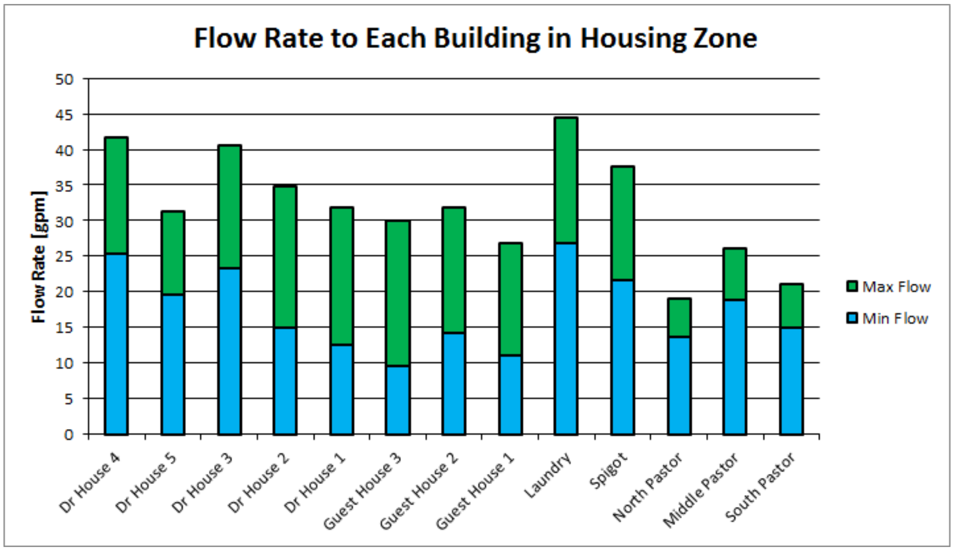


Figure 14: Housing Zone Projected Flow Rates

School Zone:

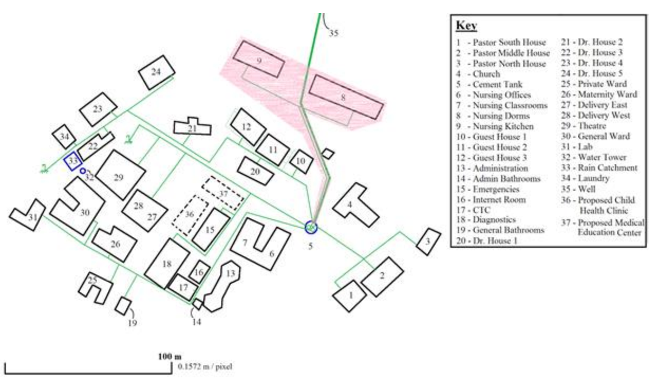


Figure 15: School Zone Map

Overview

The school zone is named on behalf of the nursing school dorms and kitchen that lie within it. The construction of these buildings is nearing completion, and all plumbing inside the buildings is completed. However, there is no connection to an external water supply or a plan in place for installing one.

Challenges

Access to water in the school zone in the current system is shown in Table 8.

Table 8: School Zone Water Situation

Building	City Water Connection	Pump Water Connection	Is there water?
Nursing Dorms	No	No	No
Nursing Kitchen	No	No	No

Proposed Solution

Just as in every other system, we propose a main pipe coming off one of the three tanks at the top of the hill. A 2-inch main pipe will carry the water down the complex and branch into various 0.75 inch pipes for each building. The general layout and the distances are shown in Figure 16.

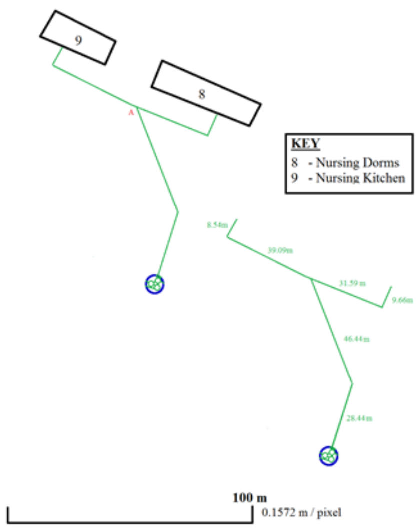


Figure 16: School Zone Proposed Solution

Using a similar method to that described in the Patient Zone, we found that each of the two buildings in this zone would receive very significant flow rates. Because this system only has two buildings, the flow rate is essentially a constant, making it a very robust system capable of expansion. The flow rates are shown in detail in Figure 17.

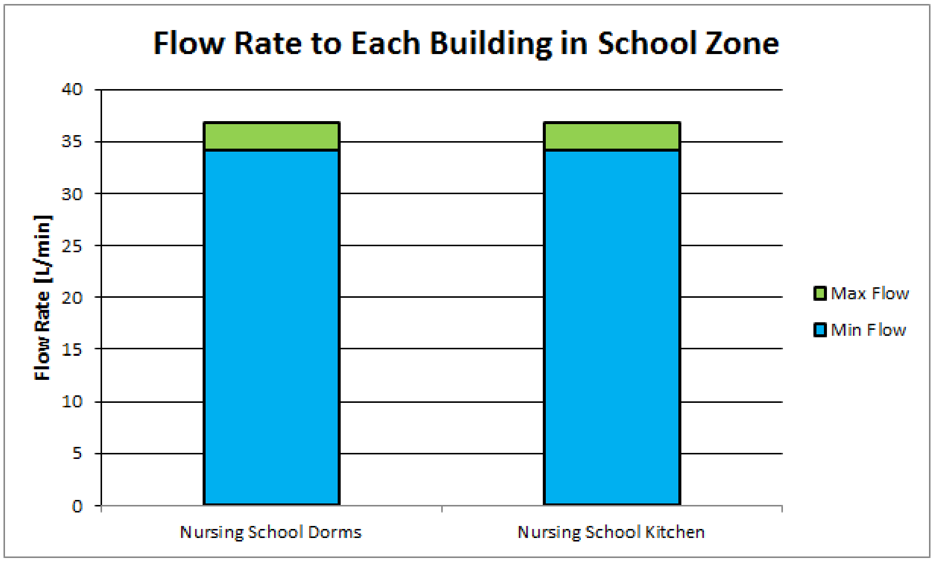


Figure 17: School Zone Projected Flow Rates

Projected Budget

The materials needed for this zone are the same as the other zones – pipe, piping components, and labor. An overall 20% contribution was assumed when making this estimate. The cost estimate for this zone is shown in Table 9.

Table 9: School Zone Projected Budget

Item No.	Description	Qty	Unit	Cost/Unit	Total Cost
1	2" HDPE pipe (63 mm)	1	150m Roll	$750.00	$750.00
2	0.75" HDPE pipe (25 mm)	1	150m Roll	$100.00	$100.00
3	Transport for pipe	1	Trip	$190.00	$190.00
4	Ball valve	1	Quantity	$30.00	$30.00
5	Pipe Components	15	Quantity	$15.00	$230.00
7	Labor for Pipeline and Plumbing	2	Building	$100.00	$200.00
8	Labor for digging trenches	175	Meter	$2.19	$390.00
	School Zone Sub-Total				**$1,890.00**
9	Less: In-Kind Contribution (20%)				$ (370.00)
	School Zone Donor Sub-Total				**$1,520.00**

Total Cost:

Ideally, all four zones would be implemented at the same time. This would allow for maximum impact on the hospital, as well as include some cost savings. The total budget for the entire project is shown in Table 10.

Table 10: Total Project Budget

	MIN	MAX
Up-Front	$1,660.00	$5,260.00
Patient Zone	$3,080.00	$3,080.00
School Zone	$1,520.00	$1,520.00
Urgent Care Zone	$2,220.00	$2,220.00
Housing Zone	$3,830.00	$3,830.00
Pipe Discount	$ (850.00)	$ (850.00)
Total Cost	**$11,460.00**	**$15,060.00**

The pipe discount shown above is a price saving that can be done by wasting less pipe. Pipe for projects like this is purchased in 150 meter bundles -- if all of the zones are done at the same time, there will be less leftover pipe overall.

In summary, the total cost to implement our entire design would be somewhere between $11,500 and $15,000.

Appendix A - Finding Building Heights:

During our visit at Ilula hospital, our GPS was not accurate enough to give us approximate heights of each of the buildings. Because the relative heights of each of the buildings was so important to the working operation of the water system (our system is powered by gravity) we developed a new method for measuring relative building heights.

The foundations of each building in the hospital complex were visible above the ground, so these were used to our advantage. One person would kneel down and place their eye level with a building foundation until the foundation made a perfect line, and then line up that foundation with the next building. A second person would run over to the second building and move their hand slowly up the building's outside wall. When the hand lined up with the first building's foundation, the first person would shout to the second person to keep their hand steady, and then run over with a tape measure and measure from the second person's hand to the second building's foundation. The relative heights between the foundations were recorded as the relative heights between the buildings. This method had an accuracy of ± 1 brick, or roughly 4 inches.

The building codes and relative heights of each building are shown in Table 11.

Table 11: Total Project Budget

Building	Name	Height Equivalence
1	Pastor South House	B5 - 10 ft
2	Pastor Middle House	B1
3	Pastor North House	B1
4	Church	B5 + 5 ft
5	Concrete Tank	Well + 110 feet
6	Nursing Offices	B5 - 54.5 in.
7	Nursing Classrooms	B6 - 53.75 in.
8	Nursing Dorms	
9	Nursing Kitchen	
10	Guest House 1	B11 - 10 in
11	Guest House 2	B12 - 46 in
12	Guest House 3	B5 - 8 ft 5 in
13	Administration	B7 - 2 ft
14	Admin Bathrooms	(B15 + B14)/2
15	Emergencies	B7 - 45.25 in
16	Internet Room	
17	CTC	B15 - 11 in
18	Diagnostics	B15 - 50 in
19	General Bathrooms	B18
20	Dr. House 1	B11

21	Dr. House 2	B12 - 6ft
22	Dr. House 3	B33 + 6 in
23	Dr. House 4	B22 - 26 in
24	Dr. House 5	
25	Private Ward	B26
26	Maternity Ward	B30 + 5 ft
27	Delivery East	B18 - 38.5 in
28	Delivery West	B27 - 10 in
29	Theatre	B28 - 7 ft
30	General Ward	B29 - 22 in
31	Lab	B30 - 53 in
32	Water Tower Foundation	B29 - 56.5
33	Rain Catchment	B29 - 67 in
34	Laundry	B33 - 20 in

Appendix B - Well Water Mineral Test Results:

THE UNITED REPUBLIC OF TANZANIA
MINISTRY OF WATER
IRINGA WATER QUALITY LABORATORY
P O BOX 570 TEL +255 26 2700134

Request by	FREDERICK HDRO ROCKS
Date of Sampling & Time	08/05/2014,AT 05:15 PM
Date Received	09/05/2014
Sampling Point	BOREHOLE AT ILULA LUTH HOSP-ST PAUL PART'S
District & Region	KILOLO-IRINGA
Laboratory Number	97/14
Purpose of Sampling	DOMESTIC

PARAMETERS	UNIT	TANZANIAN STANDARDS	CONCENTRATION
COLOUR	mg/1Pt.Co	50.0	26.0
TURBIDITY	NTU	30.0	13.9
pH		6.5-8.5	7.37
CONDUCTIVITY	µs/cm	Less than 2000	1881
TOTAL DISSOLVED SOLIDS	Mg/l	≤ 1000	940
TEMPERATURE	°C	Not specific	20.3
TOTAL - ALKALINITY	$mgCaCO_3/l$	Not specific	228
TOTAL - HARDNESS	$mgCaCO_3/l$	500	279
CALCIUM	$mgCaCO_3/l$	200	80.8
MAGNESIUM	$mgCaCO_3/l$	150	18.33
CHLORIDE	$mgCl^-/l$	250	234.34
SULPHATE	$mgSO_4^{2-}/l$	400	170
FLOURIDE	mgF^-/l	8.0	1.17
SODIUM	$Mg\ Na^+/l$	500	310.6
POTASSIUM	mgK^+/l	50	0.5
TOTAL IRON	mg Fe/l	1.0	0.06
MANGANESE	mg Mn/l	0.5	1.47
ORTHOPHOSPHATE	$mg\ PO_4^{3-}/l$	Not specific	0.25
NITRATE - NITROGEN	mg N/l	100	14.17
NITRITE - NITROGEN	mg N/l	Not specific	0.37
AMMMONIA - NTITROGEN	mg N/l	2.0	0.06
PERMANGANATE- VALUE	mg N/l	20.0	12.8

REMARKS

Slightly turbid and alkaline water
Hard water
Water is "Slightly fresh" due to the amount of total dissolved solids to be less than 1000 mg/l.

RECOMMENDATIONS
Water is suitable for drinking and other domestic purposes according to Tanzania standards.

DATE 10.05.2014 REPORTING OFFICER HEAD, WATER QUALITY LABORATORY

WATER QUALITY LABORATORY
IRINGA

Appendix C - Pump and System Curve:

The pump curve is a property of the pump, and the system curve is defined by our system, including the pipe diameter, height change, length of pipe, etc. This was done when pumping into a 1.5" pipe (already in place) and up to a location that is 15 feet higher than the bottom of the concrete tank, meant to simulate a SIM tank on top of the concrete tank. The steady state water level of the pump was assumed to be the same as the steady state water level of a 3 hp pump in this well (which was known), so it is giving an underestimate of the flow. Despite this, the flow rate out of the pump was a healthy 44.5 L/min with 85m of head being created by the pump.

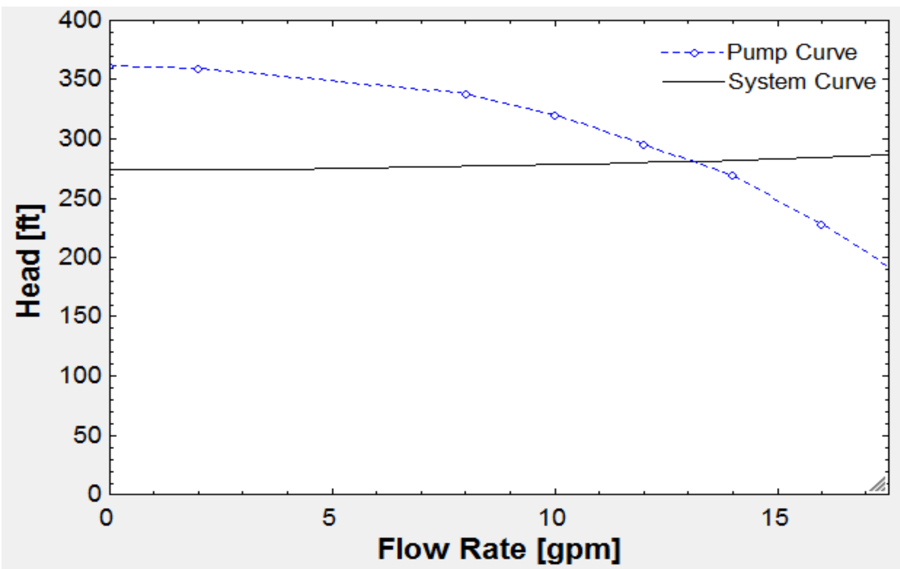


*Figure *: Pump Operating Curve*

Appendix D - Stress Analysis on the Concrete Tank:

A stress analysis was done in SolidWorks to simulate the force incurred by the 3 10 kL SIM tanks on top of the concrete tank. The concrete tank was modeled as a hollow cylinder supported by an internal post as shown in figure *. Its material properties were considered to be of the poorest quality (yield stress of 20 MPa). When full of water, the three tanks weigh approximately 300,000 Newtons (or 67,500 pounds). This force produces a max Von Mises stress of 6 MPa near the post. While this provides a safety of approximately 3, caution should still be taken due to the uncertainty involved in the method and quality of the concrete poured. Figure * provides a screenshot view of the study. The black lines signify the intended layout of the SIM tanks configuration.

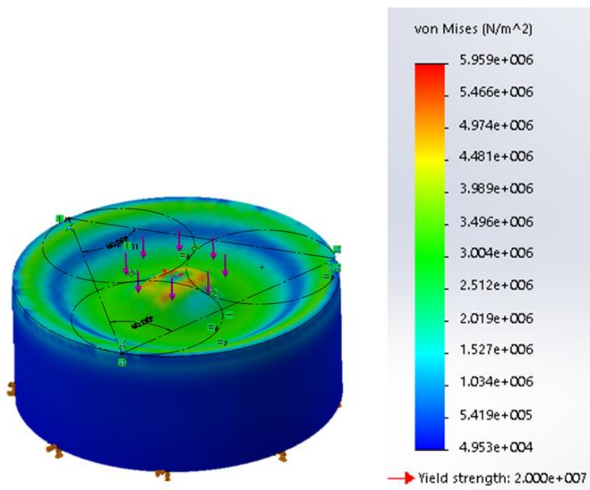


*Figure *: Stress Analysis on the Concrete Tank*

Appendix E1 - EES Code for Patient Zone:

```
function f_val(Re)
IF (Re < 2300) THEN
f_val = 64/Re
ELSE
f_val = (-1.8*LOG10(6.9/Re))^(-2)
ENDIF
END

{CONVERSIONS and CONSTANTS}
ipf = 12 [in/ft]
fpm = 1/ipf * 1/2.54 [cm/in] * 100 [cm/m]
ipm = ipf*fpm
rho = 1000 [kg/m^3]
g = 9.81 [m/s^2]
nu = 1.31 * 10^(-6)
sinkHeight = 1
sinkLength = 2
extraTankHeight = 14 [ft] / fpm

{-------------NECESSARY HEIGHTS-----------}
H_tank=(110[ft])/fpm  {32kL cement tank}
H_nurse_office=H_tank-54.5[in]/ipm {nurse school offices}
H_nurse_class=H_nurse_office-53.75[in]/ipm {nurse school classrooms, floor 1}
H_emerg=H_nurse_class-(45.25[in])/ipm {emergency room}
H_diag=H_emerg-50[in]/(ipf*fpm) {diagnostics}
H_delivery_east=H_diag-38.5[in]/ipm {Delivery east half}
H_delivery_west=H_delivery_east-10[in]/ipm {Delivery west half}
H_theatre=H_delivery_west-7[ft]/fpm {Theatre}
H_admin=H_nurse_class-2[ft]/fpm {administration building}
H_adminBr=(H_emerg+H_admin)/2 {admin bathroom}
H_CTC=H_emerg-11[in]/ipm {HIV building, CTC building, Consent to Treatment and Care}
H_bathrooms=H_diag {other bathroom}
H_private=H_maternity {private ward}
H_general=H_theatre-22[in]/ipm {General ward}
H_maternity=H_general+5[ft]/fpm {Maternity}
H_lab=H_general-53[in]/ipm {Laboratory}

H_A = H_adminBr - 1 [m] {The first pipe junction: junction A}
H_B = H_adminBr - 1 [m]
H_C = H_bathrooms - 1 [m]
H_D = H_private - 1 [m]
H_E = H_maternity - 1 [m]
H_F = H_general

{VALVE CONTROL}
open = 15 {Open sink is still a Kv of 15}
closed = 10^19
elbow = 1.5
building = 10*elbow

K_V_A_CTC = closed
K_V_B_adminBr = closed
K_V_C_bathrooms = closed
```

K_V_D_private = closed
K_V_E_maternity = closed
K_V_F_general = closed
K_V_F_lab = open

{Pipe Diameters}
mainPipeIn = 2 [in]
mainPipe = mainPipeIn / ipm
smallPipe = 0.75 [in] / ipm

{Pipe Diameters}
D_tank_A = mainPipe
D_A_CTC = smallPipe
D_A_B = mainPipe
D_B_adminBr = smallPipe
D_B_C = mainPipe
D_C_bathrooms = smallPipe
D_C_D = mainPipe
D_D_private = smallPipe
D_D_E = mainPipe
D_E_maternity = smallPipe
D_E_F = mainPipe
D_F_general = smallPipe
D_F_lab = smallPipe

{Pipe Lengths}
L_tank_A = 60 + 60
L_A_CTC = 5 + sinkLength
L_A_B = 5
L_B_adminBr = 5 + sinkLength
L_B_C = 5 + 40
L_C_bathrooms = 20 + sinkLength
L_C_D = 15
L_D_private = 15 + sinkLength
L_D_E = 10
L_E_maternity = 5 + sinkLength
L_E_F = 20
L_F_general = 20 + 5 + sinkLength
L_F_lab = 35 + sinkLength

{Length Losses}
K_L_tank_A = elbow
K_L_A_CTC = building
K_L_A_B = 0
K_L_B_adminBr = building
K_L_B_C = elbow
K_L_C_bathrooms = building
K_L_C_D = 1.5
K_L_D_private = building
K_L_D_E = 0
K_L_E_maternity = building
K_L_E_F = 0
K_L_F_general = building + elbow
K_L_F_lab = building

```
{==BERNOULI EQUATIONS==}
{tank to A}
f_tank_A = f_val(Re_tank_A)
Re_tank_A = (4*abs(Q_tank_A))/(pi*nu*D_tank_A)
Q_tank_A = (pi * D_tank_A^2/4) * v_A
(p_A-p_tank)/(rho*g) +(v_A^2-v_tank^2) / (2*g) + (H_A) - (H_tank + extraTankHeight) = -1 * v_A^2/(2*g) * (f_tank_A*L_tank_A/D_tank_A +
K_L_tank_A)
p_tank = 0 [Pa]
v_tank = 0 [m/s]

{A to CTC}
f_A_CTC = f_val(Re_A_CTC)
Re_A_CTC = (4*abs(Q_A_CTC))/(pi*nu*D_A_CTC) {Holland Eqn}
Q_A_CTC = (pi  * D_A_CTC^2/4) * v_CTC
(p_CTC - p_A)/(rho * g) + (H_CTC + sinkHeight) - (H_A) = -1 * v_CTC^2/(2*g) * (f_A_CTC * L_A_CTC/D_A_CTC + K_L_A_CTC + K_V_A_CTC)
{Bernoulis}
p_CTC = 0 [Pa]

{A to B}
Q_A_B = (pi  * D_A_B^2/4) * v_B
Re_A_B = (4*abs(Q_A_B))/(pi*nu*D_A_B) {Holland Eqn}
f_A_B = f_val(Re_A_B)
(p_B - p_A)/(rho * g) + (H_B) - (H_A) = -1 * v_B^2/(2*g) * (f_A_B * L_A_B/D_A_B + K_L_A_B) {Bernoulis}

{B to Admin Br}
Q_B_adminBr= (pi  * D_B_adminBr^2/4) * v_adminBr
Re_B_adminBr = (4*abs(Q_B_adminBr))/(pi*nu*D_B_adminBr) {Holland Eqn}
f_B_adminBr = f_val(Re_B_adminBr)
(p_adminBr - p_B)/(rho * g) + (H_adminBr + sinkHeight) - (H_B)= -1 * v_adminBr^2/(2*g) * (f_B_adminBr * L_B_adminBr/D_B_adminBr +
K_L_B_adminBr+ K_V_B_adminBr) {Bernoulis}
p_adminBr = 0 [Pa]

{B to C}
Q_B_C= (pi  * D_B_C^2/4) * v_C
Re_B_C = (4*abs(Q_B_C))/(pi*nu*D_B_C) {Holland Eqn}
f_B_C = f_val(Re_B_C)
(p_C - p_B)/(rho * g) + (H_C) - (H_B) = -1 * v_C^2/(2*g) * (f_B_C * L_B_C/D_B_C + K_L_B_C) {Bernoulis}

{C to bathrooms}
Q_C_bathrooms= (pi  * D_C_bathrooms^2/4) * v_bathrooms
Re_C_bathrooms = (4*abs(Q_C_bathrooms))/(pi*nu*D_C_bathrooms) {Holland Eqn}
f_C_bathrooms = f_val(Re_C_bathrooms)
(p_bathrooms - p_C)/(rho * g) + (H_bathrooms + sinkHeight) - (H_C) = -1 * v_bathrooms^2/(2*g) * (f_C_bathrooms *
L_C_bathrooms/D_C_bathrooms + K_L_C_bathrooms + K_V_C_bathrooms) {Bernoulis}
p_bathrooms = 0 [Pa]

{C to D}
Q_C_D = (pi  * D_C_D^2/4) * v_D
Re_C_D = (4*abs(Q_C_D))/(pi*nu*D_C_D) {Holland Eqn}
f_C_D = f_val(Re_C_D)
(p_D - p_C)/(rho * g) + (H_D) - (H_C) = -1 * v_D^2/(2*g) * (f_C_D * L_C_D/D_C_D + K_L_C_D) {Bernoulis}

{D to Private Ward}
Q_D_private = (pi  * D_D_private^2/4) * v_private
Re_D_private = (4*abs(Q_D_private))/(pi*nu*D_D_private) {Holland Eqn}
```

f_D_private = f_val(Re_D_private)
(p_private - p_D)/(rho * g) + (H_private+sinkHeight) - (H_D) = -1 * v_private^2/(2*g) * (f_D_private * L_D_private/D_D_private + K_L_D_private + K_V_D_private) {Bernoulis}
p_private = 0 [Pa]

{Junction D to Junction E}
Q_D_E= (pi * D_D_E^2/4) * v_E
Re_D_E = (4*abs(Q_D_E))/(pi*nu*D_D_E) {Holland Eqn}
f_D_E = f_val(Re_D_E)
(p_E - p_D)/(rho * g) + (H_E) - (H_D) = -1 * v_E^2/(2*g) * (f_D_E * L_D_E/D_D_E + K_L_D_E) {Bernoulis}

{Junction E to Maternity}
Q_E_maternity = (pi * D_E_maternity^2/4) * v_maternity
Re_E_maternity = (4*abs(Q_E_maternity))/(pi*nu*D_E_maternity) {Holland Eqn}
f_E_maternity = f_val(Re_E_maternity)
(p_maternity - p_E)/(rho * g) + (H_maternity+sinkHeight) - (H_E) = -1 * v_maternity^2/(2*g) * (f_E_maternity * L_E_maternity/D_E_maternity + K_L_E_maternity + K_V_E_maternity) {Bernoulis}
p_maternity = 0 [Pa]

{Junction E to Junction F}
Q_E_F = (pi * D_E_F^2/4) * v_F
Re_E_F = (4*abs(Q_E_F))/(pi*nu*D_E_F) {Holland Eqn}
f_E_F = f_val(Re_E_F)
(p_F - p_E)/(rho * g) + (H_F) - (H_E) = -1 * v_F^2/(2*g) * (f_E_F * L_E_F/D_E_F + K_L_E_F) {Bernoulis}

{Junction F to Generral}
Q_F_general= (pi * D_F_general^2/4) * v_general
Re_F_general = (4*abs(Q_F_general))/(pi*nu*D_F_general) {Holland Eqn}
f_F_general = f_val(Re_F_general)
(p_general - p_F)/(rho * g) + (H_general+sinkHeight) - (H_F) = -1 * v_general^2/(2*g) * (f_F_general * L_F_general/D_F_general + K_L_F_general + K_V_F_general) {Bernoulis}
p_general = 0 [Pa]

{Junction F to lab}
Q_F_lab = (pi * D_F_lab^2/4) * v_lab
Re_F_lab = (4*abs(Q_F_lab))/(pi*nu*D_F_lab) {Holland Eqn}
f_F_lab = f_val(Re_F_lab)
(p_lab - p_F)/(rho * g) + (H_lab+sinkHeight) - (H_F) = -1 * v_lab^2/(2*g) * (f_F_lab * L_F_lab/D_F_lab + K_L_F_lab + K_V_F_lab) {Bernoulis}
p_lab = 0 [Pa]

{Flow divisions}
Q_tank_A = Q_A_CTC + Q_A_B
Q_A_B = Q_B_adminBr + Q_B_C
Q_B_C = Q_C_bathrooms + Q_C_D
Q_C_D = Q_D_private + Q_D_E
Q_D_E = Q_E_maternity + Q_E_F
Q_E_F = Q_F_general + Q_F_lab

{Nicer Units}
Q_tank_A_lpm = Q_tank_A * 60000 [s*L/(m^3*min)]
Q_A_CTC_lpm = Q_A_CTC * 60000 [s*L/(m^3*min)]
Q_B_adminBr_lpm = Q_B_adminBr * 60000 [s*L/(m^3*min)]
Q_C_bathrooms_lpm = Q_C_bathrooms * 60000 [s*L/(m^3*min)]

Q_D_private_lpm = Q_D_private * 60000 [s*L/(m^3*min)]
Q_E_maternity_lpm = Q_E_maternity * 60000 [s*L/(m^3*min)]
Q_F_general_lpm = Q_F_general * 60000 [s*L/(m^3*min)]
Q_F_lab_lpm = Q_F_lab * 60000 [s*L/(m^3*min)]

Appendix E2 - EES Code for Urgent Care Zone:

```
function f_val(Re)
IF (Re < 2300) THEN
f_val = 64/Re
ELSE
f_val = (-1.8*LOG10(6.9/Re))^(-2)
ENDIF
END

{CONVERSIONS and CONSTANTS}
1 / fpm = ipf * 2.54 [cm/in] * .01 [m/cm]
ipf = 12 [in/ft]
ipm = ipf*fpm
rho = 1000 [kg/m^3]
g = 9.81 [m/s^2]
nu = 1.31 [m^2/s] * 10^(-6)
sinkHeight = 1
sinkLength = 2
extraTankHeight = 5 [ft] / fpm

{-----------RELEVANT HEIGHTS--------------}

H_well=0  {well}
H_tank=(110[ft])/fpm  {32kL cement tank}

H_nurse_office=H_tank-54.5[in]/ipm {nurse school offices}
H_nurse_class=H_nurse_office-53.75[in]/ipm {nurse school classrooms, floor 1}
H_emerg=H_nurse_class-(45.25[in])/ipm {emergency room}
H_diag=H_emerg-50[in]/(ipf*fpm) {diagnostics}
H_delivery_east=H_diag-38.5[in]/ipm {Delivery east half}
H_delivery_west=H_delivery_east-10[in]/ipm {Delivery west half}
H_theatre=H_delivery_west-7[ft]/fpm {Theatre}
H_lochness=H_theatre-67[in]/ipm{cement tank}
H_laundry=H_lochness-20[in]/ipm {Laundry}
H_general=H_theatre-22[in]/ipm {General ward}
H_lab=H_general-53[in]/ipm {Laboratory}
H_wash_spigot = (H_laundry + H_lab)/2 {washing wash_spigot}
H_drinking_spigot = H_theatre

H_A = H_emerg - 1 [m]
H_B = H_emerg - 1 [m]
H_C = H_delivery_east
H_D = H_theatre

mainPipe = 2 [in] / ipm
minorPipe = 0.75 [in] / ipm
open = 15
closed = 10^19
elbow = 1.5
building = 10*elbow

{Habkuk's Hut}
K_V_B_emerg = closed
K_V_B_diag = closed
```

```
K_V_C_delivery_east = closed
K_V_D_theatre = closed
K_V_D_drinking_spigot = open



{Tank to Junction A}
D_tank_A = mainPipe
L_tank_A = 40 [m]
K_L_tank_A = 0
Q_tank_A = (pi * D_tank_A^2/4) * v_A
Re_tank_A = (4*abs(Q_tank_A))/(pi*nu*D_tank_A) {Holland Eqn}
f_tank_A = f_val(Re_tank_A)
{Bernouli}
(p_A-p_tank)/(rho*g) +(v_A^2-v_tank^2) / (2*g) + (H_A) - (H_tank + extraTankHeight) = -1 * v_A^2/(2*g) * (f_tank_A*L_tank_A/D_tank_A +
K_L_tank_A)
p_tank = 0 [Pa] {guage pressure}
v_tank = 0 [m/s]

{Junction A to B}
D_A_B = mainPipe
L_A_B = 20
K_L_A_B = 0
Q_A_B = (pi  * D_A_B^2/4) * v_B
Re_A_B = (4*abs(Q_A_B))/(pi*nu*D_A_B) {Holland Eqn}
f_A_B = f_val(Re_A_B)
(p_B - p_A)/(rho * g) + (H_B) - (H_A) = -1 * v_B^2/(2*g) * (f_A_B * L_A_B/D_A_B + K_L_A_B) {Bernoulis}

{Junction B to emerg}
D_B_emerg = minorPipe
L_B_emerg = 10 + 5 + sinkLength
K_L_B_emerg = building + elbow
Q_B_emerg = (pi  * D_B_emerg^2/4) * v_emerg
Re_B_emerg = (4*abs(Q_B_emerg))/(pi*nu*D_B_emerg) {Holland Eqn}
f_B_emerg = f_val(Re_B_emerg)
(p_emerg - p_B)/(rho * g) + (H_emerg + sinkHeight) - (H_B) = -1 * v_emerg^2/(2*g) * (f_B_emerg * L_B_emerg/D_B_emerg + K_L_B_emerg +
K_V_B_emerg) {Bernoulis}
p_emerg = 0 [Pa]

{Junction B to diag}
D_B_diag = minorPipe
L_B_diag = 35 + 25 + 5 + building
K_L_B_diag = building + elbow*2
Q_B_diag = (pi  * D_B_diag^2/4) * v_diag
Re_B_diag = (4*abs(Q_B_diag))/(pi*nu*D_B_diag) {Holland Eqn}
f_B_diag = f_val(Re_B_diag)
(p_diag - p_B)/(rho * g) + (H_diag + sinkHeight) - (H_B) = -1 * v_diag^2/(2*g) * (f_B_diag * L_B_diag/D_B_diag + K_L_B_diag + K_V_B_diag)
{Bernoulis}
p_diag = 0 [Pa]

{Junction A to C}
D_A_C = mainPipe
L_A_C = 50 [m]
K_L_A_C = 0
Q_A_C = (pi  * D_A_C^2/4) * v_C
Re_A_C = (4*abs(Q_A_C))/(pi*nu*D_A_C) {Holland Eqn}
```

```
f_A_C = f_val(Re_A_C)
(p_C - p_A)/(rho * g) + (H_C) - (H_A) = -1 * v_C^2/(2*g) * (f_A_C * L_A_C/D_A_C + K_L_A_C) {Bernoulis}

{Junction C to delivery_east}
D_C_delivery_east = minorPipe
L_C_delivery_east = 35 + sinkLength
K_L_C_delivery_east = building
Q_C_delivery_east = (pi  * D_C_delivery_east^2/4) * v_delivery_east
Re_C_delivery_east = (4*abs(Q_C_delivery_east))/(pi*nu*D_C_delivery_east) {Holland Eqn}
f_C_delivery_east = f_val(Re_C_delivery_east)
(p_delivery_east - p_C)/(rho * g) + (H_delivery_east + sinkHeight) - (H_C) = -1 * v_delivery_east^2/(2*g) * (f_C_delivery_east *
L_C_delivery_east/D_C_delivery_east + K_L_C_delivery_east + K_V_C_delivery_east) {Bernoulis}
p_delivery_east = 0 [Pa]

{Junction C to D}
D_C_D = mainPipe
L_C_D = 20 [m]
K_L_C_D = 0
Q_C_D = (pi  * D_C_D^2/4) * v_D
Re_C_D = (4*abs(Q_C_D))/(pi*nu*D_C_D) {Holland Eqn}
f_C_D = f_val(Re_C_D)
(p_D - p_C)/(rho * g) + (H_D) - (H_C) = -1 * v_D^2/(2*g) * (f_C_D * L_C_D/D_C_D + K_L_C_D) {Bernoulis}

{Junction D to theatre}
D_D_theatre = minorPipe
L_D_theatre = 25 + sinkLength
K_L_D_theatre = building
Q_D_theatre = (pi  * D_D_theatre^2/4) * v_theatre
Re_D_theatre = (4*abs(Q_D_theatre))/(pi*nu*D_D_theatre) {Holland Eqn}
f_D_theatre = f_val(Re_D_theatre)
(p_theatre - p_D)/(rho * g) + (H_theatre) - (H_D) = -1 * v_theatre^2/(2*g) * (f_D_theatre * L_D_theatre/D_D_theatre + K_L_D_theatre +
K_V_D_theatre) {Bernoulis}
p_theatre = 0 [Pa]

{Junction D to drinking_spigot}
D_D_drinking_spigot = minorPipe
L_D_drinking_spigot = 15 + 15 + sinkLength
K_L_D_drinking_spigot = 5*elbow
Q_D_drinking_spigot = (pi  * D_D_drinking_spigot^2/4) * v_drinking_spigot
Re_D_drinking_spigot = (4*abs(Q_D_drinking_spigot))/(pi*nu*D_D_drinking_spigot) {Holland Eqn}
f_D_drinking_spigot = f_val(Re_D_drinking_spigot)
(p_drinking_spigot - p_D)/(rho * g) + (H_drinking_spigot + sinkHeight) - (H_D) = -1 * v_drinking_spigot^2/(2*g) * (f_D_drinking_spigot *
L_D_drinking_spigot/D_D_drinking_spigot + K_L_D_drinking_spigot + K_V_D_drinking_spigot) {Bernoulis}
p_drinking_spigot = 0 [Pa]

{Flow Balance}
Q_tank_A = Q_A_B + Q_A_C
Q_A_B = Q_B_emerg + Q_B_diag
Q_A_C = Q_C_delivery_east + Q_C_D
Q_C_D = Q_D_drinking_spigot + Q_D_theatre

{Easy to Read}
flow_conv =  60000
Q_tank_A_lpm = Q_tank_A * flow_conv
Q_B_emerg_lpm = Q_B_emerg * flow_conv
```

Q_B_diag_lpm = Q_B_diag * flow_conv
Q_C_delivery_east_lpm = Q_C_delivery_east * flow_conv
Q_D_theatre_lpm = Q_D_theatre * flow_conv
Q_D_drinking_spigot_lpm = Q_D_drinking_spigot * flow_conv

Appendix E3 - EES Code for Housing Zone:

```
function f_val(Re)
IF (Re < 2300) THEN
f_val = 64/Re
ELSE
f_val = (-1.8*LOG10(6.9/Re))^(-2)
ENDIF
END

{CONVERSIONS and CONSTANTS}
1 / fpm = ipf * 2.54 [cm/in] * .01 [m/cm]
ipf = 12 [in/ft]
ipm = ipf*fpm
rho = 1000 [kg/m^3]
g = 9.81 [m/s^2]
nu = 1.31 [m^2/s] * 10^(-6)
sinkHeight = 1
sinkLength = 2
extraTankHeight = 5 [ft] / fpm {14 feet if tank is full}



{-----------RELEVANT HEIGHTS--------------}

H_well=0  {well}
H_tank=(110[ft])/fpm  {32kL cement tank}

{Housing}
H_guest1=H_tank-(8[ft] * ipf + 5[in]) / ipm
H_guest2=H_guest1 - 46[in]/ipm
H_guest3=H_guest2 - 10[in]/ipm
H_dr3=H_lochness + 6[in]/ipm
H_dr5 = 22 [m] {ESTIMATE}
H_dr2 = 27 [m] {ESTIMATE}
H_dr1 = H_guest2 {ESTIMATE}
H_dr4=H_dr3 - 26[in]/ipm
H_old_pastor = H_tank-10[ft] / fpm  {south pastor's house}
H_new_pastor=H_old_pastor {middle pastor's house}
H_old_old_pastor=H_old_pastor {north pastor's house}

H_nurse_office=H_tank-54.5[in]/ipm {nurse school offices}
H_nurse_class=H_nurse_office-53.75[in]/ipm {nurse school classrooms, floor 1}
H_emerg=H_nurse_class-(45.25[in])/ipm {emergency room}
H_diag=H_emerg-50[in]/(ipf*fpm) {diagnostics}
H_delivery_east=H_diag-38.5[in]/ipm {Delivery east half}
H_delivery_west=H_delivery_east-10[in]/ipm {Delivery west half}
H_theatre=H_delivery_west-7[ft]/fpm {Theatre}
H_lochness=H_theatre-67[in]/ipm{cement tank}
H_laundry=H_lochness-20[in]/ipm {Laundry}
H_general=H_theatre-22[in]/ipm {General ward}
H_lab=H_general-53[in]/ipm {Laboratory}
H_spigot = (H_laundry + H_lab)/2 {washing spigot}

H_A = H_guest1 - 1 [m]
H_B = H_guest2 - 1 [m]
```

```
H_C = H_dr1 - 1 [m]
H_D = H_guest3 - 1 [m]
H_E = H_dr2 - 1 [m]
H_F = H_dr3 - 1 [m]
H_G = H_dr4 - 1 [m]
H_H = H_dr3 - 1 [m]
H_I = H_laundry - 1 [m]
H_J = H_new_pastor - 1 [m]

mainPipeID = 2 [in]
mainPipe = mainPipeID / ipm
minorPipe = 0.75 [in] / ipm
open = 15
closed = 10^19
elbow = 1.5
building = 15

{Habkuk's Hut}
KV_A_guest1 = open
KV_B_guest2 = open
KV_C_dr1 = open
KV_D_guest3 = open
KV_E_dr2 = open
KV_F_dr5 = open
KV_G_dr4 = open
KV_H_dr3 = open
KV_I_laundry = open
KV_I_spigot = open
K_V_J_old_pastor = closed
K_V_J_new_pastor = closed
K_V_J_old_old_pastor = open


{Pipe Diameters}
D_tank_A = mainPipe
D_A_guest1 = minorPipe
D_A_B = mainPipe
D_B_guest2 = minorPipe
D_B_C = mainPipe
D_C_dr1 = minorPipe
D_C_D = mainPipe
D_D_guest3 = minorPipe
D_D_E = mainPipe
D_E_dr2 = minorPipe
D_E_F = mainPipe
D_F_dr5 = minorPipe
D_F_G = mainPipe
D_G_dr4 = minorPipe
D_G_H = mainPipe
D_H_dr3 = minorPipe
D_H_I = mainPipe
D_I_laundry = minorPipe
D_I_spigot = minorPipe

{Pipe Losses}
```

```
KL_tank_A = elbow
KL_A_guest1 = building
KL_A_B = 0
KL_B_guest2 = building
KL_B_C = 0
KL_C_dr1 = building
KL_C_D = 0
KL_D_guest3 = building
KL_D_E = elbow * 2
KL_E_dr2 = building
KL_E_F = 0
KL_F_dr5 = building + elbow
KL_F_G = 0
KL_G_dr4 = building
KL_G_H = 0
KL_H_dr3 = building
KL_H_I = 0
KL_I_laundry = building
KL_I_spigot = elbow * 4

{Pipe Lengths}
L_tank_A = 25 + 15
L_A_guest1 = 10 [m] + sinkLength
L_A_B = 20 [m]
L_B_guest2 = 5 [m] + sinkLength
L_B_C = 10 [m]
L_C_dr1 = 5 [m] + sinkLength
L_C_D = 20 [m]
L_D_guest3 = 10 [m] + sinkLength
L_D_E = 10 [m] + 20 [m] + 20 [m]
L_E_dr2 = 10 [m] + sinkLength
L_E_F = 40 [m]
L_F_dr5 = 35 [m] + 5 [m] + sinkLength
L_F_G = 10 [m]
L_G_dr4 = 10 [m] + sinkLength
L_G_H = 15 [m]
L_H_dr3 = 10 [m] + sinkLength
L_H_I = 25 [m]
L_I_laundry = 5 [m] + sinkLength
L_I_spigot = 25 [m] + sinkLength

{Tank to Junction A}
Q_tank_A = (pi * D_tank_A^2/4) * v_A
Re_tank_A = (4*abs(Q_tank_A))/(pi*nu*D_tank_A) {Holland Eqn}
f_tank_A = f_val(Re_tank_A)
{Bernouli}
(p_A-p_tank)/(rho*g) +(v_A^2-v_tank^2) / (2*g) + (H_A) - (H_tank + extraTankHeight) = -1 * v_A^2/(2*g) * (f_tank_A*L_tank_A/D_tank_A +
KL_tank_A)
p_tank = 0 [Pa] {guage pressure}
v_tank = 0 [m/s]

{Junction A to Guest House 1}
Q_A_guest1 = (pi  * D_A_guest1^2/4) * v_guest1
Re_A_guest1 = (4*abs(Q_A_guest1))/(pi*nu*D_A_guest1) {Holland Eqn}
f_A_guest1 = f_val(Re_A_guest1)
```

```
(p_guest1 - p_A)/(rho * g) + (H_guest1 + sinkHeight) - (H_A) = -1 * v_guest1^2/(2*g) * (f_A_guest1 * L_A_guest1/D_A_guest1 + KL_A_guest1 + KV_A_guest1) {Bernoulis}
p_guest1 = 0 [Pa]

{Junction A to B}
Q_A_B = (pi  * D_A_B^2/4) * v_B
Re_A_B = (4*abs(Q_A_B))/(pi*nu*D_A_B) {Holland Eqn}
f_A_B = f_val(Re_A_B)
(p_B - p_A)/(rho * g) + (H_B) - (H_A) = -1 * v_B^2/(2*g) * (f_A_B * L_A_B/D_A_B + KL_A_B) {Bernoulis}

{Junction B to Guest House 2}
Q_B_guest2 = (pi  * D_B_guest2^2/4) * v_guest2
Re_B_guest2 = (4*abs(Q_B_guest2))/(pi*nu*D_B_guest2) {Holland Eqn}
f_B_guest2 = f_val(Re_B_guest2)
(p_guest2 - p_B)/(rho * g) + (H_guest2 + sinkHeight) - (H_B) = -1 * v_guest2^2/(2*g) * (f_B_guest2 * L_B_guest2/D_B_guest2 + KL_B_guest2 + KV_B_guest2) {Bernoulis}
p_guest2 = 0 [Pa]

{Junction B to C}
Q_B_C = (pi  * D_B_C^2/4) * v_C
Re_B_C = (4*abs(Q_B_C))/(pi*nu*D_B_C) {Holland Eqn}
f_B_C = f_val(Re_B_C)
(p_C - p_B)/(rho * g) + (H_C) - (H_B) = -1 * v_C^2/(2*g) * (f_B_C * L_B_C/D_B_C + KL_B_C) {Bernoulis}

{Junction C to Dr. House 1}
Q_C_dr1 = (pi  * D_C_dr1^2/4) * v_dr1
Re_C_dr1 = (4*abs(Q_C_dr1))/(pi*nu*D_C_dr1) {Holland Eqn}
f_C_dr1 = f_val(Re_C_dr1)
(p_dr1 - p_C)/(rho * g) + (H_dr1 + sinkHeight) - (H_C) = -1 * v_dr1^2/(2*g) * (f_C_dr1 * L_C_dr1/D_C_dr1 + KL_C_dr1 + KV_C_dr1) {Bernoulis}
p_dr1 = 0 [Pa]

{Junction C to D}
Q_C_D = (pi  * D_C_D^2/4) * v_D
Re_C_D = (4*abs(Q_C_D))/(pi*nu*D_C_D) {Holland Eqn}
f_C_D = f_val(Re_C_D)
(p_D - p_C)/(rho * g) + (H_D) - (H_C) = -1 * v_D^2/(2*g) * (f_C_D * L_C_D/D_C_D + KL_C_D) {Bernoulis}

{Junction D to guest3}
Q_D_guest3 = (pi  * D_D_guest3^2/4) * v_guest3
Re_D_guest3 = (4*abs(Q_D_guest3))/(pi*nu*D_D_guest3) {Holland Eqn}
f_D_guest3 = f_val(Re_D_guest3)
(p_guest3 - p_D)/(rho * g) + (H_guest3 + sinkHeight) - (H_D) = -1 * v_guest3^2/(2*g) * (f_D_guest3 * L_D_guest3/D_D_guest3 + KL_D_guest3 + KV_D_guest3) {Bernoulis}
p_guest3 = 0 [Pa]

{Junction D to E}
Q_D_E = (pi  * D_D_E^2/4) * v_E
Re_D_E = (4*abs(Q_D_E))/(pi*nu*D_D_E) {Holland Eqn}
f_D_E = f_val(Re_D_E)
(p_E - p_D)/(rho * g) + (H_E) - (H_D) = -1 * v_E^2/(2*g) * (f_D_E * L_D_E/D_D_E + KL_D_E) {Bernoulis}

{Junction E to dr2}
Q_E_dr2 = (pi  * D_E_dr2^2/4) * v_dr2
Re_E_dr2 = (4*abs(Q_E_dr2))/(pi*nu*D_E_dr2) {Holland Eqn}
```

```
f_E_dr2 = f_val(Re_E_dr2)
(p_dr2 - p_E)/(rho * g) + (H_dr2 + sinkHeight) - (H_E) = -1 * v_dr2^2/(2*g) * (f_E_dr2 * L_E_dr2/D_E_dr2 + KL_E_dr2 + KV_E_dr2) {Bernoulis}
p_dr2 = 0 [Pa]

{Junction E to F}
Q_E_F = (pi  * D_E_F^2/4) * v_F
Re_E_F = (4*abs(Q_E_F))/(pi*nu*D_E_F) {Holland Eqn}
f_E_F = f_val(Re_E_F)
(p_F - p_E)/(rho * g) + (H_F) - (H_E) = -1 * v_F^2/(2*g) * (f_E_F * L_E_F/D_E_F + KL_E_F) {Bernoulis}

{Junction F to dr5}
Q_F_dr5 = (pi  * D_F_dr5^2/4) * v_dr5
Re_F_dr5 = (4*abs(Q_F_dr5))/(pi*nu*D_F_dr5) {Holland Eqn}
f_F_dr5 = f_val(Re_F_dr5)
(p_dr5 - p_F)/(rho * g) + (H_dr5 + sinkHeight) - (H_F) = -1 * v_dr5^2/(2*g) * (f_F_dr5 * L_F_dr5/D_F_dr5 + KL_F_dr5 + KV_F_dr5) {Bernoulis}
p_dr5 = 0 [Pa]

{Junction F to G}
Q_F_G = (pi  * D_F_G^2/4) * v_G
Re_F_G = (4*abs(Q_F_G))/(pi*nu*D_F_G) {Holland Eqn}
f_F_G = f_val(Re_F_G)
(p_G - p_F)/(rho * g) + (H_G) - (H_F) = -1 * v_G^2/(2*g) * (f_F_G * L_F_G/D_F_G + KL_F_G) {Bernoulis}

{Junction G to dr4}
Q_G_dr4 = (pi  * D_G_dr4^2/4) * v_dr4
Re_G_dr4 = (4*abs(Q_G_dr4))/(pi*nu*D_G_dr4) {Holland Eqn}
f_G_dr4 = f_val(Re_G_dr4)
(p_dr4 - p_G)/(rho * g) + (H_dr4 + sinkHeight) - (H_G) = -1 * v_dr4^2/(2*g) * (f_G_dr4 * L_G_dr4/D_G_dr4 + KL_G_dr4 + KV_G_dr4) {Bernoulis}
p_dr4 = 0 [Pa]

{Junction G to H}
Q_G_H = (pi  * D_G_H^2/4) * v_H
Re_G_H = (4*abs(Q_G_H))/(pi*nu*D_G_H) {Holland Eqn}
f_G_H = f_val(Re_G_H)
(p_H - p_G)/(rho * g) + (H_H) - (H_G) = -1 * v_H^2/(2*g) * (f_G_H * L_G_H/D_G_H + KL_G_H) {Bernoulis}

{Junction H to dr3}
Q_H_dr3 = (pi  * D_H_dr3^2/4) * v_dr3
Re_H_dr3 = (4*abs(Q_H_dr3))/(pi*nu*D_H_dr3) {Holland Eqn}
f_H_dr3 = f_val(Re_H_dr3)
(p_dr3 - p_H)/(rho * g) + (H_dr3 + sinkHeight) - (H_H) = -1 * v_dr3^2/(2*g) * (f_H_dr3 * L_H_dr3/D_H_dr3 + KL_H_dr3 + KV_H_dr3) {Bernoulis}
p_dr3 = 0 [Pa]

{Junction H to I}
Q_H_I = (pi  * D_H_I^2/4) * v_I
Re_H_I = (4*abs(Q_H_I))/(pi*nu*D_H_I) {Holland Eqn}
f_H_I = f_val(Re_H_I)
(p_I - p_H)/(rho * g) + (H_I) - (H_H) = -1 * v_I^2/(2*g) * (f_H_I * L_H_I/D_H_I + KL_H_I) {Bernoulis}

{Junction I to laundry}
Q_I_laundry = (pi  * D_I_laundry^2/4) * v_laundry
Re_I_laundry = (4*abs(Q_I_laundry))/(pi*nu*D_I_laundry) {Holland Eqn}
f_I_laundry = f_val(Re_I_laundry)
```

```
(p_laundry - p_I)/(rho * g) + (H_laundry + sinkHeight) - (H_I) = -1 * v_laundry^2/(2*g) * (f_I_laundry * L_I_laundry/D_I_laundry + KL_I_laundry +
KV_I_laundry) {Bernoulis}
p_laundry = 0 [Pa]

{Junction I to spigot}
Q_I_spigot = (pi  * D_I_spigot^2/4) * v_spigot
Re_I_spigot = (4*abs(Q_I_spigot))/(pi*nu*D_I_spigot) {Holland Eqn}
f_I_spigot = f_val(Re_I_spigot)
(p_spigot - p_I)/(rho * g) + (H_spigot + sinkHeight) - (H_I) = -1 * v_spigot^2/(2*g) * (f_I_spigot * L_I_spigot/D_I_spigot + KL_I_spigot +
KV_I_spigot) {Bernoulis}
p_spigot = 0 [Pa]

{Tank to Junction J}
D_tank_J = mainPipe
L_tank_J = 40
K_L_tank_J = elbow * 2 {to go under ground from above the tank}
Q_tank_J = (pi * D_tank_J^2/4) * v_J
Re_tank_J = (4*abs(Q_tank_J))/(pi*nu*D_tank_J) {Holland Eqn}
f_tank_J = f_val(Re_tank_J)
{Bernouli}
(p_J-p_tank)/(rho*g) +(v_J^2-v_tank^2) / (2*g) + (H_J) - (H_tank + extraTankHeight) = -1 * v_J^2/(2*g) * (f_tank_J*L_tank_J/D_tank_J +
K_L_tank_J)
p_tank = 0 [Pa] {guage pressure}
v_tank = 0 [m/s]

{Junction J to old_pastor}
D_J_old_pastor = minorPipe
L_J_old_pastor = 25 [m] + 10 [m] + sinkLength
K_L_J_old_pastor = building
Q_J_old_pastor = (pi  * D_J_old_pastor^2/4) * v_old_pastor
Re_J_old_pastor = (4*abs(Q_J_old_pastor))/(pi*nu*D_J_old_pastor) {Holland Eqn}
f_J_old_pastor = f_val(Re_J_old_pastor)
(p_old_pastor - p_J)/(rho * g) + (H_old_pastor + sinkHeight) - (H_J) = -1 * v_old_pastor^2/(2*g) * (f_J_old_pastor *
L_J_old_pastor/D_J_old_pastor + K_L_J_old_pastor + K_V_J_old_pastor) {Bernoulis}
p_old_pastor = 0 [Pa]

{Junction J to new_pastor}
D_J_new_pastor = minorPipe
L_J_new_pastor = 15 [m] + sinkLength
K_L_J_new_pastor = building
Q_J_new_pastor = (pi  * D_J_new_pastor^2/4) * v_new_pastor
Re_J_new_pastor = (4*abs(Q_J_new_pastor))/(pi*nu*D_J_new_pastor) {Holland Eqn}
f_J_new_pastor = f_val(Re_J_new_pastor)
(p_new_pastor - p_J)/(rho * g) + (H_new_pastor + sinkHeight) - (H_J) = -1 * v_new_pastor^2/(2*g) * (f_J_new_pastor *
L_J_new_pastor/D_J_new_pastor + K_L_J_new_pastor + K_V_J_new_pastor) {Bernoulis}
p_new_pastor = 0 [Pa]

{Junction J to old_old_pastor}
D_J_old_old_pastor = minorPipe
L_J_old_old_pastor = 30 [m] + 15 [m] + sinkLength
K_L_J_old_old_pastor = building + elbow
Q_J_old_old_pastor = (pi  * D_J_old_old_pastor^2/4) * v_old_old_pastor
Re_J_old_old_pastor = (4*abs(Q_J_old_old_pastor))/(pi*nu*D_J_old_old_pastor) {Holland Eqn}
f_J_old_old_pastor = f_val(Re_J_old_old_pastor)
```

(p_old_old_pastor - p_J)/(rho * g) + (H_old_old_pastor + sinkHeight) - (H_J) = -1 * v_old_old_pastor^2/(2*g) * (f_J_old_old_pastor * L_J_old_old_pastor/D_J_old_old_pastor + K_L_J_old_old_pastor + K_V_J_old_old_pastor) {Bernoulis}
p_old_old_pastor = 0 [Pa]

{Easy to Read}
flow_conv = 60000 [s*L/(m^3*min)]

{Flow Balance}
Q_tank_A = Q_A_B + Q_A_guest1
Q_A_B = Q_B_C + Q_B_guest2
Q_B_C = Q_C_D + Q_C_dr1
Q_C_D = Q_D_E + Q_D_guest3
Q_D_E = Q_E_F + Q_E_dr2
Q_E_F = Q_F_G + Q_F_dr5
Q_F_G = Q_G_H + Q_G_dr4
Q_G_H = Q_H_dr3 + Q_H_I
Q_H_I = Q_I_laundry + Q_I_spigot
Q_tank_J = Q_J_old_pastor + Q_J_new_pastor + Q_J_old_old_pastor

{Easy to Read}
flow_conv = 60000
Q_tank_A_lpm = Q_tank_A * flow_conv
Q_A_guest1_lpm = Q_A_guest1 * flow_conv
Q_B_guest2_lpm = Q_B_guest2 * flow_conv
Q_C_dr1_lpm = Q_C_dr1 * flow_conv
Q_D_guest3_lpm = Q_D_guest3 * flow_conv
Q_E_dr2_lpm = Q_E_dr2 * flow_conv
Q_F_dr5_lpm = Q_F_dr5 * flow_conv
Q_G_dr4_lpm = Q_G_dr4 * flow_conv
Q_H_dr3_lpm = Q_H_dr3 * flow_conv
Q_I_spigot_lpm = Q_I_spigot * flow_conv
Q_I_laundry_lpm = Q_I_laundry * flow_conv
Q_tank_J_lpm = Q_tank_J * flow_conv
Q_J_old_pastor_lpm = Q_J_old_pastor * flow_conv
Q_J_new_pastor_lpm = Q_J_new_pastor * flow_conv
Q_J_old_old_pastor_lpm = Q_J_old_old_pastor * flow_conv

Appendix E4 - EES Code for School Zone:

```
function f_val(Re)
IF (Re < 2300) THEN
f_val = 64/Re
ELSE
f_val = (-1.8*LOG10(6.9/Re))^(-2)
ENDIF
END

{CONVERSIONS and CONSTANTS}
1 / fpm = ipf * 2.54 [cm/in] * .01 [m/cm]
ipf = 12 [in/ft]
ipm = ipf*fpm
rho = 1000 [kg/m^3]
g = 9.81 [m/s^2]
nu = 1.31 [m^2/s] * 10^(-6)
sinkHeight = 1
sinkLength = 2
extraTankHeight = 5 [ft] / fpm


{-----------RELEVANT HEIGHTS--------------}

H_well=0  {well}
H_tank=(110[ft])/fpm  {32kL cement tank}

H_nursing_dorm = H_well + 40[ft]/fpm  {nursing house dorms}
H_nursing_kitchen = H_nursing_dorm {nursing house kitchen}
H_A = H_nursing_dorm + 2 [m]

mainPipe = 2 [in] / ipm
minorPipe = 0.75 [in] / ipm
open = 15 {sink at open still has losses}
closed = 10^19
elbow = 1.5
building = elbow * 10

{Habkuk's Hut}
K_V_A_nursing_dorm= closed
K_V_A_nursing_kitchen = open


{Tank to Junction A}
D_tank_A = mainPipe
L_tank_A = 30 + 50
K_L_tank_A = elbow
Q_tank_A = (pi * D_tank_A^2/4) * v_A
Re_tank_A = (4*abs(Q_tank_A))/(pi*nu*D_tank_A) {Holland Eqn}
f_tank_A = f_val(Re_tank_A)
{Bernouli}
(p_A-p_tank)/(rho*g) +(v_A^2-v_tank^2) / (2*g) + (H_A) - (H_tank + extraTankHeight) = -1 * v_A^2/(2*g) * (f_tank_A*L_tank_A/D_tank_A +
K_L_tank_A)
p_tank = 0 [Pa] {guage pressure}
```

```
v_tank = 0 [m/s]

{Junction A to nursing_dorm}
D_A_nursing_dorm = minorPipe
L_A_nursing_dorm = 35 + 10 + sinkLength
K_L_A_nursing_dorm = 15 + elbow + building
Q_A_nursing_dorm = (pi  * D_A_nursing_dorm^2/4) * v_nursing_dorm
Re_A_nursing_dorm = (4*abs(Q_A_nursing_dorm))/(pi*nu*D_A_nursing_dorm) {Holland Eqn}
f_A_nursing_dorm = f_val(Re_A_nursing_dorm)
(p_nursing_dorm - p_A)/(rho * g) + (H_nursing_dorm + sinkHeight) - (H_A) = -1 * v_nursing_dorm^2/(2*g) * (f_A_nursing_dorm *
L_A_nursing_dorm/D_A_nursing_dorm + K_L_A_nursing_dorm + K_V_A_nursing_dorm) {Bernoulis}
p_nursing_dorm = 0 [Pa]

{Junction A to nursing_kitchen}
D_A_nursing_kitchen = minorPipe
L_A_nursing_kitchen = 35 + 10 + sinkLength
K_L_A_nursing_kitchen = 15 + elbow + building
Q_A_nursing_kitchen = (pi  * D_A_nursing_kitchen^2/4) * v_nursing_kitchen
Re_A_nursing_kitchen = (4*abs(Q_A_nursing_kitchen))/(pi*nu*D_A_nursing_kitchen) {Holland Eqn}
f_A_nursing_kitchen = f_val(Re_A_nursing_kitchen)
(p_nursing_kitchen - p_A)/(rho * g) + (H_nursing_kitchen + sinkHeight) - (H_A) = -1 * v_nursing_kitchen^2/(2*g) * (f_A_nursing_kitchen *
L_A_nursing_kitchen/D_A_nursing_kitchen + K_L_A_nursing_kitchen + K_V_A_nursing_kitchen) {Bernoulis}
p_nursing_kitchen = 0 [Pa]

{Flow Balance}
Q_tank_A = Q_A_nursing_dorm + Q_A_nursing_kitchen

{Easy to Read}
flow_conv =  60000
Q_tank_A_lpm = Q_tank_A * flow_conv
Q_A_nursing_dorm_lpm = Q_A_nursing_dorm * flow_conv
Q_A_nursing_kitchen_lpm = Q_A_nursing_kitchen * flow_conv
```