Village Supply-Distribution System Subteam

Maria Veronica Cordova, Tianchen Yu

December 12, 2014

Abstract

The Team Village Supply has three sub teams working on the photovoltaic pump, distribution and household design. The Village Supply-Distribution System Subteam has worked based on last semesters code 2canzzzz’ and improved it so that it has more accurate final results and it can be set continuous, meaning that this code can be updated with any characteristics of other villages. The overall design of the subteam consist in the network of pipes that distribute water coming from the tank to every house in the village. The new code has taken into account the flow variation into each tier of pipes, and thus the result in the sizing of the pipes has changed significantly. As a result we obtain the critical path and the correspondent head loss through the pipes, considering major and minor losses and differences in height elevations. The cost of the total network design including pipes and tees has been calculated with updated costs for the optimal solution.

Table of Contents

Introduction

In the end of December 2013, The World Bank and Indian Government launched $1 billion rural water and sanitation project for low income states. The onset of the project signified the fundamental need for different approaches in designing water supply system for small villages. This sub team's primary goal is to design a distributed storage system for a village water supply. In the past, six teams from CEE 4540 Fall 2013 explored options for the design of village schemes. (Background information is available) Each team researched and evaluated related topics such as efficiency of elevated/non-elevated storage tank, assessment of centralized/decentralized distribution system, household distribution system design, and solutions for household water storage shortage with parameters determined by each team.

The designed systems were based on conditions of Gufu Village in India where one of the AguaClara stacked rapid sand filters is located. Solar-powered pumps draw water from a well half a kilometer outside the village and pump it through a transmission line to the village, then through a three-tiered system of pipes to each house. Lengths of tubing at each house were considered to restrict the flow rate and ensure equity, so that no house receives significantly more water than any other house. The past teams also came up with Mathcad code that sizes a photovoltaic (PV) array and optimizes pipe and tubing sizes based on equity constraints, local weather data, desired flow rate, and system cost.

At the conclusion of the semester, the teams passed on two major challenges. One is increasing system designs affordability by replacing the elevated storage tank. The other is providing equitable distribution of water without expensive meters. After reviewing last code, we conclude the following:

- The 48 houses defined in the code does not represent houses, but boxes that distribute water to 2 houses each.
- The flow rate inside each pipe is calculated with the mean flow rate of each tier, assuming that all tiers (1,2 and 3) maintain the same flow rate.

Fall 2014 Village Supply System team is divided into three sub teams: Distribution System Design, Household Infrastructure, and Pump Design. Based on what CEE 4540 Fall 2013 teams have explored, each sub team aims to come up with more applicable village supply system that shall meet the expectation of the World Bank and the Indian government's rural water and sanitation project for low income states. In order to reflect the need of Indian villages, the team will actively converse with our partners in India about the growth and equity targets. Also, the team will utilize resource inventories such as solar radiation data, precipitation data, and satellite images to incorporate objective data of the area.

Keeping four core standards– (1) lowering cost, and (2) increasing efficiency, (3) equity, and (4) convenience–in mind, the Distribution System Design team will create a generalized algorithm for supplying treated groundwater to each household with additional inputs such as population growth and projected lifespan of the infrastructure. The team will devise a flexible algorithm that can be easily adjusted to changes in population (shrinking or expanding of the village) and climate (dry season and monsoon season).

Three main components of the design shall be pipe sizes, pressure target, and flow restriction.

Literature Review

The spring 2014 team started with the 2canzzzz' capstone design, one of the final projects completed for CEE 4540 Sustainable Municipal Drinking Water Treatment in Fall 2013. The design was revised to optimize cost and equity in the village supply system. The past code was only designed for Gufu Village in India and used an electric pump powered by solar panels to lift water from a well located outside the village. The water was treated by an AguaClara low flow stacked rapid sand filter at an elevated storage tank and distributed to each household. The distribution was made twice a day, but the outcome was not satisfactory. The central tap, that did not go to the households but to the central location in the village, was being left open with a small bucket beneath to catch the water. When the water came on, no one would be there to turn the spigot, or faucet, off when the bucket was full. Usually, the buckets used were contaminated. Also, the design required an elevated tank which is not so effective when building and operating cost are considered.

In order to improve the design and resolve the addressed problems, SP14 team made some different approaches. The revised design of spring semester implements a small diameter tubing that restricts the flow for each house. The flow can be modified by increasing or decreasing the length of the tube at each house. This design assumes flow is turbulent. Flow equity in the design means that each house should be within 10% of the flow target. The flow target is calculated according to the number of houses, assuming 5 people per house and a flow rate per capita of 100 L/day.

The distribution of the pipes has three tiers (noted on Figure 1 with blue, red, and yellow lines) that carry the water from the well through the main pipe to the village and to each household. Flow is restricted by the coil of tubing located at street level (the white box with grey cover shown in Figure 2) and discharges the water into the household tank which is controlled with a valve. Images below are the illustration for distribution system created by SP14 team:

Figure 1: Distribution Layout

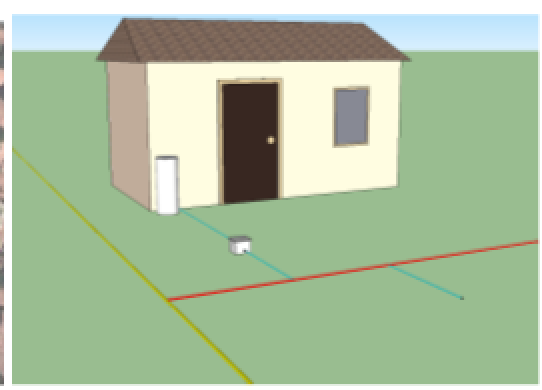

Figure 2: Distribution Illustration

The past code is based on an energy analysis, head through the system and in each household (as shown in Figure 3) and neglects heights differences between each house and head loss for each pipe diameter.

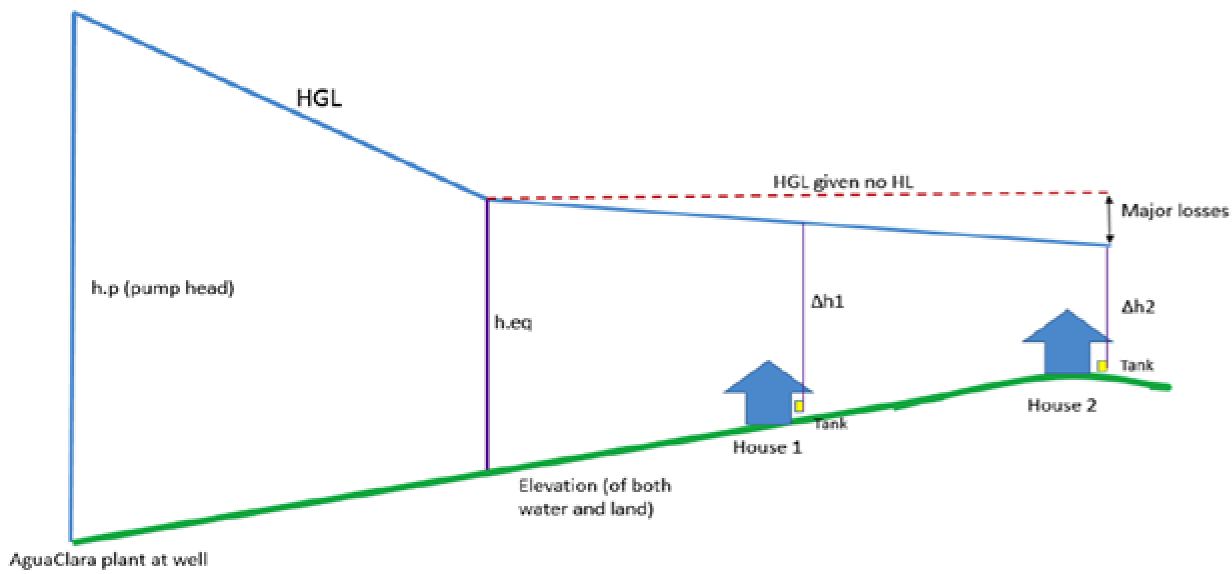

Figure 3: Hydraulic gradient line (HGL) following energy throughout the entire distribution system.

The inputs for the Mathcad code were: population, flow rate per capita, number of hours that the sun will produce electricity to the pump, system geometry and available pipe and tubing sizes.

The last semester's algorithm is summarized in the Figure 4 and Figure 5 below (Kelterborn et al. 2014 18-20):

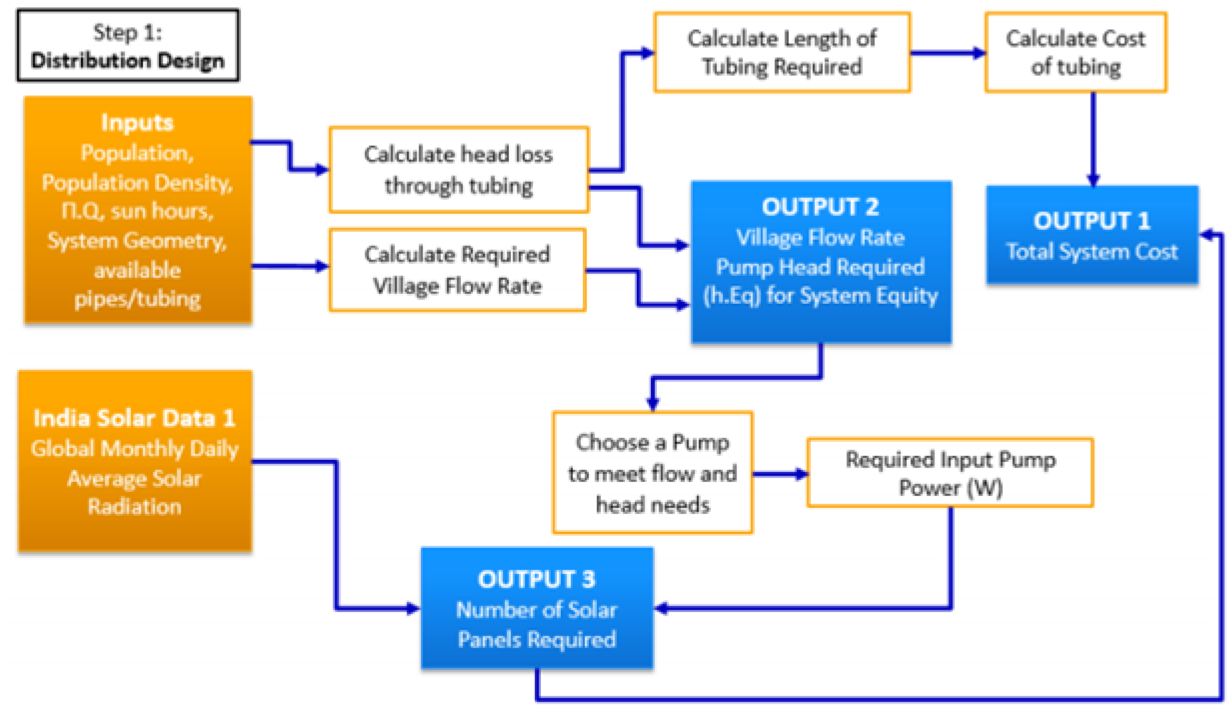

Figure 4: Algorithm part 1

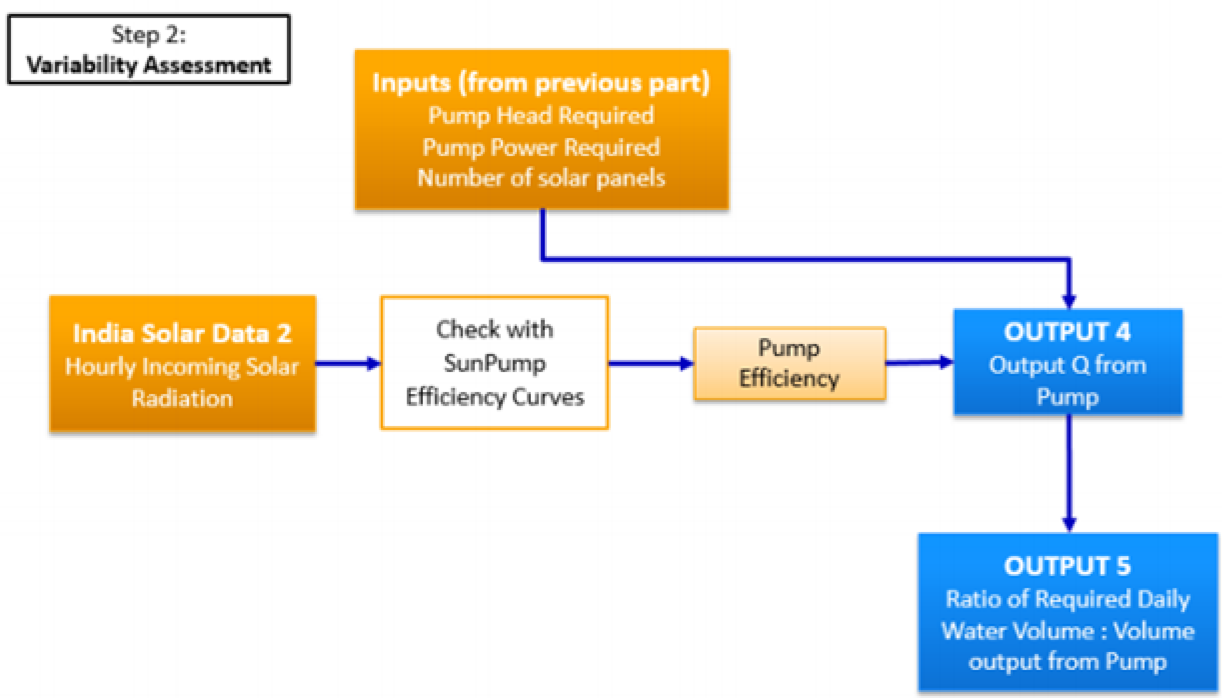

Figure 5: Algorithm part 2

The distribution code completed by the spring 2014 (SP14) team projected the optimized total cost of $27,220 USD which included PVC pipes, PV panels, and pumps.

Optimal system values such as pipe diameters, tubing lengths, number of solar panels, pump power, pump head, and equity head were also determined by the algorithm. Various solar pump systems were also evaluated. This will more discussed in photovoltaic and pump sub team.

Concluding the semester, the previous team suggested improving the code for flow type variability so that the code can optimize the distribution system in circumstance of either turbulent or laminar flow. Also, another agenda item left over was to minimize and simplify inputs in order to make the code more user-friendly.

In general, the design of pipes is usually confined to two main inputs (Wagner and Lanoix, 1959):

· The computation of the size and the length of pipe required to convey a specified amount of water under a given hydraulic gradient
· The determination of the amount of water which will be delivered by a pipeline of a given size under a known pressure

For our project, Gufu village sits on a relatively flat site so the water can't be transferred only by gravity, which requires pressure support from the outside such as pump or by elevating the distribution tank. In order to convey the water to each household, enough head should be maintained by the pump or achieved through the height of the storage. To save energy, the head provided by the pump should be as close to the required value as possible, which requires accurate calculation of head loss in all segments of the pipes. To calculate the major head loss, we compare the Darcy - Weisbach, and Hanzen - Williams formulas.

The Darcy - Weisbach formula that takes into account the friction into the pipes by calculating a dimensionless friction factor known as Darcy friction factor, Darcy - Weisbach friction factor or Moody friction factor.

Darcy - Weisbach Formula

Head loss through a pipe

$$h_f = f_D \frac{L}{D}\frac{V^2}{2g} \qquad (1.1)$$

To solve for pressure we define the pressure as a function of the head loss that represents the column of water

$$\Delta_p = \rho\ g\ h_f \qquad (1.2)$$

To obtain the pressure in terms of the friction factor we plug equation (1.1) into (1.2) and obtain equation (1.3).

$$\Delta_p = f_D \frac{L}{D}\frac{\rho V^2}{2} \qquad (1.3)$$

Where,

hf	=	head loss inside the pipe	(m)
fd	=	dimensionless friction factor	
L	=	total length of pipe run	(m)
V	=	velocity	(m/s)
D	=	internal diameter of pipe	(m)
g	=	gravity	(m^2/s)
ρ	=	the density of the fluid,	(kg/m^3)

The dimensionless friction factor has to be calculated with the Moody diagram and will depend on the characteristics of the pipes and the velocity of the fluid, this can be laminar or turbulent. The calculations for each condition are described below.

The Reynolds Number will define if the flow is turbulent or laminar. If Re>2100 then the fluid will be turbulent.

$$Re = \frac{4Q}{\pi\, D\, \nu} \qquad (1.4)$$

Where,

Re	=	Reynolds Number	
Q	=	flow	(m^3/s)
D	=	internal diameter of pipe	(m)
v	=	kinematic viscosity	(10^{-6} m^2/s)

For laminar flow the friction factor is defined as

$$f_D = \frac{Re}{64} \qquad (1.5)$$

For turbulent flow the friction factor is obtained by using the Moody diagram.

Hazen - Williams Formula

Solving for psi pressure drop per 100 feet of pipe

$$P_d = \frac{4.52 x Q^{1.85}}{C^{1.85} x d^{4.87}}$$

Solving for total psi pressure drop in system

$$T_d = 0.002082\, L\, \frac{100^{1.85}}{C} x \frac{Q^{1.85}}{d^{1.8655}}$$

Solving for velocity

$$V = 1.318\ x\ C\ x\ R^{0.63}\ x\ S^{0.54}$$

Solving for flow rate

$$Q = 0.849\ x\ C\ x\ A\ x\ R^{0.63}\ x\ S^{0.54}$$

Solving for friction head loss per 100 feet of type, SI units

$$f = \frac{6.05\ x\ Q^{1.85}}{C^{1.85}\ x\ d^{4.87}}$$

Where,

Q = quantity rate of flow, gpm (LPM)

C = roughness coefficient, dimensionless

d = inside pipe diameter, in. (mm)

f = friction head loss in ft. hd./100 ft. of pipe (m per 100m)

Pd = pressure drop, psi/100 feet of pipe

R = hydraulic radius, feet (m)

V = velocity, feet per second

A = cross section area, in (mm)

Td = total drop system, psi

L = total length of pipe run, ft

The Hazen Williams Equation has its own limits, as we can see from the definition; each equation has to be applied with specified units. To simplify the calculation, we will use the Darcy - Weisbach Equation. The head loss in each pipe could be calculated more accurate, and as a result we will define the required power that the pump must provide and finally the cost of the network design and pump.

Previous Work

First they calculated the total flow for the village

The Reynolds Number for the turbulent flow was calculated with the following equation. The ratio represents the maximum flow under the 20% equity constraint, and the 1.5 factor is to account for variability in solar power.

$$Re = \Pi_{RatioMaxAvg} * 1.5 * \frac{Q_{TargetHouse}}{\frac{\pi}{4}\nu Min_{DTubing}} = 5,744 \quad (2.1)$$

Assuming the difference in head loss between closest and furthest house to the transmission line they defined the head loss equation.

$$h_{f.tubing.max} = \Delta h_{f.dist} + h_{f.tubing.min} \quad (2.2)$$

The maximum and minimum pipe flow according to their respective head loss are calculated with the following equations.

$$Q_{Max} = \sqrt{\frac{h_{f.tubing.max}}{\alpha}} = \sqrt{\frac{\Delta h_{f.dist} + h_{f.tubing.min}}{\alpha}}$$

$$Q_{Min} = \sqrt{\frac{h_{f.tubing.avg}}{\alpha}} = \Pi_{RatioAvgMin}\sqrt{\frac{h_{f.tubing.min}}{\alpha}} \quad (2.3)$$

The length of the necessary tubing to dissipate the average head loss for each household in the system is represented in the following equation.

$$L_{Tubing} = \frac{g * h^2_{f.tubing}\left(\frac{\pi D^2_{Tubing}}{4}\right)^2 * D_{Tubing}}{f * Q^2_{Tubing}} \quad (2.4)$$

In the previous design the flow equity has not yet been achieved.

Selecting pipe materials for use is also important for us. In order to select the most optimal pipe, we should pay special attention to the quality of the water to be distributed. The concentration of carbon dioxide and hardness can significantly affect the rate of corrosion of the pipe. The different type of material may result in different head loss in the pipelines. In the end, most probably we will choose the PVC pipe same as the previous report, since the PVC is a tough, high resistance material with relatively lower cost.

The goal for the new design is to maintain equity of flow rate, low cost design, and ensure the drinking water supply required by the village at any time of the day in a safe way.
We will optimize our code according to the distribution of the houses and topographic conditions. In the end, our code will as accurate as possible to the real case, which will include all the minor losses such as head losses due to the changing shape of the pipes.

Methods

To determine the actual situation in India, we contacted Maysoon Sharif, Designer Engineer, Principal, AguaClara LLC and got the following information:

· The most imminent problem of current distribution system is that it was not designed for equity flow, so the disparity of water supply from household to household is large

· Although the distribution system uses ferruls (small orifices that restrict flow through a path) to try to equalize flow, there were larger distribution design errors that prevent them from being effective

· The idea of building a reservoir in order to collect raw water (both groundwater and rainwater) is not feasible. Since the land is incredibly precious in the villages, it is difficult to get people to give up their land for these systems, at least without significant compensation.

· The rainwater quality should be good, but there is no data available of quality nor quantity

· The monsoons are not exactly consistent, but the solar pump should run at least a little even on cloudy days

Also, we have communicated among the sub teams. Below are the assumptions that we have agreed on a meeting (10/14/2014):

Sub teams assumptions

- Household Team
  - The outlet for each house is located 2 meters above ground level. The storage tank is 1 meter height, it is placed 1 meter above the ground level and that the outlet is at the top of the tank.
  - The group is waiting for answer from our partners in India relevant to the use of the grey water, according to the real conditions in the field.
  - The coil will be kept this semester to control the amount of water coming into each house, to prevent the extra water in the houses.
  - Grey water is assumed to be dumped in a village's sewage system, for now. The team also asked May about this.

- Photovoltaic and Pump Team
  - The type of pump will depend on the target flow rate and the cost. The design does not rely on a specific pump. The latest information from India about the available pumps is:
    - Power: HP ⅓ - 3
    - Price: 50 USD - 300 USD
  - The system will be evaluated for two cases:

        - One pump
        - Two pumps
    - Currently, they are still using solar radiation data and precipitation data from Gufu Village

- Our Team
    - We will focus our code in controlling flow upstream first, in the main and sub main pipes, so if we can provide a good distribution from the start, equity flow for each household will not be a problem.
    - We will consider new inputs to define the target flow rate for any given village, according to past data of the population. The new inputs are population growth rate and lifespan of the distribution system and the treatment facility.
    - Building a reservoir seems to be too expensive and consuming idea, but it is also a nice solution for the absence of constant power source, especially in rainy season. The cost evaluation should be made prior to including a reservoir to the design.
    - We are doing research in rainwater harvesting infrastructures located above the filter room, or above the pump house that would conserve land area and make the design more appealing.

Evaluate the design that eliminates the need for an elevated storage tank and an elevated AguaClara plant

The water transmission or distribution system can be designed for different alternatives according to the topographic conditions from any given village. The two alternatives for Gufu Village are distribution by gravity or by pumping. The first alternative accounts for an elevated storage tank that collects water from the well and distributes the treated water to the houses by gravity using one pump at the well (Figure 4). The second alternative is the ground level storage tank that collects water from the well with a pump and then distributes the water to the houses with another pump (Figure 5).

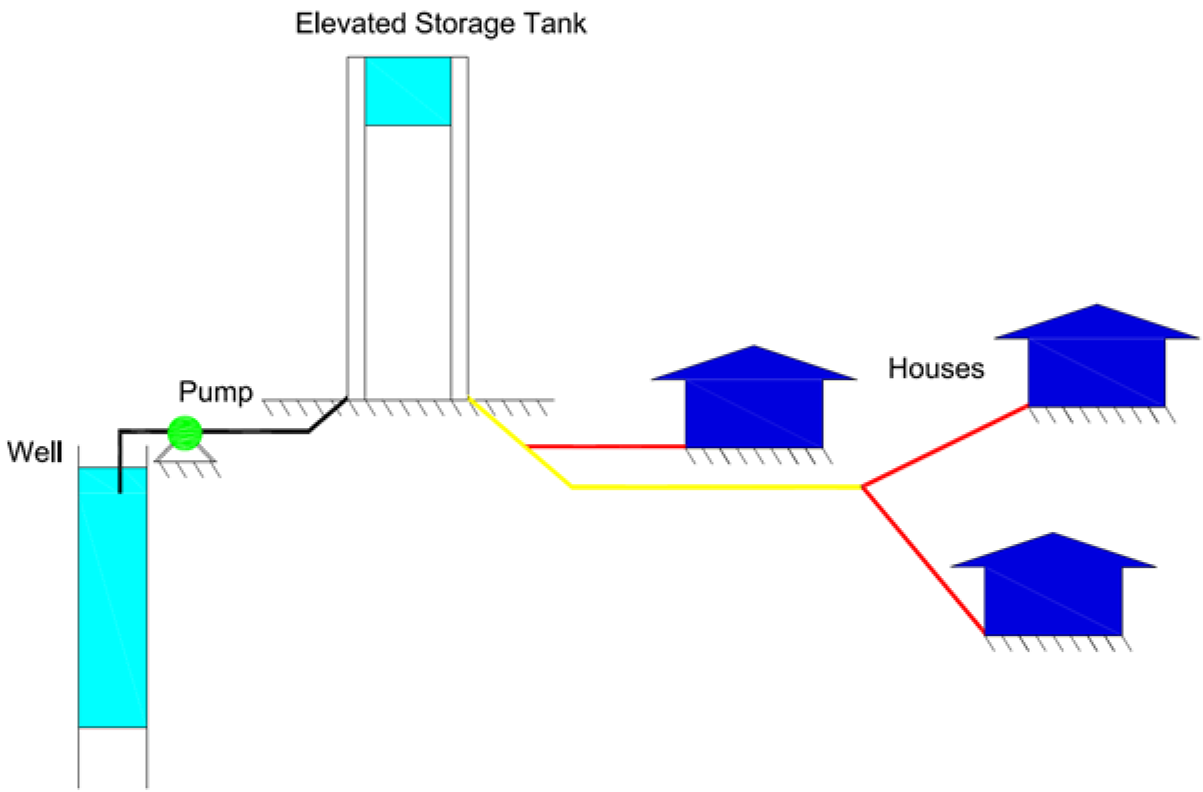

Figure 4: Elevated Storage Tank for water distribution using one pump system

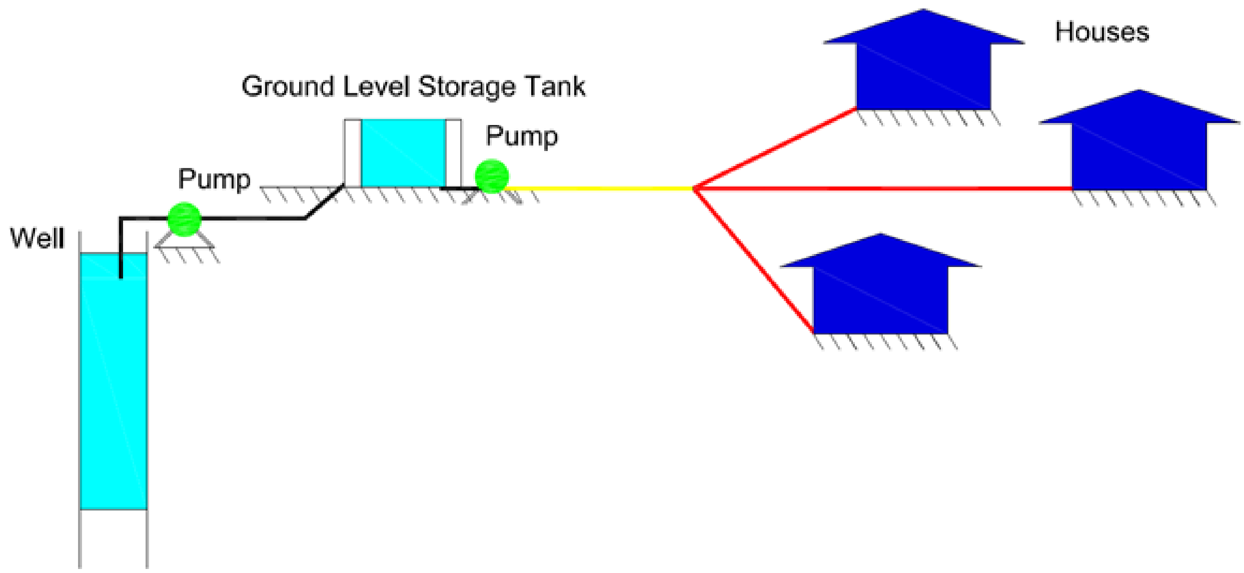

Figure 5: Ground Level Storage Tank for water distribution using two pump system

To evaluate the cost for one pump system and two pump system we used last semester's code 2Canzzz. For these calculations we updated the cost of the pipes and accounted for a population growth parameter of 1.014 according to the data of The World Bank (2012), which was considered from past data of India.The total cost of each alternative will account for the cost of the pumps, different tier sizes, available tees and the cost of the tank. For this case we used the values of Gufu Village and figured out that the height of the storage tank for the first alternative would be around 30 meters to be able to provide enough head in order to distribute flow equally. The idea of building such a high tank is not feasible.

Although the first alternative will not be chosen for this analysis, we compared the costs of both alternatives and obtained that the the optimal solution for the elevated storage tank system would be $15,630 versus $10,370 for the ground level plant system including pumps. This data is being recalculated, since we change the code.With this analysis we eliminate the need of an elevated storage tank for an AguaClara Plant.

Compare and decide on the number of pumps (work with PV/Pump sub team)

Option 1: A single electric pump sends water through a pressurized LFSRSF and to the town. Chlorine and coagulant are both somehow metered into the influent of the pump

Option 2: One electric pump lifts water from the well to an Agua Clara facility that is at ground level. A second electric pump sends water to the distribution system

Since our group is divided in sub teams, we have to work together to make decisions in our code. The Pump team analyzed the options above for the system and their analysis resulted in two pump design, which is the same condition our team decided.

Our Design

The main goal for our design is to ensure equity flow in every household. In order to be able to evaluate the total head needed to supply this need, we account in our design for major and minor losses, difference in height elevations between houses and changing in flow rate inside the pipes. Our calculations throughout the pipes will always be turbulent flow.

Inputs:

Variable	Value	Units	Description
N_{Houses}	96	Houses	Number of houses in system
N_{Pph}	5	Person	Number of people per house
N_{People}	480	Person	Number of people in village
$Q_{PerCapita}$	100	L/day	Per capita flow rate desired per day
$\Pi_{SunHours}$	0.33		Percentage of the day with sunlight
Q_{Target}	2.52*10^-5	M^3/s	Target flow rate per house
Π_{Design}	1.014		Estimated Population growth
E_{Pvc}	0.12	mm	Roughness coefficient for the PVC pipe
Nu_{Water}	10^-6	M^2/s	Viscosity of water
E_{Well}	527.609	m	Elevation of the ground level at the well
E_{In}	538.886	m	Elevation at the node enters the village
L_{Trans}	681	m	Length of pipe from the well to village
L_{Tier1}	225	M	Length of Tier 1 pipe
L_{Tier2}	600	M	Length of Tier 2 pipe
Π_{Q}	0.1		Equity measurement
Π_{Pump}	0.45		Efficiency of the pump
$Cost_{PV}$	1.35	USD/W	Cost of PV

$\Pi_{Derating}$	0.77		Derating factor inverter loss, resistive factors
H_{GW}	9	M	Height of the groundwater in the well during the dry season
$HL_{ACPlant}$	40	Cm	Max Headloss
H_{Et}	0.614	M	Height of the entrance tank
$Cost_{Concrete}$	77	USD/yd^3	Cost of concrete

Tier 1: Is the main pipe that originates in the tank and carries water to the next tier of pipes. It is shown in yellow on the diagram (Figure 1)

Tier 2: Carries water from the Tier 1 pipe to the Tier 2 pipes that serve each house. Shown in red on the diagram (Figure 1).

Tier 3: Carries water from the Tier 2 pipe to each household. Shown in blue on the diagram (Figure 1).

In order to reduce the pipe length, the tank should be located in the area closer to the middle of any village according to the land availability. In Gufu Village, the distribution system carries water from the well to the tank located in the center of the village and then the water is carried through the Tier of pipes until it reaches the final destination which is the household.

The purpose of placing our main node in the center of the village is to reduce the distance between the tank and the houses. If our main node were placed in the corner of the distribution system, the length of the pipe from the tank to the furthest house would be double. The ultimate parameters to define our system's efficiency are equitable flow and low cost. Major losses affect both of these conditions, so if we can minimize the length of the pipes, we could improve our design.

As we can see from Figure 1 before, the place where the tank located is almost the highest elevation in the village, and gravity will bring down the water. The elevation difference between this central node and each house is smaller than they would be if the node is placed at the edge of the village.

The flow for each household's orifice is determined by the total head driving for each house, that also depend on the elevation differences between houses and from the tank.

The critical restriction in our code is to maintain equity flow for each house, so the difference in head loss between the maximum and minimum value must be as small as possible. Major and minor head losses can be reduced by minimizing the diameter variations from Tier 1 pipes and Tier 2 pipes. Another way to accomplish this is by designing each Tier 2 pipe serve the same number of Tier 3 pipes and Tier 1 pipe server around the same number of Tier 2 pipe.

According to the data from the village, the system has already an infrastructure that carries the water to the houses. The new code will use this distribution to calculate the head loss throughout the system. One major change in the code is that we will not assume that the flow in the tiers (1,2 and 3) will be constant and estimated as the mean flow. The new code evaluates the flow rate for each segment of the tiers. For example, tier 1 has 2 segments that has 6 branches and each branch has a different number of tier 3 connections that carry water to the boxes that are connected to each household.

Based on the new assumptions we calculated the new diameters for tier 1, 2 and 3 to estimate the new updated cost.

Physics of the design

Equity Flow

To calculate the equity flow for our design we use the next formula, which provides a flow difference between houses from 10%.

$$Pi_Q = \frac{Q_{Max} - Q_{Min}}{Q_{Avg}} = 0.1 \qquad (3.1)$$

In terms of head we define our formula:

$$Pi_Q = \left[\frac{\Pi_{VC} * A_{Orifice}\sqrt{2g(h_{Equity} - h_{LEMinimum})} - \Pi_{VC} * A_{Orifice}\sqrt{2g(h_{Equity} - h_{LEMaximum})}}{\Pi_{VC} * A_{Orifice}\sqrt{2g(h_{Equity} - h_{LEAverage})}} \right] \qquad (3.2)$$

We replaced the head loss equation for each Q, Qmax, Qmin, which correspond to the minimum and maximum height difference. The head losses combine the head loss due to elevation difference and major losses due to friction in the long pipes throughout the system. The range of this head losses is determined by $h_{LEMinimum}$ and $h_{LEMaximum}$. Simplifying the equation we obtain:

$$Pi_Q = \left[\frac{\sqrt{(h_{Equity} - h_{LEMinimum})} - \sqrt{(h_{Equity} - h_{LEMaximum})}}{\sqrt{(h_{Equity} - h_{LEAverage})}} \right] = 0.1$$

We rearranged the equations, and then solve to find the roots of the equation which is h_{Equity}.

$$F_{hEq}(h_{Equity}) = \sqrt{h_{Equity} - h_{LEMinimum}} - \sqrt{h_{Equity} - h_{LEMaximum}} - \Pi_Q\sqrt{h_{Equity} - h_{LEAverage}}$$

(3.3)

Minor losses and major losses

For the last code, it was assumed that major losses dominate minor losses. This was assumed for simplification of the system. In our code we will add this losses to our calculations. The total loss will be calculated with the equations (1.1) and he for minor losses:

$$h_l(Q, D, L, K, \nu, \varepsilon) = h_e(Q, D, K) + h_f(Q, D, L, \nu, \varepsilon) \qquad (4.1)$$

Where the h.e is representing the minor losses (caused by flow expansion) and h.f is for the major losses (caused by shear in the walls of the pipes). We use the Darcy - Weisbach formula and both equations are shown below.

$$h_e(Q, D, K) = K\frac{8}{g\pi^2}\frac{Q^2}{D^4} \qquad (4.2)$$

$$h_f(Q, D, L, \nu, \varepsilon) = f(Q, D, \nu, \varepsilon)\frac{8}{g\pi^2}\frac{LQ^2}{D^5} \qquad (4.3)$$

The flow Q will vary depending on which tier is being calculated; the diameter of the tiers, D, will be estimated as the optimal diameter from each tier; the length of the pipes is defined as L, K is the minor loss coefficient and f is the major loss coefficient. For our distribution, we defined three stages of tiers.

In order to calculate the minor and major losses, first we define the flow rate that will be available in tier 1, 2 and 3. Since we know that tier 1 is going to distribute flow to tier 2, and tier 2 will distribute flow to tier 3, we will use the maximum flow served in each tier. Our Q.Target is the flow in tier 3.

Then, we use Q.target to calculate the flow in tier 2 and tier 1. This calculation is dependent on the number of nodes in each tier (nodes represent number of distribution in each part of the tier). In our calculation we will take the Q maximum in each tier as a safety factor.

The equations that describes the flow for the tier coming into the houses, tier 3 is:

$$Q_{Tier3} = Q_{Target}$$

The flow for tier 2 will be the necessary for the nodes in that portion of the design and finally the tier in flow 1 has to be enough to satisfy the flow required for all the houses at the village.

$$Q_{Tier2} = \max(Nodes_{Tier2})Q_{Tier3} \qquad (4.4)$$

$$Q_{Tier1} = \max(Nodes_{Tier1})Q_{Tier2} \qquad (4.5)$$

Elevation differences

Depending on the topography of the village, the elevation differences between the well, tank and households will define an important constraint for the distribution design. To calculate the most critical path on the distribution, we have to evaluate the head loss resulting from the major losses and minor losses and the elevation difference between the tank and the household.

In many cases, the height differences will vary in a range of positive and negative number, depending on the location of the houses. For example if a house is higher than the tank, then the difference in elevation will be a negative number and thus the pump serving the village will have to produce a higher head in order to get the water to this higher point.

The new code calculates the most critical difference in height between the 48 final points and the tank. This value is then added to the maximum head loss calculated in the tiers 1 2 and 3. The result is the most critical path and thus the maximum head loss in the system.

Flow Rate Distribution

To calculate the flow rate in each tier, we started with the Qtarget for each point of final distribution. This Qtarget was calculated with a safe factor of 1.2 of the Qhousehold. We are assuming that each point (48) distribute water to 2 houses and therefore the flow required in tier 3 will be 2 times Qtarget.

Each tier 3 is connected to one branch of tier 2. This distribution is already defined in the code. For example for branch one of tier 2 there are four tier 3 connected and for branch two of tier 2 there are five tier 3 connected. Each tier 3 branch creates a new segment for tier 2. The code analyzes tier 2 as one complete segment with the total flow of the total tier 3 branches.

This calculations result in different values of flow for each tier 2 branches instead of all tier 2 with the same mean flow, which is the last code assumption.

The code calculates the flow of tier 1 the same way as tier 2.

Calculations for Gufu Village

To be able to calculate the head needed from the pump to provide flow to the most critical path we used the information from the Gufu Village and calculated the most critical head loss throughout the system and the highest elevation above the tank, obtaining the following results:

$$\Delta Elevation_{max} = 2.524\ m$$

First we define the flow rate that will be available in Tier 1, 2 and 3 since we know that Tier 3 is going to add flow to Tier 2, and Tier 2 will add flow to Tier 1. We will start with our Q.Target multiplied by a factor of 2 (considering that that final point will provide water for 2 households) which is the the flow in Tier 3. Then, we use 2 Qtarget to calculate the flow in Tier 2 and Tier 1. This calculation is dependent on the number of nodes in each tier (nodes represent number of distribution in each part of the tier).

To obtain the optimal diameter of the pipes we created a loop that will iterate the different sizes and calculate the headloss with each characteristic given. The constraint of last semester's code was that the head loss per unit length should be less than 0.001. We arranged the code so that we calculate the head loss per unit length for each branch of the tier with different diameters, compared each value with the constraint of 0.001 and decide the optimal diameter for that part of the system.

The connection between tier 3 and tier 2 make the flow rate inside tier 2 varies a lot. We didn't find a good way to make the code continuous while calculating all the details of each segment of tier 2. Instead we will calculate the total flow in each branch of tier 2 and choose the optimum diameter.

The head loss through tier 2 is calculated the same way as tier 3.

From last semester's code we can get some data of the length of the tiers but this data is not fully understandable, since there is not a clear description of the data. We are assuming certain distribution according to the figure we have from Gufu Village. For Tier 1 we didn't get fully organized data, so we did the calculation manually, we hope that the next team could re-organize the data, and make the code more accurate.

Results

Using the procedure explained before we calculate the optimal size dimensions for each of our tiers and we obtain the following results:

Branch	Tier	Diameter	Units
1-48	3	1	inches
1,2,4,6	2	3	inches
3,5	2	2	inches
1	1	4	inches
2	1	3	inches

For tier 2 we get two different values of pipe diameters for different branches of our system. Since we don't know the exact dimensions from the data given of the length of pipes in the village, we are assuming certain distribution. The pipe diameter is changing because each segment has a different connection to the next segment, meaning that some segments will have to carry more water than others.

The code calculates the head loss per unit length in each tier with the constraint that this coefficient is less than 0.001. The following figures show the head loss for each tier.

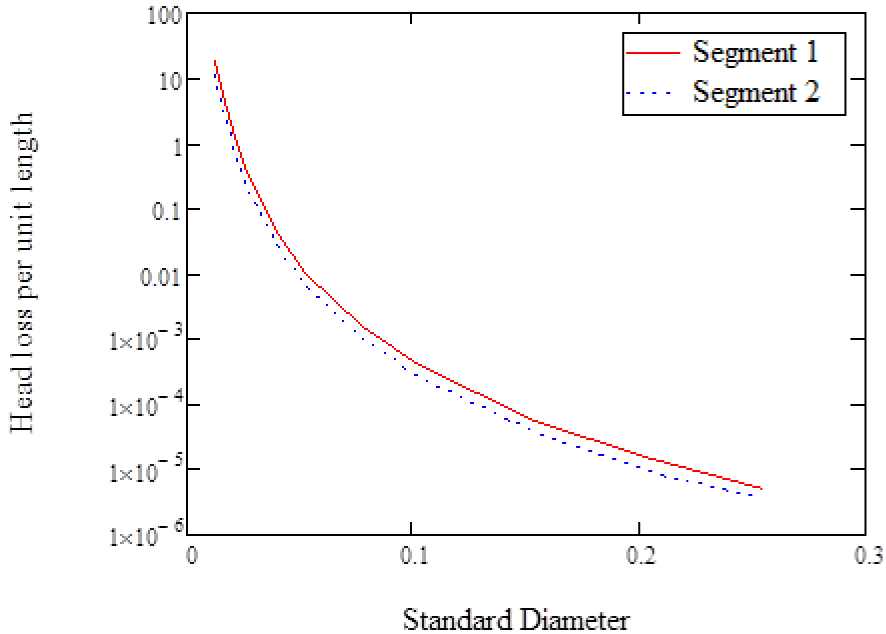

Figure 6: Head Loss per Unit Length in Tier 1

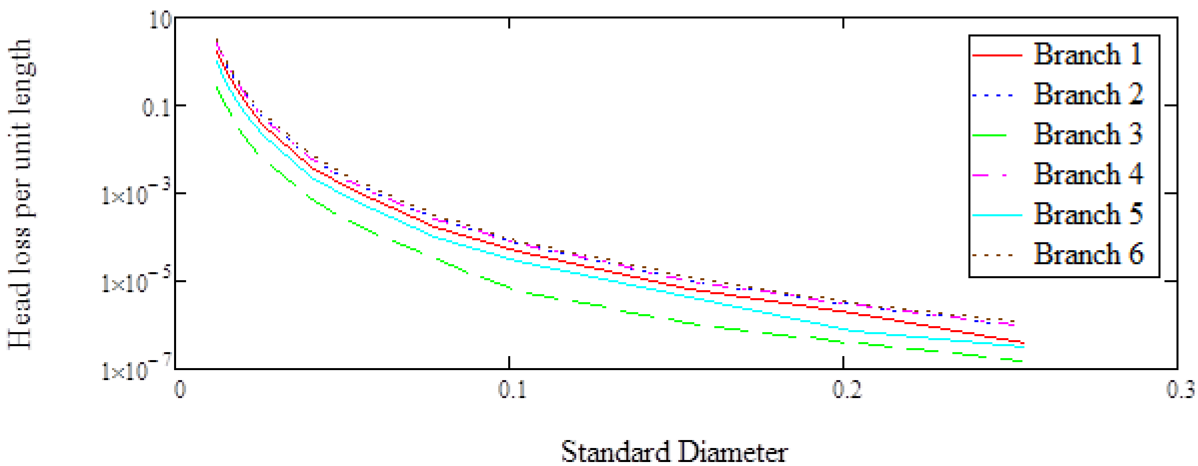

Figure 7: Head Loss per Unit Length in Tier 2

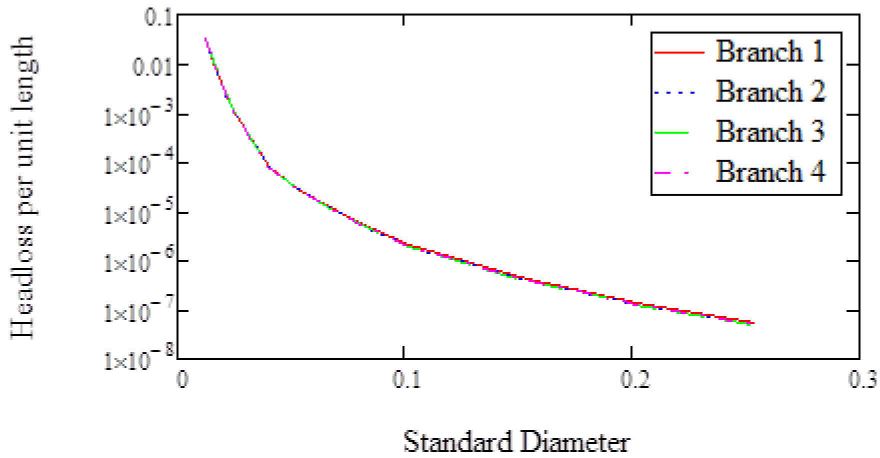

Figure 8: Head Loss per Unit Length in Tier 3

The total head loss calculated for the most critical path in the whole system is 2.95 meters. This is the value that the pump should provide.

The total cost of the pipes and tees in the entire system (without the pumps) is $25,380.

Conclusion

In order to design an optimal water supply distribution for Gufu Village we used the data given from last semester which included the length of the different tiers, the difference in elevation from each distribution point to the tank and the number of tees and elbows in each segment of the network.

As we revised the code of last semester we noticed some assumptions were not clear. The main constraint we changed is the Number of Houses, which is not quite well described, since it is set as 48 and we know that there are more than 48 houses in the village. The real meaning of the number 48 is the number of points (or boxes) that the water reaches to divide water into about 2 houses per point. We fixed this assumption as setting the flow for tier 3 as two times the target flow.

As we were trying to make the code more accurate and set a population growth rate, we had problems in finding past data of the population of the village, so we could not design for a flow rate that will be enough for 10 or 20 years from now. To be able to expand the desired flow, we chose the pipe sizes and also make the system easy to change.

After updating the cost, we came up with different final values as last semester.

Future Works

In the new code, we tried our best to make it a continuous code, so that once there is a value change in the basic data, the whole system could change automatically. But due to the way the data was collected, it is hard to connect all the calculation together. We hope that the next team can change the way how the basic data is organized and make the code a fully continuous one.

In the code we created, due to the way of organizing data, we didn't manage to calculate the detail diameter of each segment of Tier 2 and Tier 1. We hope that the next team could calculate the detail segment diameter based on the flow rate change in different segment.

Since segment diameter wasn't calculated precisely, the head loss for the whole system is relatively higher compare to the real data. The next team could make the calculation more precisely and closer to real life.

It took us quite long time to figure out what the previous team did, since the code was not presenting in an organized and clear way. The new code has all the meanings of the programming part. Future teams should keep this and make the code a more user friendly.

Based on all the suggestions above, future teams can make the code a more continuous and precise.

References

Trev, Nuadha.(2012, June) *Empirical Formula, Water Supply Network, Irrigation, Water Pipe.* Mauritius: International Book Marketing Service Ltd.

Kelterborn (May 16, 2014) *Village Source to Environment Report*. Ithaca: AguaClara.

Wagner, Edmund D. and Lanoix, J. N.. *Installation of Water-Supply Systems*, Washington DC: World Health Organization

The World Bank. (January 2012). *World Bank Indicators Databank*