Designing A Gravity-fed Water Transportation System for Itonya Village

Design for Life: Water in Tanzania, January 2017

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Executive Summary

The goal of this project was to design a gravity fed water distribution system to supply ample potable water to Itonya village in Tanzania. Itonya village has a population of 1,530 people, distributed between three sub-villages. The villagers currently collect water from mountain fed streams at the bottom of valleys, as well as from a single tap located at the Catholic church. The Catholic church distribution point is fed from a cistern which collects water which seeps out of the mountainside, but only provides enough water to serve seven families. Water samples from a current stream source and the Catholic church cistern were tested and found to be relatively clean. Itonya's current lack of a water distribution system requires the women and children to walk up to 500 m one way to obtain water, so installing taps in populated areas would be beneficial to all villagers, especially the women. The village also has a primary school and dispensary, both of which expressed a great need for clean, convenient water.

Itonya has a mountain stream with sufficient of water to supply the whole village. The stream is 800 m from the road through Itonya, and over 100 m higher in elevation than the village. This provided an ideal setup for a gravity fed system. Phase one of the system design will have a concrete cistern built on a relatively flat area somewhere along the mountain stream. The exact location of the cistern is left to the discretion of the villagers, wherever it will be easiest for them to build. The cistern will continuously feed water to a gravity main, which will fill one 10,000 L sim tank located 300 m down the hill from the cistern. From the tank, another gravity main will continue down the hill until it meets the road, where it will split into two branches, one serving the sub-village of Kati, and the other serving the sub-village of Kanisani. The Kati branch will run approximately two kilometers, with distribution points serving the primary school, Catholic church, and population center in Kati. The Kanisani branch will run one kilometer, with distribution points serving the dispensary, Lutheran church, and population center in Kanisani. There is also an option for a second phase of the design, which would serve the smallest sub-village of Tupendane. This would require purchasing an additional 5,000 L sim tank to install at the end of the Kati line, which would break the system and source the water and head for an additional 1.4 km of pipe needed to reach the population center in Tupendane.

The people of Itonya expressed their excitement and willingness to contribute to the construction and design of the system, and to a continuing commitment to organize and sustain a water committee. Phase one of the design will cost $23,500, of which $6,400 will be in kind contribution from the village, for a final total of $17,100. Phase two of the design will cost $7,600, of which $3,000 will be in kind contribution from the village, for a final total of $4,600. Both phases of this design have a high in-kind contribution percentage of about one third, due to the four kilometers of pipe which needs to be laid. Saint Paul Partner's will work with Itonya village to develop a project plan that will best serve the village as the design is finalized.

Table of Contents

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1.3 St. Paul Partners

Name	Role
Bo Skillman	Chairman
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Peter Mwakatundu	Driver and Technician, Iringa
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1.4 University of Iringa Student

Name	Affiliation	Phone Number
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1.5 Itonya Village Leaders

Name	Village Position	Phone Number
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Tolam Myonda	M/KITI	-
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2.0 Project Profile

2.1 Project Location

Region: Iringa, Tanzania
Place: Itonya Village.

Figure 2.1 below shows Itonya's relative location to the Southeast of Iringa town. A detailed map of Itonya village with important landmarks is provided in Figure 2.2 on the following page. Figure 2.3 shows the relative elevation and mountainous terrain within the village, from a Google Earth elevation view screenshot.

Coordinates of Village Center: 8.188712˚ S, 36.039283˚ E
Climate: High elevation, wet season January-May, dry season June-December.

Figure 2.1: Map of the Iringa region.

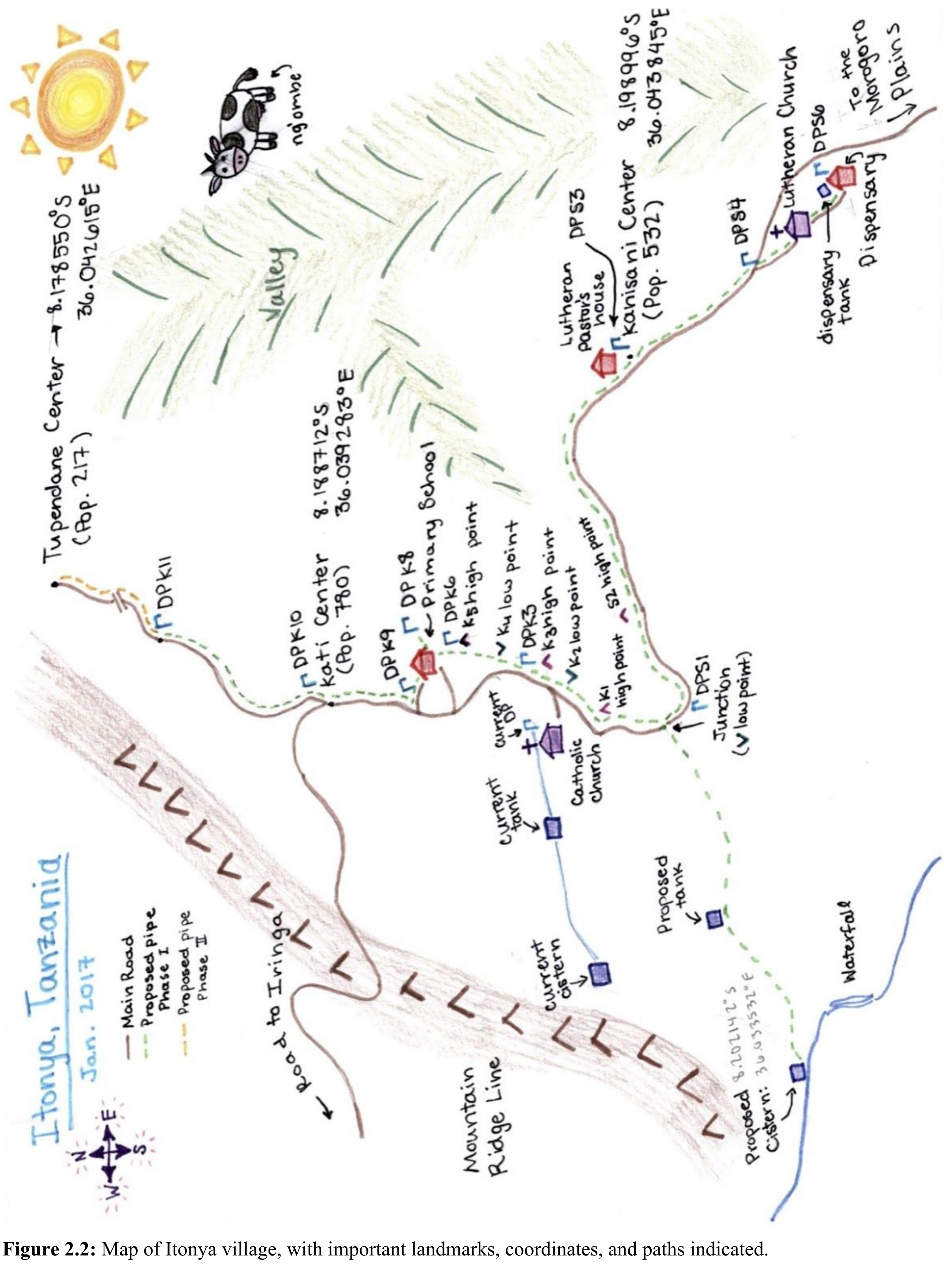

Figure 2.2: Map of Itonya village, with important landmarks, coordinates, and paths indicated.

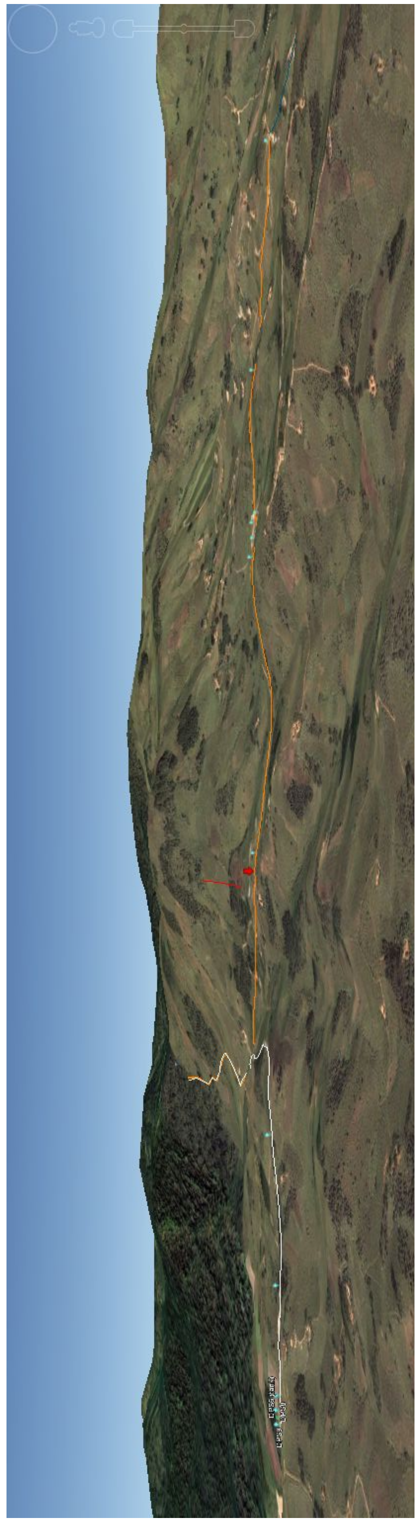

Figure 2.3: Itonya village Google Earth screenshot showing relative elevation and terrain of the village. The proposed gravity main rises up into the hills on the left side of the image. This image is taken from east of the village looking west.

2.2 Project Budget

The budget for Phase I and Phase II of the design is summarized in Table 2.1. A fully itemized cost breakdown is provided in section 8 of this report.

Table 2.1: A summary of major components and total costs for both of the Phases of the design.

Category	Phase 1	Phase 2
Raw Materials	$14,290	$3,470
Transportation	$2,850	$1,180
Labor	$6,370	$2,950
Total Cost	$23,500	$7,600
In Kind Contributions (Labor Costs)	$6,370	$3,000
Required Funds (Total Cost - In Kind Contribution)	$17,130	$4,600

3.0 Background

3.1 Itonya Village

Itonya lies approximately 60 km southeast of Iringa Town, in a mountainous region which borders the Morogoro plains. Arriving in Itonya was a feat in itself, as the road to the village is treacherous and often impassable during the rainy season. Figures 3.1 and 3.2 demonstrate the majestic scale and steepness of the hills surrounding Itonya, and show a glimpse of the pothole riddled road that we took to get there. However, the trip was well worth it; 40 villagers were waiting to greet us, and welcomed us enthusiastically with singing and dancing. One little girl in a dark green dress undoubtedly has the best dance moves in all of Tanzania, and smiled at us excitedly as she danced in a circle with her fellow villagers. We were warmly greeted by the Lutheran pastor and his wife, who have a modest stone house; Figure 3.3 shows how all of the walls had been covered with beautiful cloth for our comfort and pleasure, and made the small rooms feel like home. Every meal served by the pastor's wife and other village women was cooked over wood fires, took hours for them to prepare, and was remarkably tasty.


Figure 3.1 & 3.2: The road going south out of Kanisani, overlooking the Morogoro plains. (left) Ethan standing on a hillside to demonstrate how steep the countryside is. (right)

Figures 3.3 & 3.4: Everywhere we went in the village, we were greeted with joy and hospitality. The girl's bedroom in the pastor's house, decorated for the occasion. (left) A wise old man from Tupendane. (right)

After a welcoming meal, the Lutheran pastor, the Catholic priest's daughter, and other village leaders showed us around Itonya. Peter, from St. Paul Partners, along with Novatus, our University of Iringa student, helped translate and answer questions throughout the stay. We saw the village's only current source of running water, which is located at the Catholic Church and was nothing but a trickle of water when we were there, even when the tap was fully open. Along with the current water source, we also visited potential new sources of water. After a long day of hiking through the surrounding mountains of Itonya, we were greeted back at our homestay by village families who were enthusiastic to share their instuments, dancing, and singing with us. Despite the long day, it was uplifting and joyous to end it with music and the villagers.

On the second day, we met with village leaders, including the elected officials of Itonya. The village leaders helped us to understand Itonya's current water situation and priorities. They explained that there are three subvillages within Itonya. Kati, the village center, has the largest population of 780 people and contains the primary school and Catholic Church. Kanisani, located to the south of Kati, has a population of 532 people, and contains the dispensary and the Lutheran Church. Tupendane is located approximately one kilometer north of Kati and has a small population of 217. These locations, along with coordinates of the subvillage centers, are displayed in Figure 2.2. The leaders were supportive of the project, and agreed that they would readily form a water committee for the village in order to keep any water system in order.

We explored many of the village landmarks with the leaders. The primary school, located just south of Kati center, serves all of the village's youth. A typical classroom is shown in Figure 3.5. The primary school recently built 12 new bathrooms, shown in Figure 3.6, but they do not have nearby water source, so the bathrooms were inconvenient to use. Water was also lacking at the dispensary, where the rainwater collection tank sat empty during the dry season, shown in

Figure 3.7. The attendant at the dispensary said that people were only admitted for treatment if they brought 60 L of water, which required carrying it up a steep hill from over 200 m away. She also said they treat multiple cases of waterborne illnesses each month (more during the rainy season,) and that access to clean water was a major concern in Itonya.

Figure 3.5 & 3.6: A typical Itonya classroom. (left) The new bathrooms at the primary school. (right) The school is located at 8.190839 S, 36.040137 E.

Figure 3.7: The 4,000 L water tank on the side of the dispensary was poorly designed for rain catchment. The dispensary is located at 8.201781 S, 36.045606 E.

Despite the health issues and inconvenience from the lack of access to water, the people who we met and talked to in Itonya were wonderful. We brought frisbees and candy for the children shown in Figure 3.8 and 3.9, who were shy but eager to play with us. The children taught us to play the drums one evening, and sang and marched in a circle around us as we tried to get a hang of the beat. We all sang "We are Marching in the Light of God" together, in both English and Swahili. In exchange for the drum lessons, we played some American hip hop and had a dance off with them (although it was no contest, Tanzanians are exponentially better at dancing than we will ever be.) We met the old man with just a few teeth in Figure 3.4, who came out of his house grinning to welcome us to Tupendane. When we visited the lovely women of Tupendane, they were upset at the pastor for not alerting them of our arrival, but grateful we had made the trip out to Tupendane to visit them. Everywhere we went in the village, we were astounded and grateful for the hospitality offered to us, and the insights many villagers had to offer about the water needs of the village. We were also extremely grateful for Peter and Novatus, who were excellent translators and companions.

Figure 3.8 & 3.9: The children of Itonya and three Team Itonya group members pose with their new frisbees. (left) The children taught us how to play the drums and sang "We are Marching in the Light of God" with us in English and Swahili. (right)

3.2 Current Water Sources

Water is currently collected from springs and streams which run down the mountains into the valleys. To reach these sources the villagers, traditionally women and children, travel 100-500 m each way, frequently up and down steep hills. It is common to see a mother with a few of her children, each carrying a 20 L bucket of water on top of their heads as they casually hike up a steep hillside. There is sufficient water supply year round, but runoff from agriculture and livestock contaminates some of the water sources, particularly during the rainy season. As mentioned previously, the dispensary sees an increase in waterborne illnesses during the rainy season due to increased contamination. The water source in Figure 3.10 was next to the road midway between Kati and Tupendane, in the bottom of a valley.

Figure 3.10: One of the current water sources used by the people of Itonya. This source is located at 8.181770 S, 36.043706 E, on the road between Kati and Tupendane.

The Catholic church in the village has a distribution point, shown in Figure 3.11, which supplies water from a spring-fed cistern 430 m away. During the dry season the flow from the spring can be reduced to a trickle. Due to the drought, the tap was still only producing a trickle in January when we visited. The tank, halfway in between the cistern and the tap, only had 0.2 m of water sitting in the bottom. Figure 3.12 shows Ken measuring out the water level with a stick. The cistern, shown in Figure 3.13, was open to the atmosphere which allowed for contamination. The bottom half was covered in sludge and muck. The trickle from the mountainside which filled the cistern, depicted in Figure 3.14, was estimated at 300 L/hr using the water bottle and stopwatch method. This source only supplies water to seven nearby families, who currently pay the Catholic church for the water.

Although this is already an established source, the seven families that currently use the water source typically run the source dry on a daily basis during the dry season. This source does not supply enough water to meet the needs of the entire village.


Figure 3.11 & 3.12: The current distribution point at the Catholic church. (left) The tank, further up the hill, only had 0.2 m of water in the bottom. (right) The church is located at 8.197049 S, 36.040828 E.


Figure 3.13 & 3.14: The cistern used for the current Catholic church source. (left) The spring source trickle from the rocks which kept the cistern filled. (right) The cistern is located at 8.196900 S, 36.037669 E.

3.3 New Water Source

Since the village's current sources of water were either at risk of contamination, or had too small of a flow to supply water to the entire village, we needed to find a new source to supply water to the entire village. The town leaders led us up and down steep corn fields, and then cleared the way through an old growth forest with a machete to lead us to a series of waterfalls, shown in Figures 3.15 and 3.16. The waterfalls were fed from a mountain stream, which is a feasible source for water distribution to the villagers. It is approximately 800 m from the waterfall to the nearest road through Itonya; the junction intersects the road halfway in between Kanisani and Kati. The stream has a plentiful flow rate of 36,000 - 72,000 L/hr, based on the estimate that it would take one to two seconds to fill a 20 L bucket at the waterfall. The mountain stream and waterfalls are located 10-15 m into a village-owned old growth forest. The forest provides a buffer from the neighboring farm fields, and reduces the risk of contamination from fertilizer runoff. This source has plenty of water to sustainably supply the current and estimated future population of the village with water. It is presently unused by Itonya due to its inconvenient location, but it is used further downstream by a neighboring village, and eventually meets with a river. By the time it reaches the river, however, it is no longer a pristine source of drinking water.

Figure 3.15 & 3.16: Two of the waterfalls along the mountain stream in the forest. (Our fearless guide with the machete is pictured in both.) The big waterfall on the right is located at 8.202676 S, 36.034629 E. The bottom of the waterfall is at an elevation of 1598 m, 50 m above the center of Kati.

Figure 3.17 & 3.18: A view looking down the stream as it cascades down the mountainside. (left) The cistern would likely draw from a pool, such as the one pictured on the right.

Field water quality test kits were used to determine if the water sources contained bacteria. Chemical nutrients were added to the sample, which turned the water amber and would feed bacteria growth. The bottles were kept warm for 24 hours, and then checked again. If the samples were black, the water was unsafe to drink. If they were still amber, the water was free of harmful bacteria, and likely safe for the villagers to drink. However, the field test kits did not measure other harmful compounds that may be in the water, such as heavy metals and other contaminants. An official water test will need to be conducted on the new water source before the project is built. Tests were done on samples from the Catholic church's spring source, the stream source in Figure 3.10, and from the waterfall shown in Figure 3.15. All of the samples were amber after 24 hours. While this was a surprising result from the surface water source in Figure 3.10, Itonya was in a drought when the sample was taken, so no runoff had occurred in the past few months. The sample from the Catholic church cistern is shown when the chemical was first added in Figure 3.19, and after 24 hours in Figure 3.20. The other two samples were nearly identical to them in appearance.

Figure 3.19 & 3.20: Samples when the test was started (left) and after 24 hours (right) of the water sample from the cistern.

3.4 Demand and Priorities

The team met with village leaders to ask questions about the unmet needs for clean water, population distribution in the village, and priorities. The leaders listed each subvillage in order of importance for water. They indicated that the highest priority was to Kati, which contains the greatest number of people and the primary school. Their second priority was Kanisani, which contains the dispensary. Tupendane was the last priority to the village leaders.

Along with meeting the needs of the village, it is extremely important to make sure that system is sustainably managed by the village. Itonya does not currently have a water committee. It is imperative that the village is on board with the project, and are prepared to collect money in order to keep the system functioning. The money needs to be collected and responsibly saved, so an emergency fund is available when the system breaks or needs maintenance. These needs were communicated to the village leaders, who assured the team that their village was prepared to form a water committee. Additionally, they agreed to give someone in the village the job of checking on and performing regular cleaning and maintenance on the cistern and tanks after the system was built. This gravity fed system will be built by the people of Itonya, and they will be entirely responsible for it. We saw first hand how inventive and hard working the people in the village are, and have confidence in their ability to help develop and manage a fully functioning water system based on our design.

4.0 Design Criteria

4.1 Tanzanian Water Code

Tanzanian water code was used to determine much of the design criteria for the project. All of the design guidelines are attached in Appendix A for reference. The code was used to calculate the daily village water demand. The demand was broken down into locational categories and summarized in Table 4.1 below. As per the guidelines, the water system was designed to serve the projected population of Itonya 10 years from now, assuming a 1.5% increase in population per year. Water demand was based on 25 L/person/day, and 10 L/person/day for children at the school.

Table 4.1: Water system demand for both the current population and estimated future population of Itonya.

Location	Location Breakdown	2017			2027 (estimate 1.5% annual increase)		
		Population	Demand Per Capita (L/c/day)	Total Demand (L/day)	Population	Demand Per Capita (L/c/day)	Total Demand (L/day)
Dispensary	Patients	6.7	60	402	7.8	60	468
	Staff	3	25	75	3	25	75
Primary School	Students	327	10	3,270	379	10	3,790
	Staff	7	25	175	8	25	200
	Meal Service	-	-	-	1	500	500
Kati		780	25	19,500	905	25	22,625
Kanisani		532	25	13,300	617	25	15,425
Tupendane		217	25	5,425	252	25	6,300
Phase I Demand				36,722			43,083
Phase II Demand				5,425			6,300
Grand Total				42,147			49,383

5.0 Proposed Design

5.1 Phase 1

The goal of the first construction phase is to supply water to the sub villages of Kati and Kanisani, which include the primary school and dispensary. This system will distribute water to 12 distribution points from one, 10,000 L tank, serving approximately 1,300 people (85% of Itonya). This design requires approximately 3.6 km of buried HDPE piping and will be completely gravity fed, requiring no external power or electricity. All important locations mentioned in this section are listed with their GPS coordinates in Table 5.1 at the end of this section.

In order to use the new water source, water will be diverted from the mountain stream to a concrete cistern. This cistern will do basic filtering of water to remove debris and sediment from the surface water in the stream. A detailed description of the cistern design is discussed in Section 5.2. From the cistern, 40 mm outside diameter HDPE pipe will be buried 1 m deep and travel approximately 300 m through the old growth forest and between farm fields, down the mountain to the 10,000 L storage tank. Figure 5.2 shows a Google Earth View of where a the proposed line would run.

As shown in Table 4.1, the current demand for Phase I of the system is 36,700 L/day with a predicted future demand of 43,100 L/day. Because this design uses a constantly running source of water, it was believed that a large amount of storage capacity was unnecessary. Water will be flowing through the cistern and into the tank at a rate of 5,995 L/hr constantly. Due to this constant flow rate, the only time storage will be necessary is if there is a disruption in flow from the cistern to the storage tank. This will happen during routine cistern cleaning and maintenance.

From the storage tanks, 63 mm outside diameter HDPE pipe will be buried one meter deep and run approximately 470 m across the edge of farm fields to the side of the road that runs through Itonya, as shown in Figures 5.1 and 5.2. This gravity main meets the road between Kati and Kanisani. There is a 53 m vertical drop between the storage tanks and this point. This section, which runs from the cistern through the tank, to the branch point is outlined in the red box in Figure 5.1. Because the gravity main meets the road between Kati and Kanisani, two branches are created at this point which are outlined in the green and blue boxes respectively in Figure 5.1.

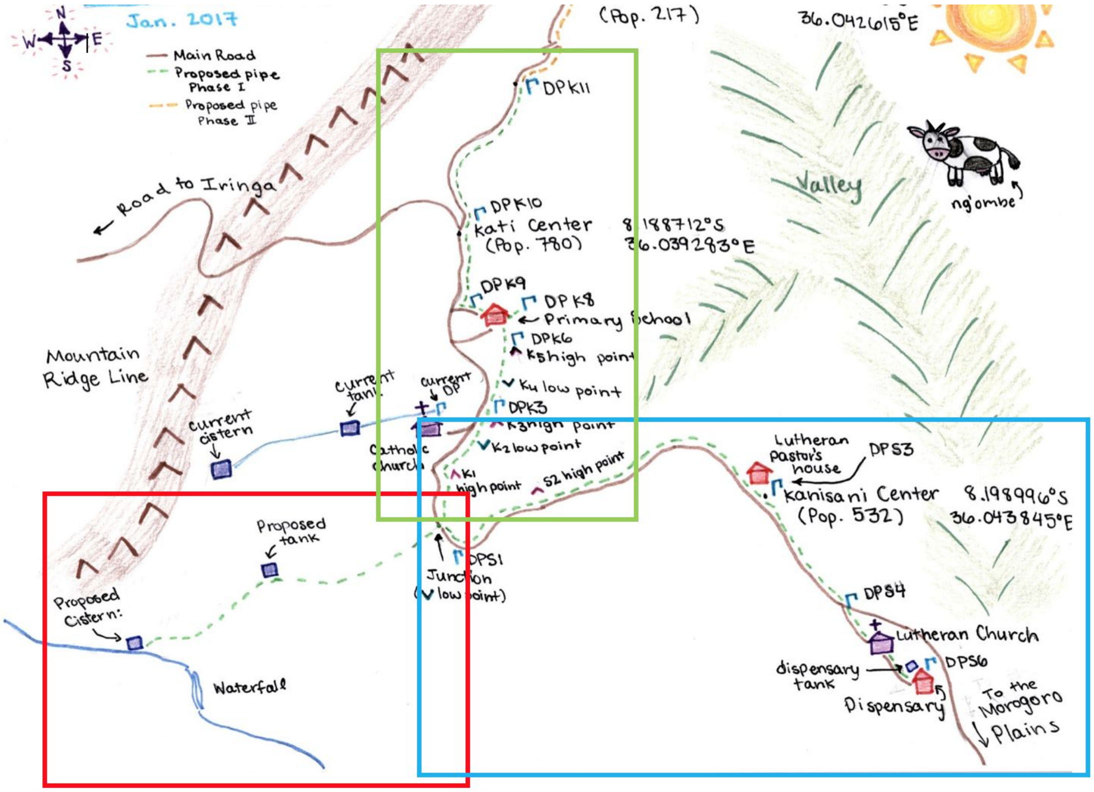

Figure 5.1: The gravity main section of the system is in the red box. The proposed tank coordinates are: 8.200827 S, 36.035839 E. For future reference, the Kanisani branch is in the blue box, while the Kati branch is in the green box.

Figure 5.2: A screenshot from Google Earth shows a blown up view of the area in the red box in Figure 5.1, the main gravity line. Multiple points along the mountain stream are labeled, and the cistern could be built at any point where the ground is relatively flat and hard. The pipe line splits into two branches right before DPS1.

The Kanisani branch will run along the road 957 m and end at the dispensary, which can be seen in Figure 5.3. All piping will be 63 mm outside diameter HDPE piping and will be buried one meter underground. This branch has seven outlets with six being distribution points and one being a outlet to fill the existing tank at the dispensary. The 4,000 L tank is utilized in this design as a backup source of water for the dispensary in case the system is broken for some time. The 4,000 L tank would be able to supply the dispensary for over 8 days at the current demand without needing to be resupplied. Three of the distribution points will be located at the dispensary and the other three distribution points will be public access. The public distribution points can be seen on Figure 5.1 and are labeled as DPS1, DPS3, and DPS4.

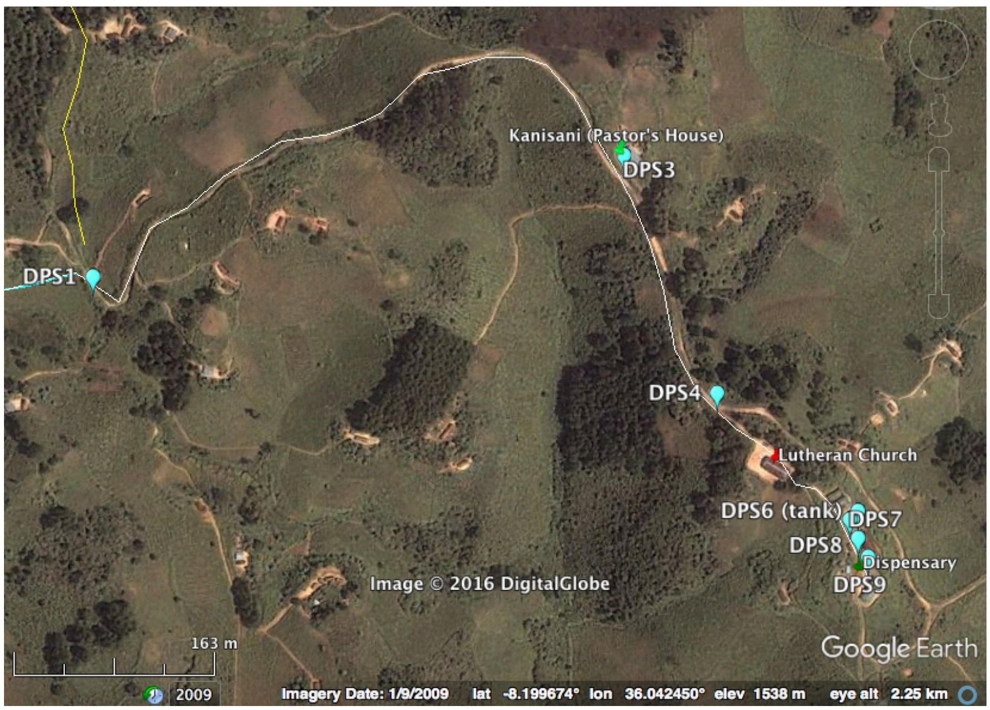

Figure 5.3: The Kanisani branch of the system, also shown in the blue box in Figure 5.1. The six distribution points and the dispensary location are labeled for reference.

The Kati branch will also run approximately along the road, although it branches away from the road near the primary school to avoid more extreme elevation changes followed by the road. The Kati branch runs 1,890 m before ending beyond the Kati village center as seen in Figure 5.4. All piping will be 63 mm HDPE piping and be buried one meter underground. The Kati branch will have six distribution points, three of which will be located at the primary school. One of the distribution points at the school will serve both the school and the public, giving a total of four public distribution points in the Kati branch. The four public distribution points can be seen in Figure 5.4 and are labeled as DPK3, DPK7, DPK10, and DPK11.

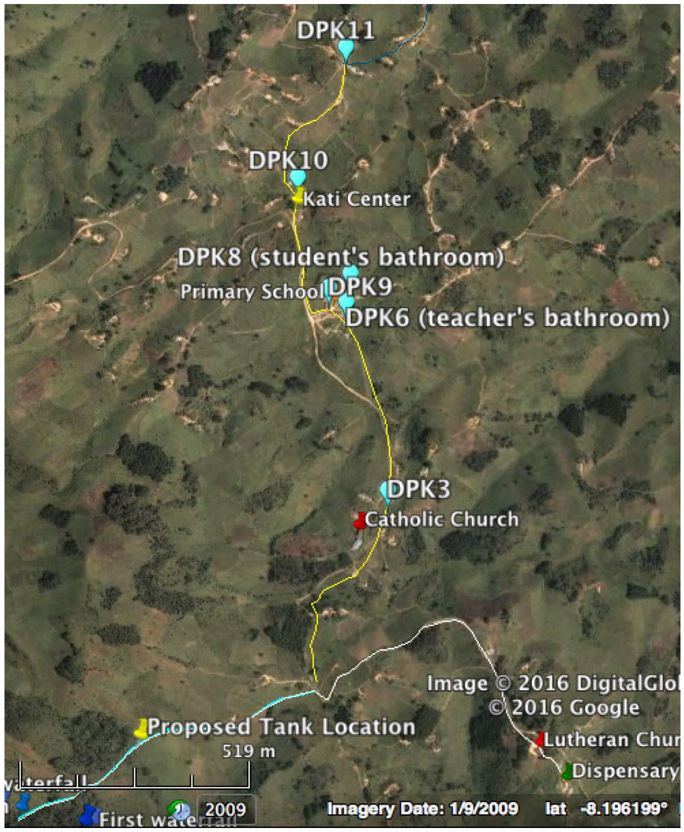

Figure 5.4: The Kati branch of the system, which is the area in the green box in Figure 5.1. The six distribution points and important landmarks are labeled for reference.

To ensure that the Tanzanian design guideline that no villager has to travel more than 400 m for water was met, Google Earth was used to create Figure 5.5. The radius of each of the blue circles is 400 m, centered around each distribution point. While some of the circles do significantly overlap, this ensures that no distribution point has to serve more than 250 people. Additionally, the mountainous countryside made it difficult to cover a few of the areas at the edges of the village, which were at significantly higher elevations than the road and therefore difficult to reach with the gravity system.

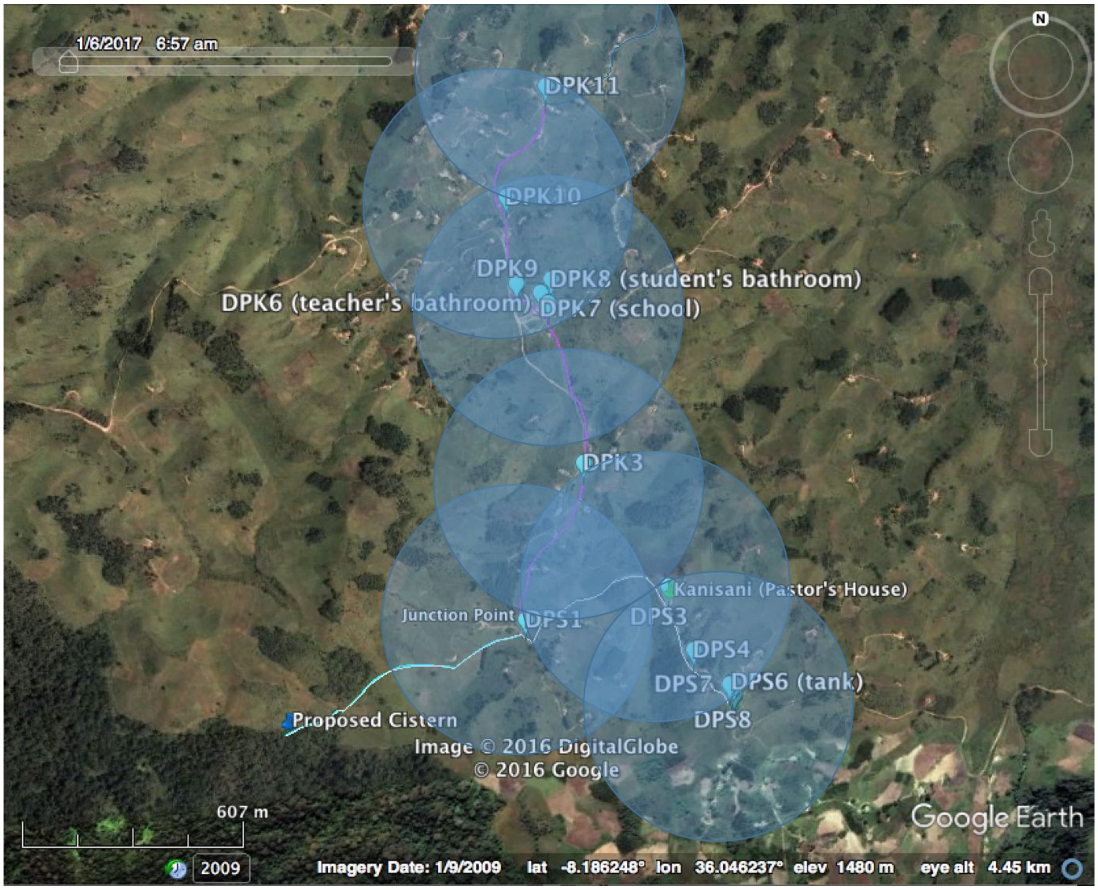

Figure 5.5: Each blue circle has a radius of 400 m, the maximum distance anyone should have to walk to gather water.

The hilly terrain also required a careful analysis of pressures throughout the system, especially at high and low points. Figure 5.6 shows the elevation profile of the entire Phase I of the design as well as grade lines between the tank and the end of each branch. As shown, the pipe elevation does get above the grade line in both branches. Although this is of some concern, this does not pose a problem to the operation of the system under normal operating conditions. The pressures inside the system become negative when nearly all of the taps are open at the same time, which would lead to air getting into the piping if there were leaks in the piping or fittings. However, it is anticipated that this will rarely happen due to the different schedules of the villagers, the primary school, and the dispensary.

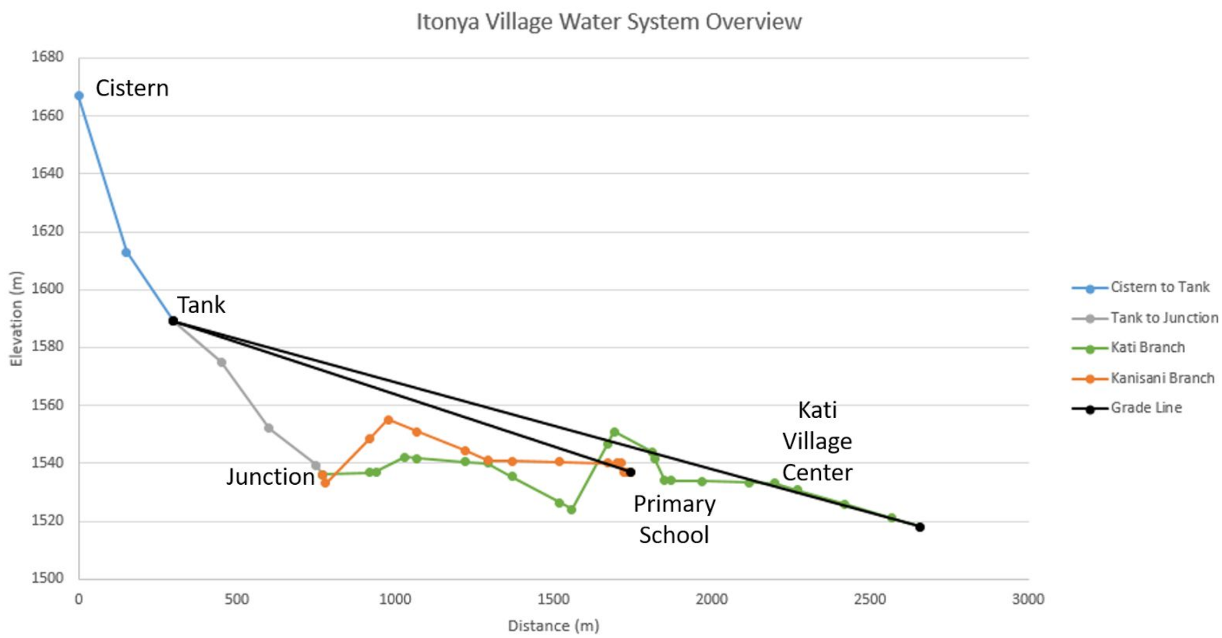

Figure 5.6: Whole system elevation profile from the cistern at the mountain stream to the end of each of the respective lines with key points labeled

When designing the system the bimodal nature of the daily demand was taken into consideration to ensure that the system could handle the peak demands. Peak demand is estimated to be 2.5 time average daily demand for the whole system. It was found that the peak demand when accounting for future growth is 10,580 L/hr. Our system is able to supply over 16,000 L/hr which is well above the design guideline. Sample calculations can be found in Appendix H.

The system will require air bleed valves at the local high points and washout valves at the local low points. Kati has three local low points and three local high points, easily identifiable in the profile above. Kanisani has two local low points and one local high point. In total, five washout valves and four air bleed valves will need to be installed in the system.

Five isolation valves will be added to the system as additional safety checks. They will be located directly after the cistern, directly after the tank, at the beginning of both the Kanisani and Kati branches, and immediately after the primary school distribution points. This will allow part of the system to be shut off if there is a problem, while allowing other portions of the system to remain operational. For example, if there is a broken pipe in the Kanisani Branch, Kati would still be able to get water due to the isolation valve.

Because of the varying pressures in the system due to the relatively large elevation differences, piping throughout the system had to be properly rated for the pressures that each section of pipe will see. A thorough analysis was done for each 150 m section of pipe to determine the proper rating of pipe to be used for each section. Pressures at various points in the system were found by simultaneously solving multiple Bernoulli's equations with Engineering Equation Solver (EES). A sample code can be found in Appendix B and sample calculations can be found in Appendix I. After pressures for each section of pipe were found, a safety factor of 1.25 times the calculated maximum pressure was used to determine the pressure rating for each 150 m section of pipe. Pipe ratings range from PN 4 to PN 10 throughout Phase I. Appendix E shows the break down the entire system into pipe sections, and specifies the required pressure rating for each section.

Table 5.1: GPS coordinates for important locations for Phase I of the design

Item	Description	GPS Coordinates
Cistern	Cistern near water source	Variable, can be anywhere near water source at greater elevation than tank
10,000 L Tank	Storage Tank	8°12’2.98”S, 36°2’9.06”E
Junction	Junction from gravity main to Kati and Kanisani branches	8°11'59.08"S, 36° 2'23.21"E
DPS1	Kanisani Distribution Point 1	8°11'59.66"S, 36° 2'23.60"E
DPS3	Kanisani Distribution Point 2	8°11'56.40"S, 36° 2'37.87"E
DPS4	Kanisani Distribution Point 3	8°12'2.79"S, 36° 2'40.48"E
DPS7	Dispensary Distribution Point 1	8°12'6.17"S, 36° 2'44.06"E
DPS8	Dispensary Distribution Point 2	8°12'6.67"S, 36° 2'44.29"E
DPS9	Dispensary Distribution Point 3	8°12'7.18"S, 36° 2'44.56"E
DPK3	Kati Distribution Point 1	8°11'44.16"S, 36° 2'29.37"E
DPK6	Primary School Distribution Point 1	8°11'28.44"S, 36° 2'25.85"E
KPK8	Primary School Distribution Point 2	8°11'26.05"S, 36° 2'26.13"E
DPK9	Kati Distribution Point 2 / Primary School Distribution Point 3	8°11'26.46"S, 36° 2'22.68"E
DPK10	Kati Distribution Point 3	8°11'17.94"S, 36° 2'21.66"E
DPK11	Kati Distribution Point 4	8°11'6.79"S, 36° 2'25.59"E

5.2 Cistern Design

A cistern will be implemented to collect water from the source and provide primary treatment prior to distribution. It will collect debris and settle out suspended solids, similar to a conventional settling tank in a water treatment system. The cistern will be divided into three zones: the inlet zone, the settling zone, and the outlet zone, as shown in Figure 5.7.

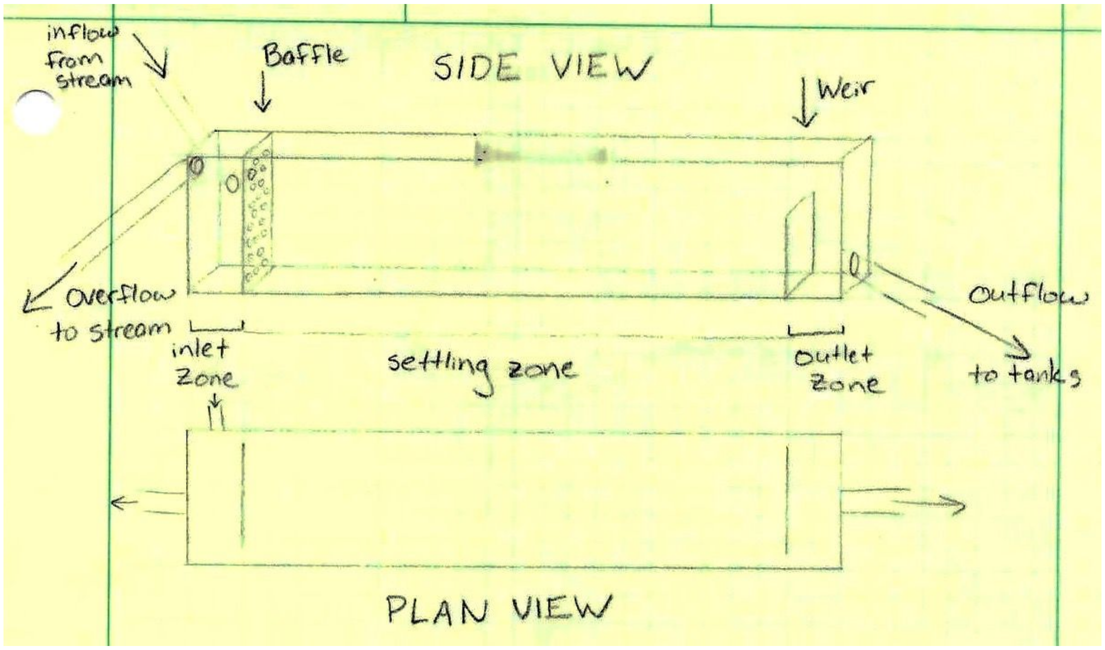

Figure 5.7: Sketch of the Cistern Design including inlet zone, settling zone, and outlet zone.

The inlet zone will contain an inflow pipe, which will divert water from the stream to the cistern, and an overflow pipe, which will return excess water to the stream. The inlet zone will be separated from the settling zone by a baffle. The location of the inlet pipe connection will ideally be along one of the sides rather than the front to help reduce jet effects, which cause short-circuiting, inhibiting the settling efficiency. Having a larger inlet zone will also reduce the jet effects. The height of the inlet connection is arbitrary, as long as sufficient head is provided to exceed the 6,000 L/hr demand. A velocity of 0.6 m/s is a guideline to ensure nothing settles in and clogs the pipe (Figure AC.1 in Appendix G). To obtain this velocity with a 5 cm diameter, 20 m long pipe, an elevation change of 19 cm between the two ends of the pipe is sufficient. If the pipe needs to be be longer, the required head will be larger.

In the stream the pipe will open upwards and be covered with a screen to keep large objects out. The pipe cannot go above this entry point at anywhere along its length or else the water will not flow the entire way to the cistern. Once the water enters the cistern it will run through a baffle, which will catch large objects and floatables, as well as reduce jet effects from the inlet pipe by distributing the the velocity across the entire cross-sectional area of the cistern.

The baffle should reach the top of the cistern to work most effectively so no water flows over the top. The overflow pipe should be at the top of the tank, and it should be oversized. This will ensure that any inflow to the cistern which exceeds the outflow demand will exit through the overflow pipe where and be diverted back to the river.

The largest section of the cistern is the settling zone, which functions as a sedimentation basin. A larger plan area leads to improved settling capabilities in the cistern, allowing smaller particles to be removed from suspension. Suspended particles can carry pathogens, so an increased removal efficiency will improve the health benefits of this design. To ensure the removal of medium sized silt of a diameter 0.03 mm given a flow rate of 6,000 L/hr, the settling zone area should have the minimum dimensions of 4x1 m. Guidelines indicate that the length to width ratio should be a minimum of 4:1, so any changes in size should be proportionally appropriate, maintaining a 4:1 or greater ratio, with 6:1 being recommended to account for dead zones at either end of the settling zone (see Figure AC.1.). The height of the cistern should not impact the effectiveness of the design and need not be specified.

The outlet zone is the section beyond the weir which contains the outlet pipe to the tank. It is critical that the height be less than that of the outlet pipe. Otherwise, the water will never reach the outlet zone. A weir height of 50-75% of the cistern height is recommended. Since the inlet flow should always exceed the outlet flow, the water level in the cistern should always be at the level of the overflow pipe. The water in the outlet zone that gets delivered to the tank should contain no debris and significantly fewer suspended particles than the water entering the cistern, improving health and pipe maintenance by reducing the risk of build-up occurring.

The outlet pipe should be located near the bottom to keep any floatables that made it through the screen from reaching the distribution system. It should also be raised up from the floor to keep additional settled material out of the outlet. There will also be a valve allowing the inflow to be shut off for cleaning, and drains on either side of the weir for the same reason.

The cistern will be made out of reinforced concrete and must be designed to support the water pressure on the interior walls and be watertight. This was done in accordance with the American Concrete Institute's (ACI) standards. Concrete reinforcement is important to provide resistance to the torque due to the water pressure. Since concrete is strong in compression but weak in tension, the reinforcement can supply that tensional strength and act as a cantilever to counteract the moment and support the wall.

Since the height of the cistern is unspecified, the exact pressures are unknown, so the load calculations were performed for water depths of 1 - 1.5 m. These loads were used to determine the concrete wall thickness. This ranged from 1 - 2.5 in (2.5 - 6.25 cm), with shorter walls bearing a smaller load. However, with steel reinforcement in a water bearing structure ACI standards require a concrete cover - a minimum thickness of the concrete covering each side of the steel to prevent corrosion. For this design the concrete cover is the limiting factor determining the thickness, rather than the shear demand placed on the wall. The cover requirement for a wall cast on earth is 3 in (75 mm). Therefore the total thickness of the wall should be 6 in plus the diameters of the transverse and longitudinal reinforcement.

The area of steel reinforcement within the wall structure was selected according to ACI specifications. In this structure the loads are not large enough to be the limiting factor but rather ACI determined minimum requirements. For walls cast-in-place using welded-wire reinforcement the minimum reinforcement ratios are 0.0012 and 0.0020 for longitudinal and transverse steel respectively. Therefore the longitudinal and transverse steel areas are 0.072 in^2/ft of width (1.5 cm^2/m of width) and 0.0432 in^2/ft of width (0.9 cm^2/m of width). The selection of the spacing and size of the wire reinforcement can be chosen using a chart, which provides all of the appropriate combinations (see Figure 2 in Appendix G).

5.3 Phase II

The goal of Phase II is to supply water to the remaining subvillage of Itonya: Tupendane. Tupendane is located about one kilometer north of Kati village center and is difficult to reach by vehicle. Tupendane only contains 15% of the total population of Itonya. Because of its small population and isolation from the rest of the village, Tupendane subvillage was left out of Phase I of the design plan. All important locations mentioned in this phase are listed with their GPS coordinates in Table 5.2 at the end of this section.

Phase II will supply water to the 220 people who live in Tupendane and will contain two distribution points. Figure 5.8 shows the proposed pipe route and distribution point locations for Phase II. Because Tupendane is located downhill from Kati, it is possible to apply a pressure break to the end of Phase I by installing a 5,000 L tank at the end of the Kati line. This will reset the pressures to atmospheric. The 5,000 L storage tank will meet the Tanzanian design guideline of having a storage capacity equal to 50% of the daily demand, so the storage tank will only need to be refilled once or twice per day. Table 4.1 shows the water demand for Phase II of the design.

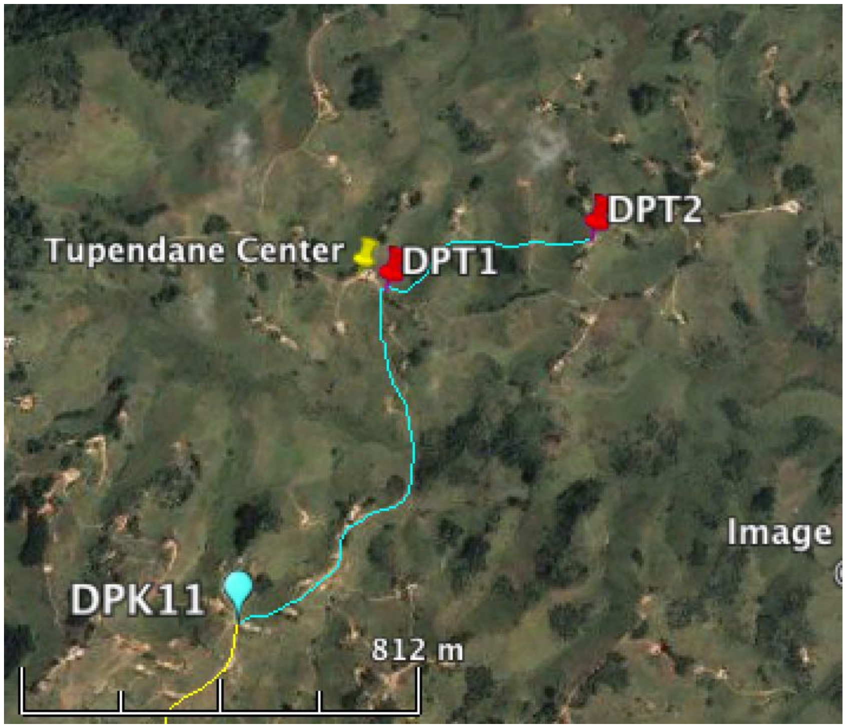

Figure 5.8: Map of proposed pipe route and distribution point locations for Phase II of the design, serving Tupendane.

From the new storage tank, 40 mm outside diameter HDPE piping will be laid one meter underground and run along the road to the Tupendane Center where the first distribution point will be located. Beyond this distribution point 40 mm outside diameter HDPE piping will continue to be laid underground, travelling east along roads and paths until the second distribution point where the line will end. In total, approximately 1.5 km of HDPE piping is required for Phase II of this design.

As discussed, the line was broken after Phase I to restart the system for Phase II. Because of this, the elevation profile only takes into account the elevation for the line from Kati to Tupendane. As is shown in Figure 5.9, there is plenty of elevation difference from the end of the Kati line to the end of the Tupendane line. The pipe does briefly rise above the grade line of the system but it does not affect the pressures or flows through the system. Both taps can be open simultaneously without difficulty.

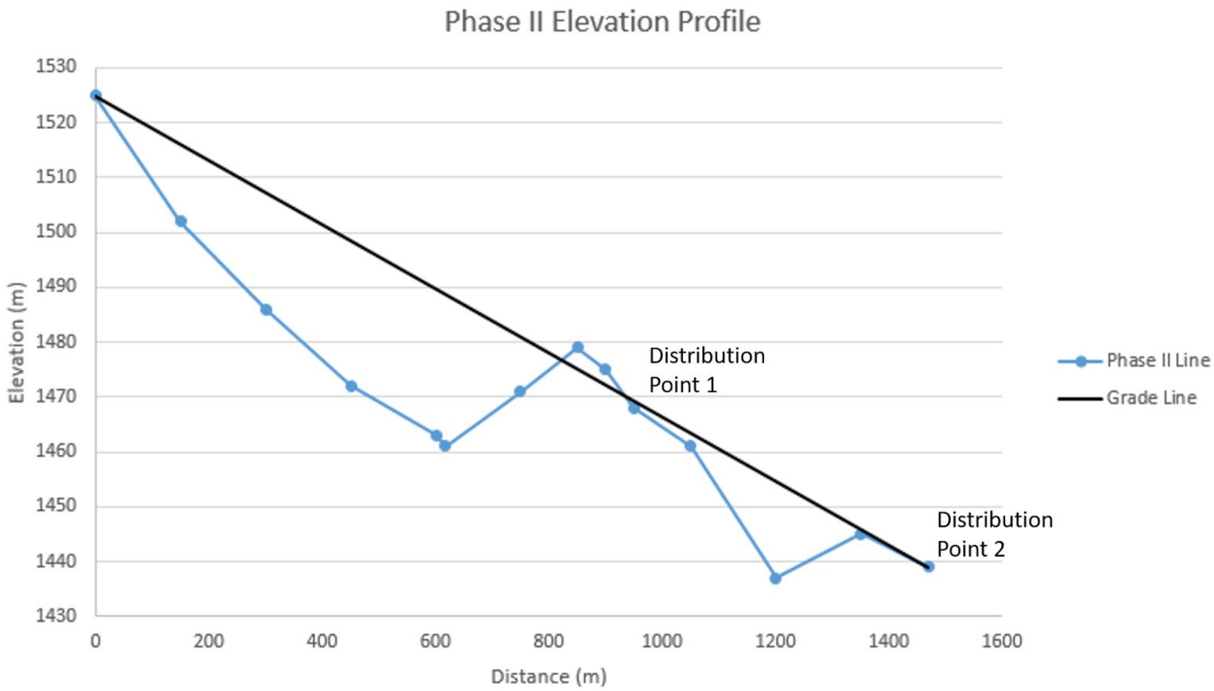

Figure 5.9: Elevation profile and grade line of Phase II of the proposed design.

A pressure analysis similar to the one done for Phase I was done for Phase II to determine the pressure rating required for each 150 m section of pipe. Once again, a combination of EES code and Excel was used to calculate the pipe rating for each section of pipe. A safety factor of 1.25 was used throughout this Phase II system. The pressure ratings for each 150 m section for this design can be found in Appendix F.

Table 5.2: GPS coordinates for important locations for Phase II of the design.

Item	Description	GPS Coordinates
Tank	5,000 L tank at end of Kati branch	8°11'6.66"S, 36° 2'25.66"E
DPT1	Tupendane Distribution Point 1	8°10'43.53"S, 36° 2'35.28"E
DPT2	Tupendane Distribution Point 2	8°10'40.18"S, 36° 2'49.82"E

6.0 Alternative Designs

6.1 Phase I Alternative

The original proposed design for Phase I was to use the cistern as the storage tank for the system instead of the 10,000 L storage tank. However, this design had a number of problems that made it necessary to add the tank. The biggest issue with using the cistern for storage was the high elevation. The cistern will be located next to the stream by necessity, which is 50-100 m above the village. The huge elevation drop caused pressures of up to 18 atm is the pipes, and caused a majority of the pipe sections to be PN16 and PN20, which are incredibly expensive due to their high pressure ratings. By adding a tank 300 m down the hillside from the stream, the system was "broken" and the pressures reset, since the tank was open to the atmosphere. This reduced all of the pressures in the pipes throughout the system, and cut the piping costs by approximately $6,000.

In addition to reducing the safety risks associated with high pressures as well as the cost, adding the tank will allow for water storage to supply the village with continuous water, even when the cistern is being cleaned. Without a storage tank, the water supply would have to be shut off every time the cistern needed to be cleaned, which would be at least once a week. The tank can easily provide water for an hour or two during off-peak hours when the inlet to the cistern is shut off to allow the baffle and weir to be cleaned. However, if for some reason it was inconvenient or too difficult to get a 10,000 L tank up the hill to the necessary position, the design without a tank could be revisited.

6.2 Phase II Alternative

A feasible and cost effective alternative to Phase II of the design is to drill a well and install a hand pump in Tupendane Center instead of connecting Phase I to Tupendane. Phase II requires an additional 1.5 km of pipe to be bought, transported, and buried, and only serves 217 people. That much pipe is expensive, and renders Phase II uneconomical, especially in light of the small number of people who would benefit. There is plenty of water from mountain streams in the valleys around Tupendane (Fig. 3.10), so it is reasonable to assume that a well could be dug with mud rotary and could provide ample water for the small population. This option would cost around $5,000 for the mud rotary well drilling and manual pump. This comparable with the current cost estimate for Phase II of $4,600, with an additional $3,000 of in-kind contribution required from the village. The proposed Phase II does have the benefit of providing two distribution points, which ensures that no one in Tupendane has to walk more than 400 m to get water- this would not be the case if there was only one location to get water in Tupendane.

6.3 Additional Considerations

Another issue which was considered but explored was the difficulty of burying pipe in the forest. Due to the thick vegetation surrounding the stream, it may be very difficult for the villagers to dig one meter through all of the forest roots. While this design could work without having the pipe buried in the forest, a different type of pipe would be need for that section, since HDPE degrades in the sunlight. PVC or another material would be needed instead.

Lastly, it should be noted that all distribution point locations and proposed pipe routes are simply suggestions based on our short time in the village and Tanzanian design guidelines.

These suggestions will need to be revisited and changed as seen fit by the villagers and project engineers before the project is actually implemented.

7.0 Impact of Design

7.1 Health & Safety

The proposed water supply system will lead to reduced cases of waterborne illnesses such as Diarrhea and Typhoid that are pervasive with the existing water sources. This is due to the fact that the tank and cistern will be adequately protected from any agricultural runoff and other contamination. This is especially relevant when seen in light of of the fact that such water borne diseases occur with greater frequency during the rainy season, during which Itonya tends to get isolated from nearby towns due to its mountainous geography. The dispensary in Kanisani sub-village of Itonya currently lacks the resources to treat such patients in a critical condition and transportation to the nearest hospital in Kidaga is extremely difficult. Hence, the proposed design will have a significant impact in reducing mortality cases due to water borne illnesses, especially during the rainy period.

7.2 Environmental Impact

One of the key concerns for the impact of our design is that water is being taken from a natural spring source that supplies a river that runs through the valleys of the mountains. Since the water is being taken from this natural source, there was a possibility of deleterious impacts to the river and other communities downstream that depend on this water. However, the daily water demand of the entire village accounts for less than 1% of the daily flow rate of the waterfall. Also, there are numerous streams feeding the river that villages located downstream utilize. Hence, there should be negligible impact on the water supply for the water sources utilized by inhabitants of other villages.

7.3 Economic Impact/Operating Cost/Sustainability

The design will significantly reduce the time required to obtain water for daily needs. Hence, it will lend more time for residents to engage in economic activities such as farming, business, and education. Since children from the primary school in Kati will no longer be required to travel to the stream to fetch water, more time could be devoted to educational experiences.

Upon discussion,the village leadership agreed to form a water committee upon completion of the system to ensure that the system functions correctly, is maintained, and that water fees are collected to cover the costs of maintained the system. The water collection fees will be deposited in a bank account, consisting of multiple signatories from the water committee, and used to finance any maintenance costs. The water committee will consist of a chairperson responsible for overall administration of the committee, a treasurer for maintaining the accounts, and an official responsible for performing daily checks on the water supply network and weekly or daily cleaning of the cistern and water tank. Another official will be responsible for recording water use, and enforcing the payment of the water use fees.

8.0 Implementation Budget

8.1 Phase I and Phase II Budget

The budget has been prepared using the Tanzanian Standard guidelines and a price list from ChemiCotex, a Tanzanian plastic pipes and parts distributor. An exchange rate of USD 1= TSH 2,231.51 was used to calculate prices in different currencies. Because an older price list was being used for most parts, inflation was assumed to be 10% per year, and was added to individual product costs. An itemized budget for each phase can be found below in Table 8.1.

Table 8.1: Budget overview for Phase I of the proposed design.

Phase I					
Category	Product	Description	Quantity	Per Unit Cost	Total Cost
Raw Materials	Storage Tank	10000 L	1	$ 1,141.00	$ 1,141.00
	63 mm OD HDPE Pipe	PN 4	3	$ 190.55	$ 571.65
		PN 6	4	$ 275.60	$ 1,102.40
		PN 10	18	$ 438.23	$ 7,888.14
	Concrete	Tank Foundation	1	$ 588.00	$ 588.00
	Tap Fittings	12 DP = 24 taps	24	$ 60.00	$ 1,440.00
	Tank Fittings	Connection for tank and pipe	2	$ 60.00	$ 120.00
	Pipe Fittings	Connection for pipe sections	$ 9,562.19	15%	$ 1,434.33
Transportation	Pipe	Truck & Tractor	25	$ 100.00	$ 2,500.00
	Storage Tank	Truck & Tractor	1	$ 176.00	$ 176.00
	Concrete	Truck & Tractor	1	$ 176.00	$ 176.00
Labor	Dist.Points	6 days, 2 people, $2/day	12	$ 2.00	$ 24.00
	Digging	$2/meter, 3162 m	3162	$ 2.00	$ 6,324.00
	Cistern	3 days, 3 people, $2/day	9	$ 2.00	$ 18.00
Total Cost					$23,503
In Kind Contribution (Labor Costs)					$6,366
Required Funds (Total Cost - In Kind Contribution)					$17,137

The itemized budget for Phase II of the design is summarized below in Table 8.2:

Table 8.2: Budget overview for Phase II of the proposed design.

Phase II					
Category	Product	Description	Quantity	Per Unit Cost	Total Cost
Raw Materials	Storage Tank	5000 L	1	$ 439.00	$ 439.00
	40 mm OD HDPE Pipe	PN 4	1	$ 81.26	$ 81.26
		PN 10	7	$ 184.69	$ 1,292.83
		PN 12	2	$ 212.39	$ 424.78
	Concrete	Tank Foundation	1	$ 588.00	$ 588.00
	Tap Fittings	2 distribution points = 4 taps	4	$ 60.00	$ 240.00
	Tank Fittings	Connection for tank and pipe	1	$ 60.00	$ 60.00
	Pipe Fittings	Connection for pipe sections	$ 1,798.87	15%	$ 269.83
Transportation	Pipe	Trucks & Tractors	10	$ 100.00	$ 1,000.00
	Concrete	Truck & Tractor	1	$ 176.00	$ 176.00
Labor	Digging	$2/meter, 1470 m	1470	$ 2.00	$ 2,940.00
	Dist. Points	2 day, 2 people, $2/day	4	$ 2.00	$ 8.00
Total Cost					$7,518
In Kind Contribution (Labor Costs)					$2,948
Required Funds (Total Cost - In Kind Contribution					$4,570

An important aspect of the budget is the large in-kind contribution required from the village. It accounts for approximately a third of the total costs for both Phase I and II. Considering the hilly terrain of Itonya, burying four kilometers of pipe will be a challenging feat to accomplish. This has been discussed in detail with the village leadership, and they have understood and accepted their obligations. This in-kind contribution is, however, pivotal for the village to develop a sense of ownership of the water supply system, which is critical for the long-term success of this project. The village's agreement to undertake this significant endeavor represents a strong indication that the village will be likely to work diligently to keep the system in good repair.

8.2 Lifetime Cost Analysis

The lifetime cost analysis looks at the expected lifetime of all of the components in the system, and estimates the costs needed to replace them as they break. This cost is then divided over the lifetime years to determine the amount of money required from the village each year to keep the system running. Since villagers from Itonya currently use nearby streams to meet their water demands and the village has no functioning water committee, no price is currently charged for water. According to a the life cycle analysis of the two phases of the design, residents of Kati & Kanisani will have to pay a water tax of \$1.88 (TSh 4,383) per year per resident to ensure timely maintenance of the water system. Residents of Tupendane will be required to pay a water tax of \$2.87 (TSh 6,690) per year per resident. Alternatively, the water committee could decide to charge a price per bucket per resident. The product lifetime estimates and replacements costs were calculated using data from previous reports on water supply systems in Tanzanian villages. A full breakdown of these cost calculations for both of the phases is included below in Tables 8.3 and 8.4. The yearly fee listed above also includes a contingency cost to account for any unexpected issues, such as malfunction and replacement. As long as the committee is able to collect a total of \$2,467.62 (TSh 5,506,025) and \$623 (TSh 1,387,999) annually for Phase I and Phase II, respectively, either a water tax or a price per bucket are viable options.

Table 8.3: Lifetime cost analysis summary for Phase I of the design.

Item	Cost (USD)	Lifetime Years	Cost/Year (USD)
Piping System	9,562	15	637
Tank (10,000L)	1,141	20	57
Spigots (24)	1,440	10	144
Contingency (10% of capital cost)		\$1,629	
Total		\$2,468	
Population (2017)		1,312 people	
Per capita cost/year		\$1.88 (TSh 4,383) / person / year	

Table 8.4: Lifetime cost analysis summary for Phase II of the design.

Item	Cost (USD)	Lifetime Years	Cost/Year (USD)
Piping System	1,799	15	120

Tank (5,000L)	439	20	21.95
Spigots (4)	240	10	24
Contingency (10% of capital cost)		$457	
Total		$632	
Population (2017)		217 people	
Per capita cost/year		$2.87 (TSh 6,690) / person / year	

9.0 References

1. Chemicotex. *Plastics Division Price List*. Feb. 12, 2016.
2. Davis, Mackenzie L. *Water and Wastewater Engineering: Design Principles and Practice*. McGraw-Hill Education. 2010.
3. Plasco Ltd. *Polyethylene Pipes for Water, Mining, & Industrial Applications*. July, 19, 2015.
4. *Appendix G: Sediment Containment System Design Rationale*. March 18, 2013. http://www.transportation.alberta.ca/Content/docType372/Production/erosionAppG.pdf
5. Building Code Requirements For Structural Concrete (ACI 318-14): An ACI Standard : Commentary On Building Code Requirements For Structural Concrete (ACI 318R-14), An ACI Report.
6. Specifications for Environmental Concrete Structures (ACI 350.5-12): An ACI Standard

Appendix A: Tanzanian Design Guidelines

The following guidelines were followed when designing the water system:

- The design period should be for a minimum of 10 years. Recent population data should be inflated at a rate of 1.5% per year. This means that all designs should accommodate a population 16% higher in 2027 than today.
- Water demand should be based on 25 liters per person per day. For schools the design should be for 10 liters per student per day.
- The system should be designed to accommodate 2.5 times the average rate of demand.
- Hourly water demand is bimodal, with the largest peak in the morning, followed by a lull around noon, and a second peak in the late afternoon.
- The system should have a minimum water storage capacity equal to 50% of the average daily demand.
- The minimum capacity of each 'spigot' should be 10 liters/min. If I understand the design guidelines, each so-called DP (distribution point) should be designed with a T having 2 spigots, so each DP should be able to provide 20 liters/min.
- Pipe surface roughness: PVC and HDPE 0.01 mm; galvanized steel 0.15 mm (relative roughness epsilon/d is roughness divided by internal pipe diameter.)
- Maximum working pressure for a pipe should be approximately 80% of rating.
- Design for a total water loss of 20-25% (leaks, valves left open, etc.)
- Washout valves and air bleed valves may be required for undulating pipe layouts, low points and high points, respectively.
- Isolation valves need to be used at all branches and at 3 km intervals on straight sections.
- One DP can serve a maximum of 250 people. Maximum walking distance to a DP is 400 m.
- Minor losses should be modeled at 5% of major losses.
    - Add 15% to pipe costs for fittings.
    - Add 20% to pipe costs for freight charges.

Appendix B: Phase I Tank to End of Phase I EES Code

```
{Itonya, Tanzania Water System}
{Phase I Tank and Beyond}

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

{Constants}
g = 9.8
rho = 1000
mu = .0011
epsilon = .00001
epsilon_dp = .00015

{Known Pressures}
P_1 = 0
P_s1a = 0
P_s3a = 0
P_s4a = 0
P_s6 = 0
P_s7a = 0
P_s8a = 0
P_s9a = 0
P_k3a = 0
P_k6a = 0
P_k8a = 0
P_k9a = 0
P_k10a = 0
P_k11a = 0

{added kvs}
kv_k3v = 0
kv_k10v = 0

{Section Lengths}
L_1w1x = 150
L_1x1y = 150
L_1y1z = 150
L_1z2 = 19

L_2s1 = 10
L_s1s1a = 2
L_s1s1v = 140
L_s1vs2 = 58
L_s2s2v = 150
L_s2vs2w = 150
L_s2ws3 = 75
L_s3s3a = 2
L_s3s3v = 75
L_s3vs3w = 150
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L_s3ws3x = 150
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L_s4s4a = 2
L_s4s5 = 10
L_s5s6 = 4
L_s5s7 = 10
L_s7s7a = 2
L_s7s8 = 10
L_s8s8a = 2
L_s8s9 = 10
L_s9s9a = 2

L_2k0 = 150
L_k0k1 = 19
L_k1k2 = 93
L_k2k2v = 38
L_k2vk2w = 150
L_k2wk3 = 72
L_k3k3v = 78
L_k3vk3w = 150
L_k3k3a = 2
L_k3wk4 = 39
L_k4k4v = 111
L_k4vk5 = 22
L_k5k6 = 119
L_k6k6a = 2
L_k6k6v = 9
L_k6vk7 = 31
L_k7k8 = 15
L_k8k8a = 2
L_k7k9 = 19
L_k9k9a = 2
L_k9k9v = 100
L_k9vk9w = 150
L_k9wk10 = 80
L_k10k10a = 2
L_k10k10v = 70
L_k10vk10w = 150
L_k10wk10x = 150
L_k10xk11 = 90
L_k11k11a = 2

{All Closed Taps}
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Q_s3s3a = 1e-9
Q_s4s4a = 1e-9
Q_s5s6 = 1e-9
Q_s7s7a = 1e-9
Q_s8s8a = 1e-9
Q_s9s9a = 1e-9

Q_k3k3a = 1e-9
Q_k6k6a = 1e-9
Q_k8k8a = 1e-9
Q_k9k9a = 1e-9
Q_k10k10a = 1e-9
Q_k11k11a = 1e-9}

{Realistic Peak Taps}
Q_s1s1a = .0005
Q_s3s3a = .0005
Q_s4s4a = .0005
Q_s5s6 = 1e-9
Q_s7s7a = .0005
Q_s8s8a = 1e-9
Q_s9s9a = .0005

Q_k3k3a = .0005
Q_k6k6a = .0005
Q_k8k8a = 1e-9
Q_k9k9a = 1e-9
Q_k10k10a = .0005
Q_k11k11a = .0005

{All Open Taps}
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Q_s3s3a = .0005
Q_s4s4a = .0005
Q_s5s6 = .001
Q_s7s7a = .0005
Q_s8s8a = .0005
Q_s9s9a = .0005

Q_k3k3a = .0005
Q_k6k6a = .0005
Q_k8k8a = .0005
Q_k9k9a = .0005
Q_k10k10a = .0005
Q_k11k11a = .0005}

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z_1w = 1589
z_1x = 1575
z_1y = 1552
z_1z = 1539
z_2 = 1536

z_s1 = 1533
z_s1v = 1549
z_s2 = 1555
z_s2v = 1551
z_s2w = 1544
z_s3= 1541
z_s3v = 1541
z_s3w = 1540
z_s3x = 1540
z_s4 = 1540
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z_s6 = 1540
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z_k0 = 1537

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z_k6v = 1542
z_k7 = 1534
z_k8 = 1532
z_k9 = 1534
z_k9v = 1534
z_k9w = 1533
z_k10 = 1533
z_k10v = 1531
z_k10w = 1526
z_k10x = 1521
z_k11 = 1510

{pipe section diameters}
d_1w1x = .0614
d_1x1y = .0605
d_1y1z = .0605
d_1z2 = .0605

d_2s1 = .0600
d_s1s1v = .0600
d_s1vs2 = .0600
d_s2s2v = .0600
d_s2vs2w = .0600
d_s2ws3 = .0592
d_s3s3v = .0592
d_s3vs3w = .0592
d_s3ws3x = .0592
d_s3xs4 = .0592
d_s4s5 = .0592
d_s5s6 = .0592
d_s5s7 = .0592
d_s7s8 = .0592
d_s8s9 = .0592

d_2k0 = .0600
d_k0k1 = .0600
d_k1k2 = .0600
d_k2k2v = .0600
d_k2vk2w = .0605
d_k2wk3 = .0605
d_k3k3v = .0605
d_k3vk3w = .0600
d_k3wk4 = .0600
d_k4k4v = .0600
d_k4vk5 = .0605
d_k5k6 = .0605

d_k6k6v = .0605
d_k6vk7 = .0600
d_k7k8 = .0600
d_k7k9 = .0600
d_k9k9v = .0600
d_k9vk9w = .0600
d_k9wk10 = .0600
d_k10k10v = .0600
d_k10vk10w = .0600
d_k10wk10x = .0592
d_k10xk11 = .0592
d_dp = .02

{pipe section areas}
A_1w1x = pi*(d_1w1x/2)^2
A_1x1y = pi*(d_1x1y/2)^2
A_1y1z = pi*(d_1y1z/2)^2
A_1z2 = pi*(d_1z2/2)^2

A_2s1 = pi*(d_2s1/2)^2
A_s1s1v = pi*(d_s1s1v/2)^2
A_s1vs2 = pi*(d_s1vs2/2)^2
A_s2s2v = pi*(d_s2s2v/2)^2
A_s2vs2w = pi*(d_s2vs2w/2)^2
A_s2ws3 = pi*(d_s2ws3/2)^2
A_s3s3v = pi*(d_s3s3v/2)^2
A_s3vs3w = pi*(d_s3vs3w/2)^2
A_s3ws3x = pi*(d_s3ws3x/2)^2
A_s3xs4 = pi*(d_s3xs4/2)^2
A_s4s5 = pi*(d_s4s5/2)^2
A_s5s6 = pi*(d_s5s6/2)^2
A_s5s7 = pi*(d_s5s7/2)^2
A_s7s8 = pi*(d_s7s8/2)^2
A_s8s9 =pi*(d_s8s9/2)^2

A_2k0 = pi*(d_2k0/2)^2
A_k0k1 = pi*(d_k0k1/2)^2
A_k1k2 = pi*(d_k1k2/2)^2
A_k2k2v = pi*(d_k2k2v/2)^2
A_k2vk2w = pi*(d_k2vk2w/2)^2
A_k2wk3 = pi*(d_k2wk3/2)^2
A_k3k3v = pi*(d_k3k3v/2)^2
A_k3vk3w = pi*(d_k3vk3w/2)^2
A_k3wk4 = pi*(d_k3wk4/2)^2
A_k4k4v = pi*(d_k4k4v/2)^2
A_k4vk5 = pi*(d_k4vk5/2)^2
A_k5k6 = pi*(d_k5k6/2)^2
A_k6k6v = pi*(d_k6k6v/2)^2
A_k6vk7 = pi*(d_k6vk7/2)^2
A_k7k8 = pi*(d_k7k8/2)^2
A_k7k9 = pi*(d_k7k9/2)^2
A_k9k9v = pi*(d_k9k9v/2)^2
A_k9vk9w = pi*(d_k9vk9w/2)^2
A_k9wk10 = pi*(d_k9wk10/2)^2
A_k10k10v = pi*(d_k10k10v/2)^2
A_k10vk10w = pi*(d_k10vk10w/2)^2
A_k10wk10x = pi*(d_k10wk10x/2)^2

A_k10xk11 = pi*(d_k10xk11/2)^2
A_dp = pi*(d_dp/2)^2

{Flow Rates}
Q_1w1x = Q_1x1y
Q_1x1y = Q_1y1z
Q_1y1z = Q_1z2
Q_1z2 = Q_2s1 + Q_2k0

Q_2s1 = Q_s1s1v + Q_s1s1a
Q_s1s1v = Q_s1vs2
Q_s1vs2 = Q_s2s2v
Q_s2s2v = Q_s2vs2w
Q_s2vs2w = Q_s2ws3
Q_s2ws3 = Q_s3s3a + Q_s3s3v
Q_s3s3v = Q_s3vs3w
Q_s3vs3w = Q_s3ws3x
Q_s3ws3x = Q_s3xs4
Q_s3xs4 = Q_s4s4a + Q_s4s5
Q_s4s5 = Q_s5s6 + Q_s5s7
Q_s5s7 = Q_s7s7a + Q_s7s8
Q_s7s8 = Q_s8s8a + Q_s8s9
Q_s8s9 = Q_s9s9a

Q_2k0 = Q_k0k1
Q_k0k1 = Q_k1k2
Q_k1k2 = Q_k2k2v
Q_k2k2v = Q_k2vk2w
Q_k2vk2w = Q_k2wk3
Q_k2wk3 = Q_k3k3a + Q_k3k3v
Q_k3k3v = Q_k3vk3w
Q_k3vk3w = Q_k3wk4
Q_k3wk4 = Q_k4k4v
Q_k4k4v = Q_k4vk5
Q_k4vk5 = Q_k5k6
Q_k5k6 = Q_k6k6a + Q_k6k6v
Q_k6k6v = Q_k6vk7
Q_k6vk7 = Q_k7k8 + Q_k7k9
Q_k7k8 = Q_k8k8a
Q_k7k9 = Q_k9k9a + Q_k9k9v
Q_k9k9v = Q_k9vk9w
Q_k9vk9w = Q_k9wk10
Q_k9wk10 = Q_k10k10a + Q_k10k10v
Q_k10k10v = Q_k10vk10w
Q_k10vk10w = Q_k10wk10x
Q_k10wk10x = Q_k10xk11
Q_k10xk11 = Q_k11k11a

{pipe section velocities}
V_1w1x = Q_1w1x/A_1w1x
V_1x1y = Q_1x1y/A_1x1y
V_1y1z = Q_1y1z/A_1y1z
V_1z2 = Q_1z2/A_1z2

V_2s1 = Q_2s1/A_2s1
V_s1s1v = Q_s1s1v/A_s1s1v
V_s1vs2 = Q_s1vs2/A_s1vs2

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V_s2s2v = Q_s2s2v/A_s2s2v
V_s2vs2w = Q_s2vs2w/A_s2vs2w
V_s2ws3 = Q_s2ws3/A_s2ws3
V_s3s3v = Q_s3s3v/A_s3s3v
V_s3vs3w = Q_s3vs3w/A_s3vs3w
V_s3ws3x = Q_s3ws3x/A_s3ws3x
V_s3xs4 = Q_s3xs4/A_s3xs4
V_s4s5 = Q_s4s5/A_s4s5
V_s5s6 = Q_s5s6/A_s5s6
V_s5s7 = Q_s5s7/A_s5s7
V_s7s8 = Q_s7s8/A_s7s8
V_s8s9 = Q_s8s9/A_s8s9
V_s1s1a = Q_s1s1a/A_dp
V_s3s3a = Q_s3s3a/A_dp
V_s4s4a = Q_s4s4a/A_dp
V_s7s7a = Q_s7s7a/A_dp
V_s8s8a = Q_s8s8a/A_dp
V_s9s9a = Q_s9s9a/A_dp

V_2k0 = Q_2k0/A_2k0
V_k0k1 = Q_k0k1/A_k0k1
V_k1k2 = Q_k1k2/A_k1k2
V_k2k2v = Q_k2k2v/A_k2k2v
V_k2vk2w = Q_k2vk2w/A_k2vk2w
V_k2wk3 = Q_k2wk3/A_k2wk3
V_k3k3v = Q_k3k3v/A_k3k3v
V_k3vk3w = Q_k3vk3w/A_k3vk3w
V_k3wk4 = Q_k3wk4/A_k3wk4
V_k4k4v = Q_k4k4v/A_k4k4v
V_k4vk5 = Q_k4vk5/A_k4vk5
V_k5k6 = Q_k5k6/A_k5k6
V_k6k6v = Q_k6k6v/A_k6k6v
V_k6vk7 = Q_k6vk7/A_k6vk7
V_k7k8 = Q_k7k8/A_k7k8
V_k7k9 = Q_k7k9/A_k7k9
V_k9k9v = Q_k9k9v/A_k9k9v
V_k9vk9w = Q_k9vk9w/A_k9vk9w
V_k9wk10 = Q_k9wk10/A_k9wk10
V_k10k10v = Q_k10k10v/A_k10k10v
V_k10vk10w = Q_k10vk10w/A_k10vk10w
V_k10wk10x = Q_k10wk10x/A_k10wk10x
V_k10xk11 = Q_k10xk11/A_k10xk11
V_k3k3a = Q_k3k3a/A_dp
V_k6k6a = Q_k6k6a/A_dp
V_k8k8a = Q_k8k8a/A_dp
V_k9k9a = Q_k9k9a/A_dp
V_k10k10a = Q_k10k10a/A_dp
V_k11k11a = Q_k11k11a/A_dp

{friction factors}
ff_1w1x = ff(V_1w1x*rho*d_1w1x/mu,epsilon/d_1w1x)
ff_1x1y = ff(V_1x1y*rho*d_1x1y/mu,epsilon/d_1x1y)
ff_1y1z = ff(V_1y1z*rho*d_1y1z/mu,epsilon/d_1y1z)
ff_1z2 = ff(V_1z2*rho*d_1z2/mu,epsilon/d_1z2)

ff_2s1 = ff(V_2s1*rho*d_2s1/mu,epsilon/d_2s1)
ff_s1s1v = ff(V_s1s1v*rho*d_s1s1v/mu,epsilon/d_s1s1v)
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ff_s1vs2 = ff(V_s1vs2*rho*d_s1vs2/mu,epsilon/d_s1vs2)
ff_s2s2v = ff(V_s2s2v*rho*d_s2s2v/mu,epsilon/d_s2s2v)
ff_s2vs2w = ff(V_s2vs2w*rho*d_s2vs2w/mu,epsilon/d_s2vs2w)
ff_s2ws3 = ff(V_s2ws3*rho*d_s2ws3/mu,epsilon/d_s2ws3)
ff_s3s3v = ff(V_s3s3v*rho*d_s3s3v/mu,epsilon/d_s3s3v)
ff_s3vs3w = ff(V_s3vs3w*rho*d_s3vs3w/mu,epsilon/d_s3vs3w)
ff_s3ws3x = ff(V_s3ws3x*rho*d_s3ws3x/mu,epsilon/d_s3ws3x)
ff_s3xs4 = ff(V_s3xs4*rho*d_s3xs4/mu,epsilon/d_s3xs4)
ff_s4s5 = ff(V_s4s5*rho*d_s4s5/mu,epsilon/d_s4s5)
ff_s5s6 = ff(V_s5s6*rho*d_s5s6/mu,epsilon/d_s5s6)
ff_s5s7 = ff(V_s5s7*rho*d_s5s7/mu,epsilon/d_s5s7)
ff_s7s8 = ff(V_s7s8*rho*d_s7s8/mu,epsilon/d_s7s8)
ff_s8s9 = ff(V_s8s9*rho*d_s8s9/mu,epsilon/d_s8s9)
ff_s1s1a = ff(V_s1s1a*rho*d_dp/mu,epsilon_dp/d_dp)
ff_s3s3a = ff(V_s3s3a*rho*d_dp/mu,epsilon_dp/d_dp)
ff_s4s4a = ff(V_s4s4a*rho*d_dp/mu,epsilon_dp/d_dp)
ff_s7s7a = ff(V_s7s7a*rho*d_dp/mu,epsilon_dp/d_dp)
ff_s8s8a = ff(V_s8s8a*rho*d_dp/mu,epsilon_dp/d_dp)
ff_s9s9a = ff(V_s9s9a*rho*d_dp/mu,epsilon_dp/d_dp)

ff_2k0 = ff(V_2k0*rho*d_2k0/mu,epsilon/d_2k0)
ff_k0k1 = ff(V_k0k1*rho*d_k0k1/mu,epsilon/d_k0k1)
ff_k1k2 = ff(V_k1k2*rho*d_k1k2/mu,epsilon/d_k1k2)
ff_k2k2v = ff(V_k2k2v*rho*d_k2k2v/mu,epsilon/d_k2k2v)
ff_k2vk2w = ff(V_k2vk2w*rho*d_k2vk2w/mu,epsilon/d_k2vk2w)
ff_k2wk3 = ff(V_k2wk3*rho*d_k2wk3/mu,epsilon/d_k2wk3)
ff_k3k3v = ff(V_k3k3v*rho*d_k3k3v/mu,epsilon/d_k3k3v)
ff_k3vk3w = ff(V_k3vk3w*rho*d_k3vk3w/mu,epsilon/d_k3vk3w)
ff_k3wk4 = ff(V_k3wk4*rho*d_k3wk4/mu,epsilon/d_k3wk4)
ff_k4k4v = ff(V_k4k4v*rho*d_k4k4v/mu,epsilon/d_k4k4v)
ff_k4vk5 = ff(V_k4vk5*rho*d_k4vk5/mu,epsilon/d_k4vk5)
ff_k5k6 = ff(V_k5k6*rho*d_k5k6/mu,epsilon/d_k5k6)
ff_k6k6v = ff(V_k6k6v*rho*d_k6k6v/mu,epsilon/d_k6k6v)
ff_k6vk7 = ff(V_k6vk7*rho*d_k6vk7/mu,epsilon/d_k6vk7)
ff_k7k8 = ff(V_k7k8*rho*d_k7k8/mu,epsilon/d_k7k8)
ff_k7k9 = ff(V_k7k9*rho*d_k7k9/mu,epsilon/d_k7k9)
ff_k9k9v = ff(V_k9k9v*rho*d_k9k9v/mu,epsilon/d_k9k9v)
ff_k9vk9w = ff(V_k9vk9w*rho*d_k9vk9w/mu,epsilon/d_k9vk9w)
ff_k9wk10 = ff(V_k9wk10*rho*d_k9wk10/mu,epsilon/d_k9wk10)
ff_k10k10v = ff(V_k10k10v*rho*d_k10k10v/mu,epsilon/d_k10k10v)
ff_k10vk10w = ff(V_k10vk10w*rho*d_k10vk10w/mu,epsilon/d_k10vk10w)
ff_k10wk10x = ff(V_k10wk10x*rho*d_k10wk10x/mu,epsilon/d_k10wk10x)
ff_k10xk11 = ff(V_k10xk11*rho*d_k10xk11/mu,epsilon/d_k10xk11)
ff_k3k3a = ff(V_k3k3a*rho*d_dp/mu,epsilon_dp/d_dp)
ff_k6k6a = ff(V_k6k6a*rho*d_dp/mu,epsilon_dp/d_dp)
ff_k8k8a = ff(V_k8k8a*rho*d_dp/mu,epsilon_dp/d_dp)
ff_k9k9a = ff(V_k9k9a*rho*d_dp/mu,epsilon_dp/d_dp)
ff_k10k10a = ff(V_k10k10a*rho*d_dp/mu,epsilon_dp/d_dp)
ff_k11k11a = ff(V_k11k11a*rho*d_dp/mu,epsilon_dp/d_dp)

{flow rate out of tanks in L/hr}
Q_1x1yL = Q_1x1y*3.6e6

{gravity main}
(P_1x - P_1)/(rho*g) + (z_1x - z_1w) = -(V_1w1x^2/(2*g))*((ff_1w1x*L_1w1x)/d_1w1x)*1.05
(P_1y - P_1x)/(rho*g) + (z_1y - z_1x) = -(V_1x1y^2/(2*g))*((ff_1x1y*L_1x1y)/d_1x1y)*1.05
(P_1z - P_1y)/(rho*g) + (z_1z - z_1y) = -(V_1y1z^2/(2*g))*((ff_1y1z*L_1y1z)/d_1y1z)*1.05
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(P_2 - P_1z)/(rho*g) + (z_2 - z_1z) = -(V_1z2^2/(2*g))*((ff_1z2*L_1z2)/d_1z2)*1.05

{kanisani branch}
(P_s1 - P_2)/(rho*g) + (z_s1 - z_2) = -(V_2s1^2/(2*g))*((ff_2s1*L_2s1)/d_2s1)*1.05
(P_s1v - P_s1)/(rho*g) + (z_s1v - z_s1) = -(V_s1s1v^2/(2*g))*((ff_s1s1v*L_s1s1v)/d_s1s1v)*1.05
(P_s1a - P_s1)/(rho*g) = -(V_s1s1a^2/(2*g))*(((ff_s1s1a*L_s1s1a)/d_dp)+kv_s1a)
(P_s2 - P_s1v)/(rho*g) + (z_2 - z_s1v) = -(V_s1vs2^2/(2*g))*((ff_s1vs2*L_s1vs2)/d_s1vs2)*1.05
(P_s2v - P_s2)/(rho*g) + (z_s2v - z_s2) = -(V_s2s2v^2/(2*g))*((ff_s2s2v*L_s2s2v)/d_s2s2v)*1.05
(P_s2w - P_s2v)/(rho*g) + (z_s2w - z_s2v) = -(V_s2vs2w^2/(2*g))*((ff_s2vs2w*L_s2vs2w)/d_s2vs2w)*1.05
(P_s3 - P_s2w)/(rho*g) + (z_s3 - z_s2w) = -(V_s2ws3^2/(2*g))*((ff_s2ws3*L_s2ws3)/d_s2ws3)*1.05
(P_s3a - P_s3)/(rho*g) = -(V_s3s3a^2/(2*g))*(((ff_s3s3a*L_s3s3a)/d_dp)+kv_s3a)
(P_s3v - P_s3)/(rho*g) + (z_s3v - z_s3) = -(V_s3s3v^2/(2*g))*((ff_s3s3v*L_s3s3v)/d_s3s3v)*1.05
(P_s3w - P_s3v)/(rho*g) + (z_s3w - z_s3v) = -(V_s3vs3w^2/(2*g))*((ff_s3vs3w*L_s3vs3w)/d_s3vs3w)*1.05
(P_s3x - P_s3w)/(rho*g) + (z_s3x - z_s3w) = -(V_s3ws3x^2/(2*g))*((ff_s3ws3x*L_s3ws3x)/d_s3ws3x)*1.05
(P_s4 - P_s3x)/(rho*g) + (z_s4 - z_s3x) = -(V_s3xs4^2/(2*g))*((ff_s3xs4*L_s3xs4)/d_s3xs4)*1.05
(P_s4a - P_s4)/(rho*g) = -(V_s4s4a^2/(2*g))*(((ff_s4s4a*L_s4s4a)/d_dp)+kv_s4a)
(P_s5 - P_s4)/(rho*g) + (z_s5 - z_s4) = -(V_s4s5^2/(2*g))*((ff_s4s5*L_s4s5)/d_s4s5)*1.05
(P_s6 - P_s5)/(rho*g) + (z_s6 - z_s5)  = -(V_s5s6^2/(2*g))*(((ff_s5s6*L_s5s6)/d_s5s6)+kv_s6)
(P_s7 - P_s5)/(rho*g) + (z_s7 - z_s5) = -(V_s5s7^2/(2*g))*((ff_s5s7*L_s5s7)/d_s5s7)*1.05
(P_s7a - P_s7)/(rho*g) = -(V_s7s7a^2/(2*g))*(((ff_s7s7a*L_s7s7a)/d_dp)+kv_s7a)
(P_s8 - P_s7)/(rho*g) + (z_s8 - z_s7) = -(V_s7s8^2/(2*g))*((ff_s7s8*L_s7s8)/d_s7s8)*1.05
(P_s8a - P_s8)/(rho*g) = -(V_s8s8a^2/(2*g))*(((ff_s8s8a*L_s8s8a)/d_dp)+kv_s8a)
(P_s9 - P_s8)/(rho*g) + (z_s9 - z_s8) = -(V_s8s9^2/(2*g))*((ff_s8s9*L_s8s9)/d_s8s9)*1.05
(P_s9a - P_s9)/(rho*g) = -(V_s9s9a^2/(2*g))*(((ff_s9s9a*L_s9s9a)/d_dp)+kv_s9a)

{kati branch}
(P_k0 - P_2)/(rho*g) + (z_k0 - z_2) = -(V_2k0^2/(2*g))*((ff_2k0*L_2k0)/d_2k0)*1.05
(P_k1 - P_k0)/(rho*g) + (z_k1 - z_k0) = -(V_k0k1^2/(2*g))*((ff_k0k1*L_k0k1)/d_k0k1)*1.05
(P_k2 - P_k1)/(rho*g) + (z_k2 - z_k1) = -(V_k1k2^2/(2*g))*((ff_k1k2*L_k1k2)/d_k1k2)*1.05
(P_k2v - P_k2)/(rho*g) + (z_k2v - z_k2) = -(V_k2k2v^2/(2*g))*((ff_k2k2v*L_k2k2v)/d_k2k2v)*1.05
(P_k2w - P_k2v)/(rho*g) + (z_k2w - z_k2v) = -(V_k2vk2w^2/(2*g))*((ff_k2vk2w*L_k2vk2w)/d_k2vk2w)*1.05
(P_k3 - P_k2w)/(rho*g) + (z_k3 - z_k2w) = -(V_k2wk3^2/(2*g))*((ff_k2wk3*L_k2wk3)/d_k2wk3)*1.05
(P_k3a - P_k3)/(rho*g) = -(V_k3k3a^2/(2*g))*(((ff_k3k3a*L_k3k3a)/d_dp)+kv_k3a)
(P_k3v - P_k3)/(rho*g) + (z_k3v - z_k3) = -(V_k3k3v^2/(2*g))*(((ff_k3k3v*L_k3k3v)/d_k3k3v)*1.05+kv_k3v)
(P_k3w - P_k3v)/(rho*g) + (z_k3w - z_k3v) = -(V_k3vk3w^2/(2*g))*((ff_k3vk3w*L_k3vk3w)/d_k3vk3w)*1.05
(P_k4 - P_k3w)/(rho*g) + (z_k4 - z_k3w) = -(V_k3wk4^2/(2*g))*((ff_k3wk4*L_k3wk4)/d_k3wk4)*1.05
(P_k4v - P_k4)/(rho*g) + (z_k4v - z_k4) = -(V_k4k4v^2/(2*g))*((ff_k4k4v*L_k4k4v)/d_k4k4v)*1.05
(P_k5 - P_k4v)/(rho*g) + (z_k5 - z_k4v) = -(V_k4vk5^2/(2*g))*((ff_k4vk5*L_k4vk5)/d_k4vk5)*1.05
(P_k6 - P_k5)/(rho*g) + (z_k6 - z_k5) = -(V_k5k6^2/(2*g))*((ff_k5k6*L_k5k6)/d_k5k6)*1.05
(P_k6a - P_k6)/(rho*g) = -(V_k6k6a^2/(2*g))*(((ff_k6k6a*L_k6k6a)/d_dp)+kv_k6a)
(P_k6v - P_k6)/(rho*g) + (z_k6v - z_k6) = -(V_k6k6v^2/(2*g))*((ff_k6k6v*L_k6k6v)/d_k6k6v)*1.05
(P_k7 - P_k6v)/(rho*g) + (z_k7 - z_k6v) = -(V_k6vk7^2/(2*g))*((ff_k6vk7*L_k6vk7)/d_k6vk7)*1.05
(P_k8 - P_k7)/(rho*g) + (z_k8 - z_k7) = -(V_k7k8^2/(2*g))*((ff_k7k8*L_k7k8)/d_k7k8)*1.05
(P_k8a - P_k8)/(rho*g) = -(V_k8k8a^2/(2*g))*(((ff_k8k8a*L_k8k8a)/d_dp)+kv_k8a)
(P_k9 - P_k7)/(rho*g) + (z_k9 - z_k7) = -(V_k7k9^2/(2*g))*((ff_k7k9*L_k7k9)/d_k7k9)*1.05
(P_k9a - P_k9)/(rho*g) = -(V_k9k9a^2/(2*g))*(((ff_k9k9a*L_k9k9a)/d_dp)+kv_k9a)
(P_k9v - P_k9)/(rho*g) + (z_k9v - z_k9) = -(V_k9k9v^2/(2*g))*((ff_k9k9v*L_k9k9v)/d_k9k9v)*1.05
(P_k9w - P_k9v)/(rho*g) + (z_k9w - z_k9v) = -(V_k9vk9w^2/(2*g))*((ff_k9vk9w*L_k9vk9w)/d_k9vk9w)*1.05
(P_k10 - P_k9w)/(rho*g) + (z_k10 - z_k9w) = -(V_k9wk10^2/(2*g))*((ff_k9wk10*L_k9wk10)/d_k9wk10)*1.05
(P_k10a - P_k10)/(rho*g) = -(V_k10k10a^2/(2*g))*(((ff_k10k10a*L_k10k10a)/d_dp)+kv_k10a)
(P_k10v - P_k10)/(rho*g) + (z_k10v - z_k10) = -(V_k10k10v^2/(2*g))*(((ff_k10k10v*L_k10k10v)/d_k10k10v)*1.05+kv_k10v)
(P_k10w - P_k10v)/(rho*g) + (z_k10w - z_k10v) = -(V_k10vk10w^2/(2*g))*((ff_k10vk10w*L_k10vk10w)/d_k10vk10w)*1.05
(P_k10x - P_k10w)/(rho*g) + (z_k10x - z_k10w) = -(V_k10wk10x^2/(2*g))*((ff_k10wk10x*L_k10wk10x)/d_k10wk10x)*1.05
(P_k11 - P_k10x)/(rho*g) + (z_k11 - z_k10x) = -(V_k10xk11^2/(2*g))*((ff_k10xk11*L_k10xk11)/d_k10xk11)*1.05
(P_k11a - P_k11)/(rho*g) = -(V_k11k11a^2/(2*g))*(((ff_k11k11a*L_k11k11a)/d_dp)+kv_k11a)
```

Appendix C: Phase I Cistern to Tank EES Code

```
{Itonya, Tanzania Water System}
{Cistern to Tank}

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

{Constants}
g = 9.8
rho = 1000
mu = .0011
epsilon = .00001
{open/close (open=1, close=10^9)}
oc_tank = 1
{Known Pressures}
P_1 = 0
P_tank = 0

{Section Lengths}
L_11v = 150
L_1vtank = 150
{Elevations}
z_1 = 1640
z_1v = 1613
z_tank = 1589
{pipe section diameters}
d_11v = .0312
d_1vtank = .0312

{pipe section areas}
A_11v = pi*(d_11v/2)^2
A_1vtank = pi*(d_1vtank/2)^2

{Flow Rates}
Q_11v = Q_1vtank

{pipe section velocities}
V_11v = Q_11v/A_11v
V_1vtank = Q_1vtank/A_1vtank

{friction factors}
ff_11v = ff(V_11v*rho*d_11v/mu,epsilon/d_11v)
ff_1vtank = ff(V_1vtank*rho*d_1vtank/mu,epsilon/d_1vtank)

{flow rate out of cistern in L/hr}
Q_11vL = Q_11v*3.6e6

{Bernoulli's}
(P_1v - P_1)/(rho*g) + (z_1v - z_1) = -(V_11v^2/(2*g))*((ff_11v*L_11v)/d_11v)*1.05
(P_tank - P_1v)/(rho*g) + (z_tank - z_1v) = -(V_1vtank^2/(2*g))*((ff_1vtank*L_1vtank)/d_1vtank)*1.05*oc_tank
```

Appendix D: Phase II EES Code

```
{Itonya, Tanzania Water System}
{Phase II Tupendane}

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

{Constants}
g = 9.8
rho = 1000
mu = .0011
epsilon = .00001
epsilon_dp = .00015

{Known Pressures}
P_t0 = 0
P_t9a = 0
P_t13a = 0

{Section Lengths}
L_t0t1 = 150
L_t1t2 = 150
L_t2t3 = 150
L_t3t4 = 150
L_t4t5 = 18
L_t5t6 = 132
L_t6t7 = 100
L_t7t8 = 50
L_t8t9 = 50
L_t9t10 = 100
L_t10t11 = 150
L_t11t12 = 150
L_t12t13 = 120

L_dp = 2

{All Closed Taps}
{Q_t9t9a = 1e-9
Q_t13t13a = 1e-9}

{All Open Taps}
Q_t9t9a = .0007
Q_t13t13a = .0007

{Elevations}
z_t0 = 1525
z_t1 = 1502
z_t2 = 1486
z_t3 = 1472
z_t4 = 1463
```

```
z_t5 = 1461
z_t6 = 1471
z_t7 = 1479
z_t8 = 1475
z_t9 = 1468
z_t10 = 1461
z_t11 = 1437
z_t12 = 1445
z_t13 = 1439

{pipe section diameters}
d_t0t1 = .0390
d_t1t2 = .0376
d_t2t3 = .0376
d_t3t4 = .0376
d_t4t5 = .0376
d_t5t6 = .0376
d_t6t7 = .0384
d_t7t8 = .0376
d_t8t9 = .0376
d_t9t10 = .0376
d_t10t11 = .0370
d_t11t12 = .0376
d_t12t13 = .0370

d_dp = .02

{pipe section areas}
A_t0t1 = pi*(d_t0t1/2)^2
A_t1t2 = pi*(d_t1t2/2)^2
A_t2t3 = pi*(d_t2t3/2)^2
A_t3t4 = pi*(d_t3t4/2)^2
A_t4t5 = pi*(d_t4t5/2)^2
A_t5t6 = pi*(d_t5t6/2)^2
A_t6t7 = pi*(d_t6t7/2)^2
A_t7t8 = pi*(d_t7t8/2)^2
A_t8t9 = pi*(d_t8t9/2)^2
A_t9t10 = pi*(d_t9t10/2)^2
A_t10t11 = pi*(d_t10t11/2)^2
A_t11t12 = pi*(d_t11t12/2)^2
A_t12t13 = pi*(d_t12t13/2)^2

A_dp = pi*(d_dp/2)^2

{Flow Rates}
Q_t0t1 = Q_t1t2
Q_t1t2 = Q_t2t3
Q_t2t3 = Q_t3t4
Q_t3t4 = Q_t4t5
Q_t4t5 = Q_t5t6
Q_t5t6 = Q_t6t7
Q_t6t7 = Q_t7t8
Q_t7t8 = Q_t8t9
Q_t8t9 = Q_t9t10 + Q_t9t9a
Q_t9t10 = Q_t10t11
Q_t10t11 = Q_t11t12
Q_t11t12 = Q_t12t13
```

```
Q_t12t13 = Q_t13t13a

{pipe section velocities}
V_t0t1 = Q_t0t1/A_t0t1
V_t1t2 = Q_t1t2/A_t1t2
V_t2t3 = Q_t2t3/A_t2t3
V_t3t4 = Q_t3t4/A_t3t4
V_t4t5 = Q_t4t5/A_t4t5
V_t5t6 = Q_t5t6/A_t5t6
V_t6t7 = Q_t6t7/A_t6t7
V_t7t8 = Q_t7t8/A_t7t8
V_t8t9 = Q_t8t9/A_t8t9
V_t9t10 = Q_t9t10/A_t9t10
V_t10t11 = Q_t10t11/A_t10t11
V_t11t12 = Q_t11t12/A_t11t12
V_t12t13 = Q_t12t13/A_t12t13
V_t9t9a = Q_t9t9a/A_dp
V_t13t13a = Q_t13t13a/A_dp

{friction factors}
ff_t0t1 = ff(V_t0t1*rho*d_t0t1/mu,epsilon/d_t0t1)
ff_t1t2 = ff(V_t1t2*rho*d_t1t2/mu,epsilon/d_t1t2)
ff_t2t3 = ff(V_t2t3*rho*d_t2t3/mu,epsilon/d_t2t3)
ff_t3t4 = ff(V_t3t4*rho*d_t3t4/mu,epsilon/d_t3t4)
ff_t4t5 = ff(V_t4t5*rho*d_t4t5/mu,epsilon/d_t4t5)
ff_t5t6 = ff(V_t5t6*rho*d_t5t6/mu,epsilon/d_t5t6)
ff_t6t7 = ff(V_t6t7*rho*d_t6t7/mu,epsilon/d_t6t7)
ff_t7t8 = ff(V_t7t8*rho*d_t7t8/mu,epsilon/d_t7t8)
ff_t8t9 = ff(V_t8t9*rho*d_t8t9/mu,epsilon/d_t8t9)
ff_t9t10 = ff(V_t9t10*rho*d_t9t10/mu,epsilon/d_t9t10)
ff_t10t11 = ff(V_t10t11*rho*d_t10t11/mu,epsilon/d_t10t11)
ff_t11t12 = ff(V_t11t12*rho*d_t11t12/mu,epsilon/d_t11t12)
ff_t12t13 = ff(V_t12t13*rho*d_t12t13/mu,epsilon/d_t12t13)
ff_t9t9a = ff(V_t9t9a*rho*d_dp/mu,epsilon_dp/d_dp)
ff_t13t13a = ff(V_t13t13a*rho*d_dp/mu,epsilon_dp/d_dp)

{flow rate out of tanks in L/hr}
Q_t0t1L = Q_t0t1*3.6e6

{tupendane branch}
(P_t1 - P_t0)/(rho*g) + (z_t1 - z_t0) = -(V_t0t1^2/(2*g))*((ff_t0t1*L_t0t1)/d_t0t1)*1.05
(P_t2 - P_t1)/(rho*g) + (z_t2 - z_t1) = -(V_t1t2^2/(2*g))*((ff_t1t2*L_t1t2)/d_t1t2)*1.05
(P_t3 - P_t2)/(rho*g) + (z_t3 - z_t2) = -(V_t2t3^2/(2*g))*((ff_t2t3*L_t2t3)/d_t2t3)*1.05
(P_t4 - P_t3)/(rho*g) + (z_t4 - z_t3) = -(V_t3t4^2/(2*g))*((ff_t3t4*L_t3t4)/d_t3t4)*1.05
(P_t5 - P_t4)/(rho*g) + (z_t5 - z_t4) = -(V_t4t5^2/(2*g))*((ff_t4t5*L_t4t5)/d_t4t5)*1.05
(P_t6 - P_t5)/(rho*g) + (z_t6 - z_t5) = -(V_t5t6^2/(2*g))*((ff_t5t6*L_t5t6)/d_t5t6)*1.05
(P_t7 - P_t6)/(rho*g) + (z_t7 - z_t6) = -(V_t6t7^2/(2*g))*((ff_t6t7*L_t6t7)/d_t6t7)*1.05
(P_t8 - P_t7)/(rho*g) + (z_t8 - z_t7) = -(V_t7t8^2/(2*g))*((ff_t7t8*L_t7t8)/d_t7t8)*1.05
(P_t9 - P_t8)/(rho*g) + (z_t9 - z_t8) = -(V_t8t9^2/(2*g))*((ff_t8t9*L_t8t9)/d_t8t9)*1.05
(P_t9a - P_t9)/(rho*g) = -(V_t9t9a^2/(2*g))*(((ff_t9t9a*L_dp)/d_dp)+kv_t9a)
(P_t10 - P_t9)/(rho*g) + (z_t10 - z_t9) = -(V_t9t10^2/(2*g))*((ff_t9t10*L_t9t10)/d_t9t10)*1.05
(P_t11 - P_t10)/(rho*g) + (z_t11 - z_t10) = -(V_t10t11^2/(2*g))*((ff_t10t11*L_t10t11)/d_t10t11)*1.05
(P_t12 - P_t11)/(rho*g) + (z_t12 - z_t11) = -(V_t11t12^2/(2*g))*((ff_t11t12*L_t11t12)/d_t11t12)*1.05
(P_t13 - P_t12)/(rho*g) + (z_t13 - z_t12) = -(V_t12t13^2/(2*g))*((ff_t12t13*L_t12t13)/d_t12t13)*1.05
(P_t13a - P_t13)/(rho*g) = -(V_t13t13a^2/(2*g))*(((ff_t13t13a*L_dp)/d_dp)+kv_t13a)
```

Appendix E: Phase I Pipe Sizing Chart

Cistern at z = 1667m,

Cistern to tank outside diameter = 32 mm,

Tank and beyond outside diameter = 63 mm

	Position	Distance	Elevation	Pressure	Section Max	Max in Atm	With SF	Rating	Pipe OD	Wall Thickness	Pipe ID
Gravity Main	1Cistern	0	1667	0	218144	2.153	2.691	PN 4	32	1.3	30.7
	1v	150	1613	218144							
	1w	300	1589	315096	315096	3.110	3.887	PN 4	32	1.3	30.7
	1wTank	300	1589	0	139789	1.380	1.725	PN 4	63	2.5	60.5
	1x	450	1575	139789							
	1y	600	1552	369442	369442	3.646	4.558	PN 6	63	2.5	60.5
	1z	750	1539	496882	496882	4.904	6.130	PN 6	63	2.5	60.5
Kanisani Branch	2	769	1536	529200	558600	5.513	6.891	PN 10	63	3.0	60.0
	s1	779	1533	558600							
	s1v	919	1549	537812	537812	5.308	6.635	PN 10	63	3.0	60.0
	s2	977	1555	529200							
	s2v	1069	1551	569018	569018	5.616	7.020	PN 10	63	3.0	60.0
	s2w	1219	1544	633939	666400	6.577	8.221	PN 10	63	3.8	59.2
	s3	1294	1541	666400							
	s3v	1369	1541	668201	668201	6.595	8.243	PN 10	63	3.8	59.2
	s3w	1519	1540	671699	671699	6.629	8.286	PN 10	63	3.8	59.2
	s3x	1669	1540	675388	705600	6.964	8.705	PN 10	63	3.8	59.2
	s4	1702	1540	676200							
	s5	1712	1540	676200							
	s7	1722	1537	705600							
	s8	1732	1537	705600							
	s9	1742	1537	705600							
Kati Branch	2	769	1536	529200	529200	5.223	6.528	PN 10	63	3.0	60.0
	k0	919	1537	520502	520502	5.137	6.421	PN 10	63	3.0	60.0
	k1	938	1537	519400							
	k2	1031	1542	470400							

	k2v	1069	1542	473265	473265	4.671	5.838	PN 6	63	2.5	60.5
	k2w	1219	1541	484572	490000	4.836	6.045	PN 10	63	2.5	60.5
	k3	1291	1540	490000							
	k3v	1369	1535	535807	535807	5.288	6.610	PN 10	63	3.0	60.0
	k3w	1519	1526	623897	646800	6.383	7.979	PN 10	63	3.0	60.0
	k4	1558	1524	646800							
	k4v	1669	1547	425968	450800	4.449	5.561	PN 6	63	2.5	60.5
	k5	1691	1551	382200							
	k6	1810	1544	450800							
	k6v	1819	1542	472850	548800	5.416	6.770	PN 10	63	3.0	60.0
	k7	1850	1534	548800							
	k9	1869	1534	548800							
	k9v	1969	1534	551770	551770	5.446	6.807	PN 10	63	3.0	60.0
	k9w	2119	1533	556224	558600	5.513	6.891	PN 10	63	3.0	60.0
	k10	2199	1533	558600							
	k10v	2269	1531	592900	592900	5.851	7.314	PN 10	63	3.0	60.0
	k10w	2419	1526	666400	666400	6.577	8.221	PN 10	63	3.8	59.2
	k10x	2569	1521	739900	784000	7.737	9.672	PN 10	63	3.8	59.2
	k11	2659	1518	784000							

Appendix F: Phase II Pipe Sizing Chart

Pipe outside diameter = 40mm

	Section	Distance	Elevation	Pressure	Section Max	Max in atm	With SF	Rating Required	Pipe OD	Wall Thickness	Pipe ID
Tupendane Branch	t0, Tank	0	1525	0	225400	2.225	2.781	PN 4	40	1.0	39.0
	t1	150	1502	225400							
	t2	300	1486	382200	519400	5.126	6.408	PN 10	40	2.4	37.6
	t3	450	1472	519400	627200	6.190	7.737	PN 10	40	2.4	37.6
	t4	600	1463	607600	627200	6.190	7.737	PN 10	40	2.4	37.6
	t5, low	618	1461	627200							
	t6	750	1471	529200	529200	5.223	6.528	PN 10	40	2.4	37.6
	t7, high	850	1479	450800							
	t8	900	1475	490000	558600	5.513	6.891	PN 10	40	2.4	37.6
	t9, dpt1	950	1468	558600							
	t10	1050	1461	627200	627200	6.190	7.737	PN 10	40	2.4	37.6
	t11, low	1200	1437	862400	862400	8.511	10.639	PN 12	40	3.0	37.0
	t12	1350	1445	784000	784000	7.737	9.672	PN 10	40	2.4	37.6
	t13, dpt2	1470	1439	842800	842800	8.318	10.397	PN 12	40	3.0	37.0

Appendix G: Cistern Sample Calculations and Design Guidelines

Sedimentation Basin Design Guidelines:

TABLE 10-4
Typical design criteria for horizontal-flow rectangular sedimentation basins

Parameter	Typical range of values	Comment
Inlet zone		
Distance to diffuser wall	2 m	
Diffuser hole diameter	0.10–0.20 m	
Settling zone		
Overflow rate	40–70 $m^3/d \cdot m^2$	See Table 10-2
Side water depth (SWD)	3–5 m	
Length	30 m	Wind constraint
	60 m	Chain-and-flight
	≥80–90 m	Traveling bridge
Width	0.3 m increments	Chain-and-flight
	6 m maximum per train	Chain-and-flight
	24 m maximum = 3 trains per drive	Chain-and-flight
	30 m maximum	Traveling bridge
L:W	4:1 to 6:1	≥6:1 preferred
L:D	15:1	Minimum
Velocity	0.005–0.018 m/s	Horizontal, mean
Reynolds number	< 20,000	
Froude number	$> 10^{-5}$	
Outlet zone		
Launder length	1/3–1/2 length of basin	Evenly spaced
Launder weir loading	140–320 $m^3/d \cdot m$	See Table 10-3
Sludge zone		
Depth	0.6–1 m	Equipment dependent
Slope	1:600	Mechanical cleaning
Sludge collector speed	0.3–0.9 m/min	

Sources: AWWA, 1990; Davis and Cornwell, 2008; Kawamura, 2000; MWH, 2005; Willis, 2005

Figure AC.1. Design criteria table considered during cistern design (Davis, 2010).

Sample Calculations:

<u>Sizing the cistern:</u>

$A_{plan} = \frac{Q}{V_S} = \frac{6\ m^3/hr}{2.808\ m/hr} = 2.14\ m^2$ (for a 0.03 mm diameter silt particle at 20℃)

V_S = settling velocity

Q = flow rate
A_{plan} = plan area

Diameter	Settling Velocity in Centimeters per Second					
(MM)	0 ℃	5 ℃	10 ℃	15 ℃	20 ℃	Particle
0.01	0.005	0.006	0.007	0.008	0.009	Fine Silt
0.02	0.020	0.023	0.027	0.031	0.035	Median Silt
0.03	0.044	0.052	0.060	0.069	0.078	
0.04	0.078	0.092	0.107	0.122	0.139	Coarse Silt
0.05	0.122	0.143	0.167	0.191	0.217	
0.06	0.176	0.207	0.240	0.275	0.313	
0.07	0.239	0.281	0.327	0.375	0.426	Very Fine Sand
0.08	0.312	0.367	0.427	0.490	0.556	
0.09	0.395	0.465	0.540	0.620	0.704	
0.110	0.488	0.574	0.667	0.765	0.869	
0.11	0.590	0.694	0.807	0.926	1.051	
0.12	0.703	0.826	0.960	1.101	1.251	
0.13	0.825	0.970	1.127	1.293	1.468	Fine Sand
0.14	0.956	1.125	1.307	1.499	1.703	
0.15	1.098	1.291	1.501	1.721	1.955	
0.16	1.249	1.469	1.707	1.958	2.224	
0.17	1.410	1.658	1.928	2.211	2.511	
0.18	1.581	1.859	2.161	2.478	2.815	
0.19	1.761	2.072	2.408	2.761	3.136	
0.20	1.952	2.295	2.668	3.060	3.475	
℉	32	41	50	59	68	

Table AC.1. Particle Settling Velocities (Appendix G, 2003).

Weir equation:

$$C_d = 0.611 + 0.075\tfrac{H}{H_w}$$
$$Q = C_w b H^{3/2}$$
$$C_w = \tfrac{2}{3} C_d \sqrt{2g}$$
$$H + H_w = d$$

C_d = discharge coefficent
C_w = weir coefficient
H = Height of water above the weir
H_w = Height of weir
D = depth of weir

$$Q = (\tfrac{2}{3}(0.611 + 0.075\tfrac{H}{H_w})\sqrt{2g}) b H^{3/2}$$

Substitute H for H_w - d, where d = 1 m, Q = 5 m^3/s, b = 1 m, solve for H_w

$H_w = 0.992$ m

Therefore for a weir less than 1 m high, if the head of water above the weir is greater than 1 cm the weir does not restrict the flow. This therefore need not be considered in this design.

Concrete Structure Design Sample Calculations

Shear and moment demands on the cistern walls:

$$V_{demand} = P_{avg} * A = (P_B - P_T)hb_w = \gamma h^2 b_w$$

$$M_{demand} = F_R * \tfrac{1}{3}h$$

F_R = Shear force due to water pressure
P_B = Pressure at the bottom of the wall
P_T = Pressure at the top of the wall = 0
A = area of the wall
γ = specific weight of water
h = height of wall
b_w = width of wall
M_{demand} = moment demand

Calculating the effective depth of the walls:

$$d = \frac{V_n}{2\sqrt{f_c'}b_w} = \frac{\gamma V_{demand}}{\phi 2\sqrt{f_c'}b_w}$$

d = effective depth of concrete to the centroid of the reinforcement
V_n = nominal shear
f_c' = compressive strength of concrete, assumed to be 2500 psi (17.24 MPa)
γ = magnification factor
φ = undercapacity factor

Calculating the area of reinforcement needed:

$$M_n = A_s f_y (d - \tfrac{a}{2}) = M_{demand} * \gamma/\phi$$

$$a = \frac{A_s f_y}{0.85 * f_c' b_w}$$

M_n = nominal moment
A_s = steel reinforcement area per foot of width
f_y = yield strength of steel, assumed to be 60,000 psi
a = depth of equivalent stress block (unknown)

Quadratic equation used to solve for A_s:

$a = -\frac{f_y{}^2}{2*0.85f_c'}$
$b = \frac{f_y d}{2*0.85f_c'}$
$c = -M_n$
$A_s = \frac{-b+\sqrt{b^2-4ac}}{2a}$ (selected for the larger solution)
In this case, with f_y = 60000 psi, f_c' = 2500 psi, d = 0.437, M_n = 280.8 ft*lbs/ft of width, A_s does not have a real number solution. Therefore the minimum reinforcement area to concrete area ratio requirement was followed.

$\rho = \frac{A_s}{b*d}$
$A_{s,l} = \rho_l bd = 0.002 * 12\ in/ft * 3\ in = 0.0432\ in^2/ft\ of\ width$

ρ = ratio of area of reinforcement to concrete area perpendicular to the reinforcement
ρ_l = ratio of area of longitudinal reinforcement to concrete area perpendicular to the reinforcement
b = width per foot of width
d = effective depth of concrete to the centroid of the reinforcement, using the concrete cover required
$A_{s,l}$ = longitudinal area of steel

Specifications

Cast-in-place concrete	
(a) Concrete cast against and permanently exposed to earth	3 in.
(b) Concrete exposed to earth, liquid, weather, or bearing on work mat, or slabs supporting earth cover:	
Slabs and joists	2 in.
Beams and columns	
Stirrups, spirals, and ties	2 in.
Primary reinforcement	2-1/2 in.
Walls	2 in.
Footings and base slabs	
Formed surfaces	2 in.
Top of footings and base slabs	2 in.
Shells, folded plate members	1-1/2 in.
(c) Conditions not covered in Table 3.3.2.3(a) and (b)	
Slabs and joists	
No. 11 bars and smaller	3/4 in.
No. 14 and No. 18 bars	1-1/2 in.
Beams and columns	
Stirrups, spirals, and ties	1-1/2 in.
Primary reinforcement	2 in.
Walls	
No. 11 bars and smaller	3/4 in.
No. 14 and No. 18 bars	1-1/2 in.
Shells, folded plate members	
No. 5 bars, W31 or D31 wire and smaller	1/2 in.
No. 6 bars and larger	3/4 in.

Table AC.2. Minimum concrete cover for reinforcement (ACI 350.5-12 Table 3.3.2.3).

508 BUILDING CODE REQUIREMENTS FOR STRUCTURAL CONCRETE (ACI 318-14) AND COMMENTARY (ACI 318R-14)

WRI STANDARD WIRE REINFORCEMENT*

W & D size				Nominal weight, lb/ft	Area, in.²/ft of width for various spacings						
					Center-to-center spacing, in.						
Plain	Deformed	Nominal diameter, in.	Nominal area, in.²		2	3	4	6	8	10	12
W31	D31	0.628	0.310	1.054	1.86	1.24	0.93	0.62	0.46	0.37	0.31
W30	D30	0.618	0.300	1.020	1.80	1.20	0.90	0.60	0.45	0.36	0.30
W28	D28	0.597	0.280	0.952	1.68	1.12	0.84	0.56	0.42	0.33	0.28
W26	D26	0.575	0.260	0.884	1.56	1.04	0.78	0.52	0.39	0.31	0.26
W24	D24	0.553	0.240	0.816	1.44	0.96	0.72	0.48	0.36	0.28	0.24
W22	D22	0.529	0.220	0.748	1.32	0.88	0.66	0.44	0.33	0.26	0.22
W20	D20	0.505	0.200	0.680	1.20	0.80	0.60	0.40	0.30	0.24	0.20
W18	D18	0.479	0.180	0.612	1.08	0.72	0.54	0.36	0.27	0.21	0.18
W16	D16	0.451	0.160	0.544	0.96	0.64	0.48	0.32	0.24	0.19	0.16
W14	D14	0.422	0.140	0.476	0.84	0.56	0.42	0.28	0.21	0.16	0.14
W12	D12	0.391	0.120	0.408	0.72	0.48	0.36	0.24	0.18	0.14	0.12
W11	D11	0.374	0.110	0.374	0.66	0.44	0.33	0.22	0.16	0.13	0.11
W10.5		0.366	0.105	0.357	0.63	0.42	0.315	0.21	0.15	0.12	0.105
W10	D10	0.357	0.100	0.340	0.60	0.40	0.30	0.20	0.15	0.12	0.10
W9.5		0.348	0.095	0.323	0.57	0.38	0.285	0.19	0.14	0.11	0.095
W9	D9	0.338	0.090	0.306	0.54	0.36	0.27	0.18	0.13	0.10	0.09
W8.5		0.329	0.085	0.289	0.51	0.34	0.255	0.17	0.12	0.10	0.085
W8	D8	0.319	0.080	0.272	0.48	0.32	0.24	0.16	0.12	0.09	0.08
W7.5		0.309	0.075	0.255	0.45	0.30	0.225	0.15	0.11	0.09	0.075
W7	D7	0.299	0.070	0.238	0.42	0.28	0.21	0.14	0.10	0.08	0.07
W6.5		0.288	0.065	0.221	0.39	0.26	0.195	0.13	0.09	0.07	0.065
W6	D6	0.276	0.060	0.204	0.36	0.24	0.18	0.12	0.09	0.07	0.06
W5.5		0.265	0.055	0.187	0.33	0.22	0.165	0.11	0.08	0.06	0.055
W5	D5	0.252	0.050	0.170	0.30	0.20	0.15	0.10	0.07	0.06	0.05
W4.5		0.239	0.045	0.153	0.27	0.18	0.135	0.09	0.06	0.05	0.045
W4	D4	0.226	0.040	0.136	0.24	0.16	0.12	0.08	0.06	0.04	0.04
W3.5		0.211	0.035	0.119	0.21	0.14	0.105	0.07	0.05	0.04	0.035
W3		0.195	0.030	0.102	0.18	0.12	0.09	0.06	0.04	0.03	0.03
W2.9		0.192	0.029	0.098	0.174	0.116	0.087	0.058	0.04	0.03	0.029
W2.5		0.178	0.025	0.085	0.15	0.10	0.075	0.05	0.03	0.03	0.025
W2		0.160	0.020	0.068	0.12	0.08	0.06	0.04	0.03	0.02	0.02
W1.4		0.134	0.014	0.049	0.084	0.056	0.042	0.028	0.02	0.01	0.014

$A_{s,t}$

$A_{s,l}$

*Reference "Structural Welded Wire Reinforcement Manual of Standard Practice." Wire Reinforcement Institute, Hartford, CT, sixth edition, Apr., 2001, 38 pp.

$A_{s,t} \doteq 0.072$

$A_{s,l} \doteq 0.0432$

Figure AC.2. Wire Reinforcement sizing and spacing selection chart. All selections above the bolded black lines are meet the ACI requirements for the longitudinal ($A_{s,l}$) or transverse ($A_{s,t}$) steel reinforcement area.

Appendix H: Average and Peak Demand Sample Calculations

Shortest day of the year: 11 hours 40 minutes of daylight
10 year village demand: 49,383 L/day

Average Demand = Demand / Daylight hours = 49,383 L / 11.67 hours

Average Demand = 4,232 L/hr

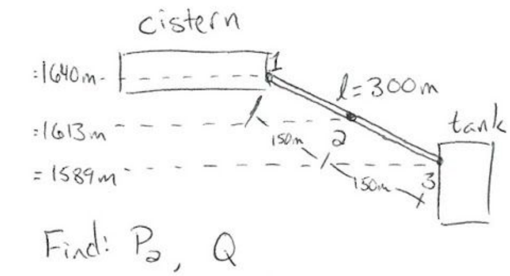
Peak demand is 2.5x average demand
Peak Demand = (2.5)*(Average Demand) = (2.5)*(4,232 L/hr)
Peak Demand = 10,580 L/hr

Assuming the tank is full, our system can supply greater than 15,995 L/hr based on storage and refill capacity of the cistern and tank system.

With an empty tank, our system can supply 5,995 L/hr but it is not anticipated that this will happen regularly.

Appendix I: Finding Pressure with Bernoulli's Equation Sample Calculations

Cistern to Tank System Analysis



Find: P_2, Q

Assume

100% gravity fed system

$g = 9.81\ m/s^2$

$\rho = 1000$

$\mu = 0.0011$

$\varepsilon = 1\times10^{-5}$

$P_1 = P_3 =$ gage pressure $= 0$ atm

$d_{pipe} = 0.0312\ m$

Bernoulli's Equations

$$\frac{P_2 - P_1}{\rho g} + (z_2 - z_1) = -\frac{V_{12}^2}{2g}\left(\frac{ff_{12} \cdot l_{12}}{d_{pipe}}\right)(1.05)$$

$P_1 = 0$, $z_2 = 1613m$, $z_1 = 1640m$, $l_{12} = 150m$, $d_{pipe} = 0.0312m$

$$\frac{P_3 - P_2}{\rho g} + (z_3 - z_2) = -\frac{V_{23}^2}{2g}\left(\frac{ff_{23} \cdot l_{23}}{d_{pipe}}\right)(1.05)$$

$P_3 = 0$, $z_2 = 1613m$, $z_3 = 1589m$, $l_{23} = 150m$, $d_{pipe} = 0.0312m$

Also, $Q_{12} = Q_{23} = Q$ $\quad V_{12} = \frac{Q}{A_{12}}$ $\quad V_{23} = \frac{Q}{A_{23}}$ $\quad A_{12} = A_{23} = \pi\left(\frac{d_{pipe}}{2}\right)^2$ so, $V_{12} = V_{23} = V$

$ff_{12} = \frac{1}{\left(1.8\log\left(\frac{\varepsilon/d_{pipe}}{3.7}\right)^{1.11} + \frac{6.9}{Re}\right)^2}$ if $Re > 2300$ $\quad Re = \frac{\rho V d}{\mu}$, unknown: V, rest known

so for Bernoulli's equations

we have 2 equations + 2 unknowns: P_2 + V

therefore solve them simultaneously

$\boxed{P_2 = 14{,}700\ Pa}$, $V = 2.178\ m/s$

$\boxed{Q = VA = 1.665\times10^{-3}\ m^3/s}$