# Household Level Infrastructure

## Village Supply Team

## Fall 2014

Pooja Desai, Paula Gomez-Nunez, Mary John

December 5, 2014

# Abstract

The Fall 2014 Household Infrastructure Team designed a storage tank, sink and a flow regulation system at the household level in a rural Indian village. The ultimate goal of the semester's designs was to provide equitable flow to each house, to be stored and used in a sanitary environment. The designs determined that a 600L HDPE storage tank at each household is necessary to store a days worth of water to the family, attached to double level sink that provides an upper basin for washing of dishes 1m above the ground and a ground level platform for washing clothes. Tanks are elevated on top of a brick stand that is approximately 1m tall. Inside the tanks, ball cock float valves with an inner diameter of ½" regulate water flow.

To provide equitable water flow to each household in the village, no matter where the house is located, flow regulation to within 10% of the target household flow, 0.021L/s was forced in our design by adding headloss elements into the distribution system before the storage tanks. Extensive research into pressure regulators as a means of flow regulation was done, but it was determined that they are impractical for villages that have only a few meters of elevation difference. The design expanded further upon previous semesters work with small diameter coiled flexible tubing that greatly restricts flow. Depending on the available tubing diameters, it was found that 1m-6.7m of tubing is required at the household level to force equitable flow throughout the village.

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## Introduction

In 2013, the Indian government and the World Bank launched a campaign for water and sanitation improvement projects in low income states. The push to start this project and the backing of $1 billion signifies the importance of designing simple, efficient, water distribution systems to improve the health and sanitation of people living in rural areas. This semester, the Village Supply research team was broken into three subteams (distribution subteam, the photovoltaic and pump subteam and the household level infrastructure subteam) to tackle this problem in rural Indian villages that are supplied with water from an AguaClara filter. The teams are working on their respective areas and then exchanging their research and findings to solve the problem as a whole.

The household level infrastructure subteam is working on the delivery of clean water at the household. Design goals for the semester includes designing a household water storage tank, a float valve and a flow restriction element to ensure equitable distribution of water between all the households in the village. Additionally this team will be designing a tap and faucet system for individual households that minimizes water contamination, the spread of waste and encourages sanitary habits. This team will also design a sink or water catch system for recycling and disposing of grey water.

# Literature Review

**Construction Materials and Local Customs**

The Construction Industry in India is a booming trade that employs most of the country's population. It is the second biggest industry in India after agriculture and contributes 11% to the country's GDP.

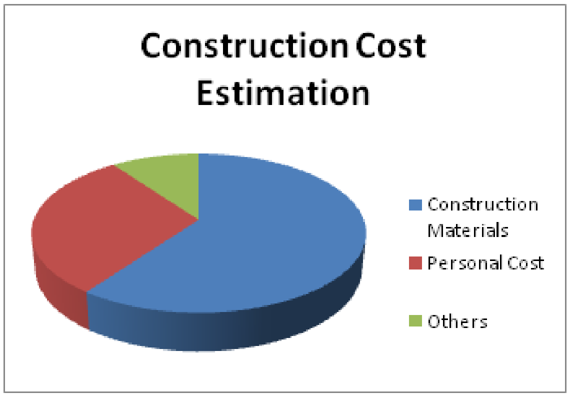



**Figure 1**. *Construction Cost Estimation*

Worldwide, India is one of the biggest producers of construction materials like cement, steel and iron. However, not all of the population has access to the best construction materials like steel and concrete for structures; plastics, fiberglass, stone, steel and concrete for water storage tanks; or stainless steel or porcelain for sinks.

These materials are too expensive for the poorer villages of Jharkhand. Most of the population in this area lives in small rural villages where the houses are made with cheap and accessible materials: wood, mud bricks, baked clay bricks, stones, adobe, bamboo, mud mortar and sometimes even cement mortar. Additionally, plastic and clay buckets are commonly used to construct sinks and water storage units.

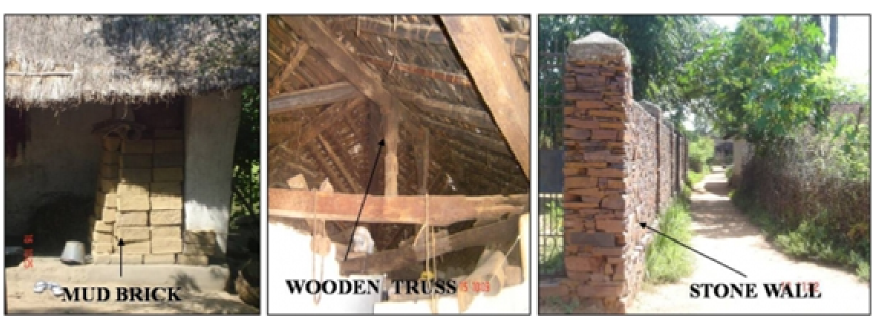



**Figure 2**: Various materials available in the market

Nevertheless, in order to create sanitary installations we may need to expand beyond local and regional materials, that are produced throughout the country. In the East-Center Zone, where Jharkhand is located, there is small scale brick, iron and steel production, and little production of aluminum.

The general costs for some materials in a New Delhi's market are listed in Table 1 below.

**Table 1:** General Materials Cost

| MATERIAL | QUANTITY | COST IN RS | COST IN $ |
|---|---|---|---|
| Cement | 1 sqf | 70 | 1.15 |
| Steel | 1 kg | 100 | 1.6 |
| Aluminum | 1 kg | 180 | 2.95 |
| Copper | 1 kg | 450 | 7.38 |
| Nickel | 1 kg | 1200 | 19.69 |
| Brass | 1 kg | 330 | 5.41 |
| PVC | 1 kg | 116 | 1.90 |

Besides these prices we would need to take into account the cost of transportation (distance, quality of roads and access to the village) in addition to the cost of labor as some materials may need specialized operators. Moreover, we should be aware of the fact that these prices are a general idea of material costs, and we will need to research the cost of specific items like taps or sinks once we have taken decisions on our design.

**Public Health**

Only a quarter of the total population of India has access to drinking water on their premises. Furthermore, 67% of Indian households do not treat the water they drink, even though lake, ocean and well water are often contaminated with a slew of pathogens and bacterial agents. Every year, over 1.5 million children under the age of five die as a result of diarrhoea - an infectious disease whose prevalence could be reduced by as much as 40 percent by maintaining sanitary hand washing habits and maintaining a household water system. While the solution of clean water may seem simple enough, many villages in India are impeded from this solution due to a lack of access to water and the work, heat and energy required to properly decontaminate large amounts of water. In rural villages such as the one in Gufu, Jharkhand water is supplied by a village water well, and residents of the village are expected to boil their water for personal use. However, boiled water is only prioritized for the purposes of consumption. Water used for bathing, washing clothes, dishes and even hands, is more often than not simply water straight from well water - largely promoting the spread of infectious diseases. Additionally, only 53% and 38% of the population uses soap after defecation and eating food, respectively. Coupled with low soap use, contaminated well water leads to poor sanitation, the rapid spread of disease and from a more macro lens, high childhood mortality. At the household level, only 11% of Indian rural families dispose of child stools safely. Often, stools are left out in the open or in the garbage, attracting insects and inviting bacterial spread.

Rural India and much of India as a whole is dependent on transporting and using water through plastic buckets or steel pots and cups *(Fig 3 and 4)*. As water isn't available at every point of need throughout a household, water is obtained from the source and then allocated to various buckets for different needs. One bucket may be used for the bathroom, while another bucket may be used for washing clothes and dishes *(Fig 8).* In rural India, clean water needs to become available not only on tap - so families may be able to use buckets of clean water for their various daily and weekly needs.

**Fig 3 *(left)* and 4 *(right)*. *(Left)*** *Plastic buckets are often used for bathing purposes in Indian culture.* ***(Right)*** *Metal pots and bins are often used to transfer water from distant locations such as rivers and and wells to households in bulk.*

An optimal household sink design would factor in the necessity of buckets in rural Indian society. The sink needs to accommodate filling large buckets to easily transport water to other areas inside and outside of the house. Namely be either constructing a deep sink basin, or allowing for a dual sink and lower tap platform.

**Grey Water Disposal**

Greywater is the water collected from bathroom and kitchen sinks, as as well washing areas. It is distinctly different than blackwater, which has come into contact with feces or other largely harmful bacterial agents. Freshly generated greywater is much safer than blackwater, but if it's not handled properly it can soon become comparably dangerous. Grey water decomposes at a much faster rate than blackwater and can become highly infectious in as little as 24 hours.

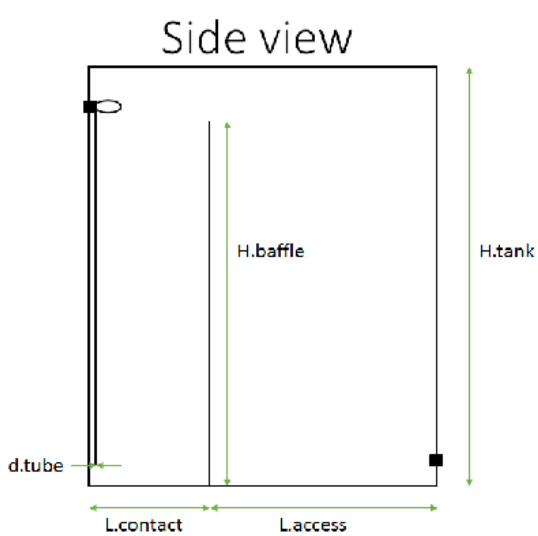
For future designs, teams may consider a tap system for toilets that reuse the grey water produced by the main household sink. Grey water recycling designs would require a chemical dose controller and a distributor (to connect the two tap systems) and would generally allow for the sanitary disposal of feces and conservation of clean water.

# Previous Work

## Fall 2013 and Spring 2014

During the Fall of 2013, students in CEE 4540 developed design ideas for a village supply system in Gufu village in India as their capstone design project. All the students approached their designs under a set of consistent assumptions about Gufu village and the water needs to a typical rural village in India. Assumptions included that the village population was 500 people, five people in a household and that each person would receive 100 liters per day. A google map of Gufu village and the location of the well supplying the village can be found through the following link.
https://maps.google.com/maps/ms?msid=213738800587733541015.0004eabfcaa56aaf724a1&msa=0

Team 2 developed a design for a household storage tank that holds 1 day of clean water plus emergency rations. They calculated the maximum water flow and the minimum flow to each house dependent on the time of the day and solar radiation. Retention time of the water and the chlorine in a storage tank is necessary because Team 2 determined that travel time of water in the pipes of the distribution system was not enough time to kill pathogens. To facilitate this, a baffle, dividing the tank into two sections is inserted into the entire tank. One section is not accessible and is where the chlorine and water come into contact with each other, the other section is where the water for household use is drawn from. Water flows over the top of the baffle after the required contact time into the accessible chamber.The contact and retention time for chlorine was calculated based on the standard AguaClara chlorine dose of 1 mg/L and a filter removal rate of 90%. The ability of the AguaClara filter to remove pathogens is important because the dosage of chlorine and contact time necessary to kill remaining pathogens can be decreased. The tanks themselves were designed to be located outside each home on an elevated platform, at no more than 95% full to avoid overflows. The tank height was restricted to below 1 meter for easy access and designed to be as close to a cube in dimensions to reduce cost. The team also designed a piezometer to allow users to see how full their tank was. Below are two figures of the tank design from Team 2's mathcad file and design write up.



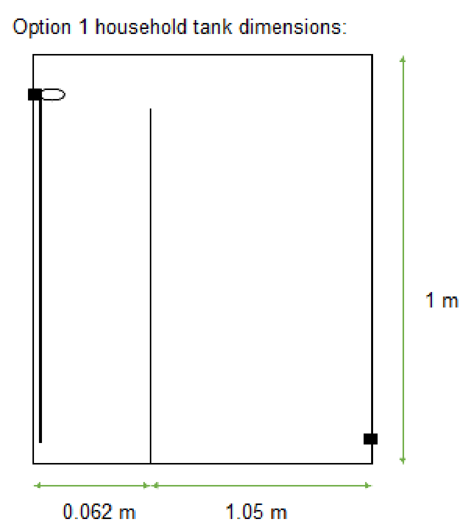




**Figure 5**. *Side View of Team 2's storage tank.* **Figure 6.** *Team 2's storage tank with dimensions*

The other 4540 team, Oceanids, completed a design project with a focus on household infrastructure. The team designed a tank with a float valve inside the tank to restrict flow and ensure equitability. The float valve included an orifice with a diameter small enough to create headloss and ensure a degree of equitability of water delivered among the households. Orifice dimensions were calculated using multiple degrees of equitability; 50%, 75%, 90% and 95%. In the end, 75% equitability was assumed to be the most optimal design based on cost versus equitability. Figure 7 provides insight into the cost of equitability; as you increase the degree of equitability, the necessary head loss increases rapidly. Due to project time constraints, other degrees of equitability were not considered.

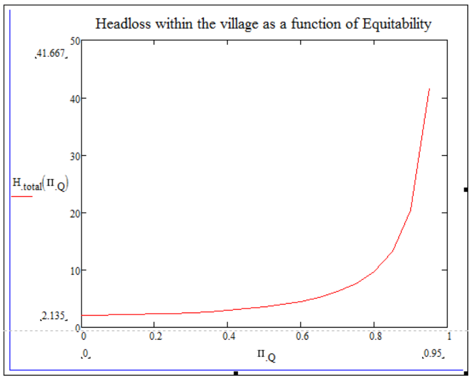
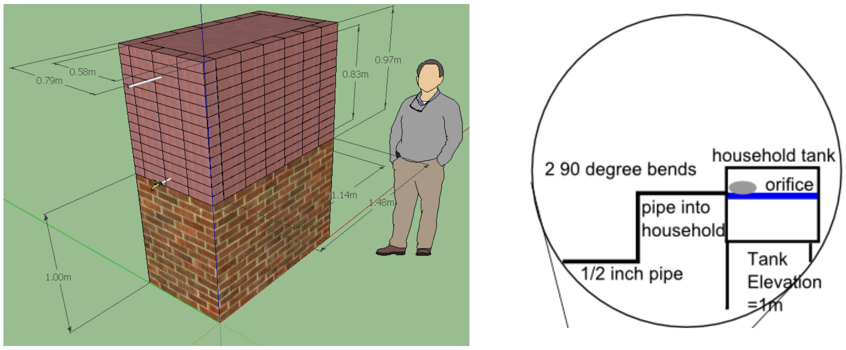



**Figure 7:** *Oceanids provided a graph of head loss versus water equitability.*

In addition, to the float valve, options that were possible for spigots/taps to allow users to access the water from the tank were considered and compared on the basis of ability to regulate flow, cost and material. The tank for water storage was designed considering the volume of water needed by each household every day(calculated using the basic population assumptions outlined above) and then increased by a factor of safety of 20%. Red brick was used for the construction material because it was researched to be locally available in India and the cost of the tank was calculated. It was unclear if other materials were considered; red brick was found to have consistent dimensions and thus aided in ease of design. A design for the piping from the larger distribution pipes into the household storage tank was also created, a picture of this pipe system is provided below. Finally, a brief discussion of drainage options for used water were discussed, including a garden, lagoon, wetlands and riparian buffers.




**Figures 8 & 9:** *(8, Left). Oceanids design of a household level storage tank, with dimensions. (9, Right). Schematic of household plumbing from distribution system.*

The AguaClara 4550 Village Supply Team from the spring semester worked mainly on designing a pipe network, optimizing costs and determining how much solar energy was available for pumps in the system. This team worked under different assumptions when calculating water flow:, the population in the village was 240 people and an equability value of 90%(so that all flows in the village were within 10% of each other). The major contribution this team made to the household infrastructure design, was the use of small diameter coiled tubing to restrict flow at each house, in place of a small orifice in the float valve. (The float valve orifice in each household storage tank still exists but are all assumed to be the same size and provide minimum head loss) This change was implemented because small orifices are prone to clogging. Varying the length of tubing at each house will create different amounts of headloss, increasing or decreasing directly with the length of tubing and ensuring an equitable flow of water to all households in the village. These coils of tubing provide easy locations for flow monitoring at each household. There is a derived equation for the length of tubing needed at each house (equation 1 and 2 in final spring semester report, see below). The length equations were derived assuming turbulent flow through the coiled tubing. Ltubing is the length of tubing necessary to dissipate the average amount of head loss at each house throughout the village. Laddition is the length necessary to add or subtract from Ltubing depending on the elevation of the house in the village. After further looking at equations 1 and 2, it is believed that there is an error in equation 1. The equation should read as equation 5, where h.f.tubing is not squared, instead multiplied by 2g (results and discussions).

$$L_{Tubing} = \frac{g * h^2_{f.tubing} \left(\frac{\pi D^2_{Tubing}}{4}\right)^2 * D_{Tubing}}{f * Q^2_{Tubing}} \quad \textbf{(1)}$$

$$L_{Additional} = \frac{g * |Elevation_{House} - Elevation_{In}|^2 * \left(\frac{\pi D_{Tubing}^2}{4}\right)^2 * D_{Tubing}}{f * Q_{Tier3}^2} \quad \textbf{(2)}$$

# Methods

**SINK AND TAP SYSTEMS**

*Research largely obtained through Maysoon Sharif and her advice and insight on current systems at AguaClara India.*

**Sink Design:** Currently sinks and taps in India do not have particular size constraints as the systems are located outdoors and contain suspended taps that empty out onto a concrete platform. These platforms are designed to have a slight angle so the water is able to drain into a corner of the platform where it is then allowed to run off into nearby agriculture, or is collected in a steel pot to water nearby grass or kitchen gardens that may be further away.

Though current sink designs are located outside due to the often uneven dirt floors inside village households, current and future designs should work to create large uniform platform basins inside the household compound with a material that is considerably easier to disinfect - namely stone or steel. Though the team originally considered a basin design, village households require flat designated areas to clean clothes, which would leave families struggling to complete this weekly, possible daily task with a basin.

Often times the current concrete platform is used for almost all household tasks involving water - namely dish washing and clothes washing. Outdoor platforms allow for the accumulation of dirt from not only food and clothes, but debris, dirt and bacteria. Additionally, the porous nature of concrete not only creates an environment for bacteria to accumulate between ridges, but is also a surface that is incredibly hard to clean *(Figure 10 and 11)*.

**Fig 10.** ***(Left)*** *In the current platform design in place, water flows directly from the platform to surrounding agriculture.* **Fig 11.** ***(Right)*** *In other platform designs, a divot in surrounding soil allows water to flow from the platform to slightly more distant agriculture.*

Ideally, a flat and disinfectable platform located under the tap and within the household compound will allow for a system that is optimally fit for public health standards within societal considerations, as well as a system that is easy to use and fits well into the lifestyles of families in the villages of Jharkhand.

**Grey Water:** Water from the platform in the compound should drain into a pipe that connects the inside of the compound to agriculture outdoors. Water should not be stored into an additional tank, but rather immediately disposed of to avoid the need to disinfect the greywater in order to prevent the transformation into black water. Space should be left below the output of the pipe to allow for a bucket to collect the grey water for agricultural use, or the water could flow directly into a garden if it is located adjacent to the household. As most village households do not have toilets, it would not be feasible to collect the grey water for stool disposal. Toilets often have a small tap that when turned on fills a bucket that locals use to clean their bodies and flush the stool either down a hole or away from the area. Clean tap would be best for this toilet system, as the water is coming into direct contact with the users bodies and genitals.

For much of India's history, and for many Indians today, women have relied on travelling to the nearest river to wash their clothes. They would soak, soap and scrub repeatedly against a nearby rock to achieve maximum abrasion. As rocks were never located comfortably by a body of water and at a higher elevation, it quickly became habit to squat down to clean; a habit that hasn't truly left.

Presumably, the concrete platform was adapted due to this habit of staying low to the ground and scrubbing against a hard surface for maximum friction. However, the process of cleaning under these circumstances requires strenuous movements and is more physically demanding.

Outside of western innovation, after questioning a small sample size of the larger Indian population, it was found that the duality of having both elevated and nonelevated cleaning systems may allow for optimal comfort and preference. The Indians questioned preferred washing dishes at an elevated level, as the process does not require excessive scrubbing, but still preferred squatting down to clean clothes.

To accommodate preferences, it appears best to preserve the platform design - but create a connected elevated structure containing and sink and basin. If space allows, a small washboard should be built into the elevated concrete, adjacent to the basin, to allow for one to complete small washing tasks without the need to squat. Furthermore, the washboard may even provide elderly home makers with a more comfortable option. The elevated faucet should be no more than one meter above ground level, and thus the storage tank should be built no more than one meter above ground level was well. The faucet pipe should divert the water to two sources: the upper basin and the lower platform tap system, allowing water to be released at the turn of the spigot.

A suggestion for fieldwork continuation involves conducting surveys amongst the people of Jharkhand to more effectively and appropriately determine the desired cleaning system.

**PRESSURE REGULATORS**

Normally, water has fluctuating pressure due to the conditions of the system (the pump does not maintain the same pressure, there are periods with no water coming to the house, etc.). This pressure needs to be controlled and kept within a range in order to protect the plumbing appliances, pipes and conduits, and avoid damages. However, in Jharkhand a pressure regulator would ensure that every household would get the same water pressure and indeed would make possible an equitable distribution of the water.

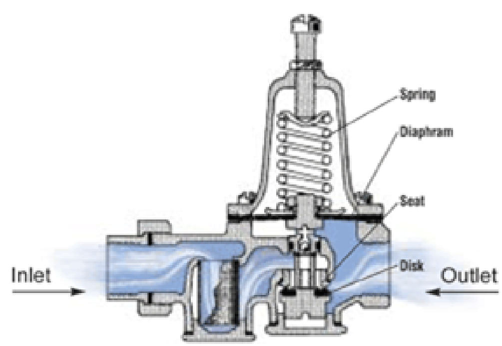



**Figure 12:** *Schematic of a pressure regulator*

A pressure regulator is a plumbing valve used to control the water pressure coming from water supply lines or storage tanks to a safe and/or usable pressure in a household. High water pressure is not only really uncomfortable for household use, but it could cause huge plumbing problems. On the other hand, low pressure does not allow proper use of the water in a household.

This device includes:

- A restricting element: valve that provides variable restriction to the flow (disk, plug, globe valve, butterfly valve…). It can be fully open, fully closed, or somewhere in between to control the amount of flow. When it is fully closed, it acts like a shutoff valve.
- A loading element which provides the force to the restricting element through a weight, a spring, a piston actuator or a diaphragm actuator in combination with a spring.
- A measuring element is usually a flexible diaphragm that senses downstream pressure; it helps determine when the inlet flow is equal to the outlet flow.

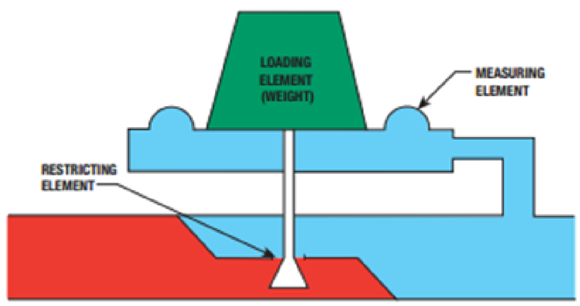



**Figure 13:** *Simplified schematic of a pressure regulator*

There are multiple classifications, for example we can differentiate between single and two stage regulators.

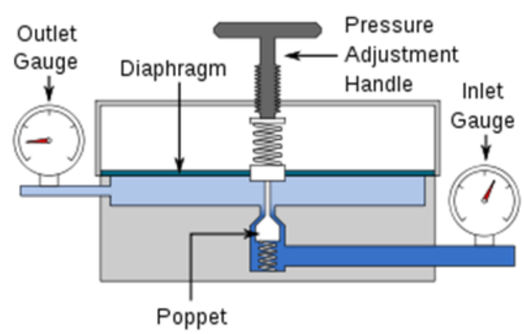



**Figure 14:** *Single Stage Regulator* outlet side.

<u>Single stage regulator</u>: high pressure fluid from the supply enters through the inlet valve to the body of the regulator, which is controlled by a needle valve. The pressure raises pushing the diaphragm, closing the valve

attached and preventing more fluid from coming in. Now the pressure is adjusted inside the device.

The spring pushes the diaphragm in until we reach the equilibrium between the outlet pressure and the spring. Therefore, the outlet pressure depends on the spring force (adjustable).

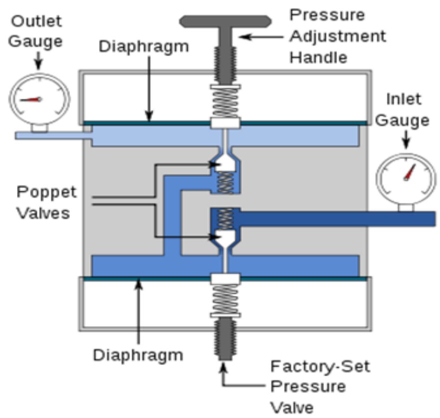



**Figure 15:** *Double Stage Regulator*

Double stage regulator: Two single stage regulators in one, reduces the pressure in two stages.

Another possible classification would be: direct-operated regulators, simplest regulator which is used when there is not a high flow rate *(Fig 16)* and pilot-operated regulators, preferred for high flow rates or where a lot of precision is needed *(Fig 17)*.

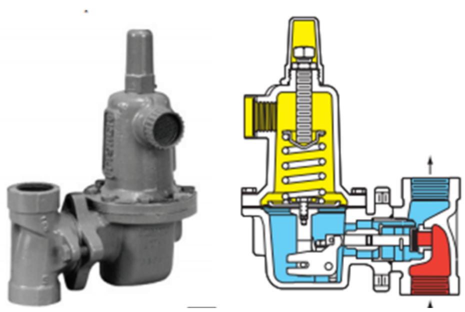


**Figure 16**: Direct operated regulator

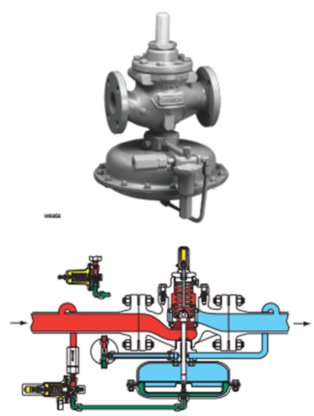


**Figure 17**: Pilot operated regulator

The prices depend on many characteristics and specifications that you can choose for your pressure regulator: the quality, material, size, capacity, size of inlet and outlet, low lead compliant (required), the temperature they can get to, the pressure they need to create, etc. A normal price range would be from $10 to hundreds of dollars. Our design would try to combine the best characteristics with the most affordable price.

The normal location for this device is outside of the house, where the main water line comes in, along with a cut off valve. Therefore, in our design the pressure regulator is located in a safety box (precautions for weather conditions and robbery) along with the coiled tube; where the distribution system reaches the storage tank. The box should have some kind of secure access and a shut off valve (in case we need to control the state of the device or to shut the water to fix the line).

As for the pressure to which we will adjust the regulator, we would need to do some calculations taking into account the amount of water that will get to each household, the frequency and the actual pressure that a normal household would need. A normal house has its pressure set around 45 psi but could estimate that a pressure of 40 psi or less would be enough. We would need to review the value if the device is going to work for multiple households.

# Results and Discussion

**FLOAT VALVES**

For the household water storage tanks, float valves are necessary in each tank to regulate the amount of water coming into the tanks, relative to the amount of water coming out. After discussions with May Sharif, the AguaClara engineer in the field, ball cock valves are most realistic flow regulating systems available for use in India. A ball cock valve is the same constant head system that is found in the back of toilets, both here and in India. However, currently there is no type of flow regulation in India, whatsoever. Thus, our decision on which type and brand of ball cock valve to use should include ease of use and maintenance, as well as cost. Below is Figure 18 of the typical ball cock valve system found in the back of toilets. Figure 19 is a picture taken from Zeal Engineers’ website of a typical ball cock valve available for sale in India, used in water tanks. These float valves range in size from ¼” to 4” British Standard Pipe, and the orifice size used for flow regulation also varies. Figure 20 is the recommended float valve for use in the household storage tank, made from US plastics.

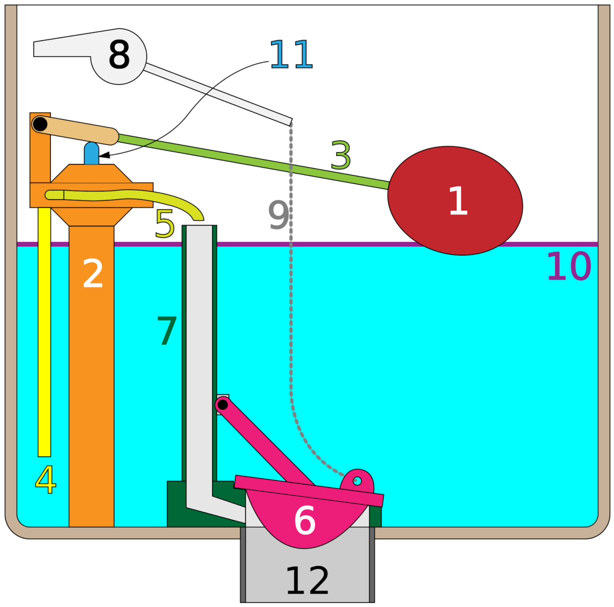



**Figure 18:** *Typical ball cock valve found in toilets in the United States and India. Includes a ball float and plunger attached to a chain.*


**Figure 19:** *Zeal Engineers Ball Cock Valve, used for water tanks.*

**Figure 20:** *PVC Float Valve from US Plastics.*

A practical float valve choice is from US Plastics, part #23184. It is a pvc float valve with a ½ inches tank mount (the pipes coming into the house are this size), a 3 inch rod, a 4x5 inch oval ball and a 0.25 inch orifice diameter. The maximum flow rate that could provide at a 20 psi pressure is 0.47 L/sec which is quite over our desired of 0.021 L/sec. We used USP as the provider for our valve and found there that the price for each of them would be around $22.

**FLOW RATE**

The flow rate that the plant can provide for the tank and tubing designs assumes 500 people in Gufu Village, 100 households, 5 people per household and a pump that runs 8 hours a day when there is sunlight. Each person consumes 100L of water and there is a factor of safety of 20%, making the water demand of each villager 120L/day. The factor of safety is applied to the flow rate, resulting in the required flow to deliver 600L per water to a household every day. The tank volume is then adjusted to accommodate this increase in water. Applying the factor of safety to the tank volume would not result in the desired flow rate to deliver enough water. This results in a Qplant = 2.1 L/s, thus a flow rate of Qhouse = 0.021L/s at the household level.

**EQUITY CONSTANT,** $\Pi c$

The end goal of the village distribution design is to achieve equal flow distribution at each household, as close to Q.house as possible. This can be achieved by creating an equity constant $\Pi c$, which acts as a parameter to force all flow rates within a certain percentage of the average flow rate, and defines the headloss necessary to do this. Ideally the equity constant would be as close to 1 as possible, so all households were getting the same water flow. However, when equity becomes closer to 1, more headloss is necessary in the distribution system. 80% percent equity was decided on as acceptable throughout the village. This means that the minimum flow reaching the houses is 10% less than the average flow and the maximum flow is 10% more than the average. From the equity curve, Figure 21, it can be seen that $\Pi c = 0.8$ is where the headloss curve begins to increase its slope upwards but is still in an affordable realm.

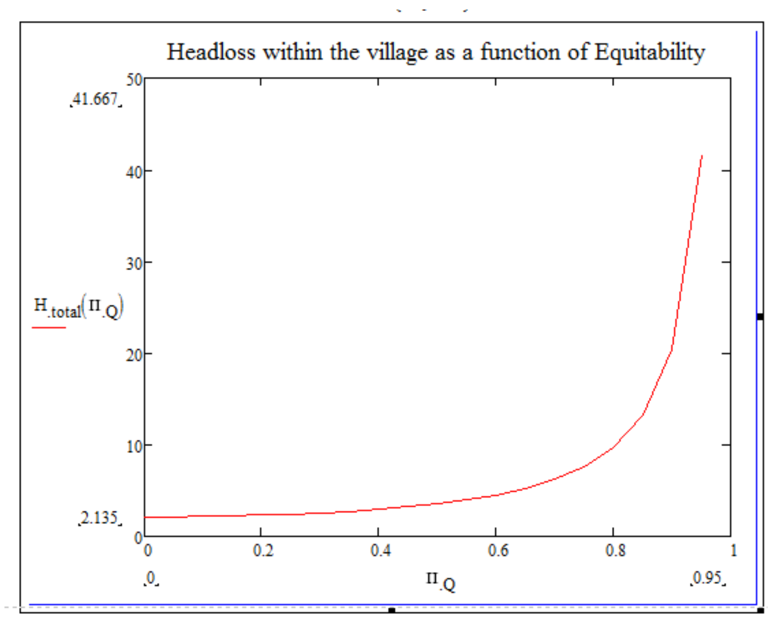



**Figure 21.** *Distribution system headloss versus equity.*

**HEAD LOSS**

Head loss within the household infrastructure is necessary to ensure equitability of flow between all the houses in the village and acts as a regulator for the flow. Head loss occurs at the orifice of the ball cock float valve that is regulating the water level in the storage tank. The orifice will not be a large source of headloss, so it cannot be depended on to be the only flow regulator at the household level. It is practical to use the diameter that is manufactured by the valve company and calculate the headloss based on the given orifice diameter, rather than calculate a desired diameter and then manufacture what is needed. The equation for head loss through an orifice is defined below as h.orifice, with the vena contracta through an orifice Pi = 0.62.

**(3)**

$$h_{orifice}(D, Pi_{VenaContractaOrifice}, Q) := \left(\frac{Q}{Pi_{VenaContractaOrifice} \cdot A_{circle}(D)}\right)^2 \cdot \frac{1}{2 \cdot g}$$

h.orifice = 0.057m in headloss, using the above equation, the household flow rate of 0.021L/s and an orifice diameter of 0.25 inches or 0.00635 meters.

Head loss also occurs through the 90 degree bends in the pipes entering the house. Figure 22 below was taken of the tap and pipes currently in use in India and shows two 90 degrees bends that water has to travel through from buried the distribution system and the tap itself. The head loss through 90 degrees bends is general minimal, but can be calculated from equation 4, where K=0.90 for a 90 degree elbow.

$$h_f(Q,D,L,\nu,\varepsilon) := f(Q,D,$$

**(4)**

The headloss through 2 ninety degree bends and the household level piping with d.pipe =0.5in is 0.0025m.

**Figure 22:** *Pipe from distribution system and tap, including two 90 degree elbows.*

There is also an elevation difference from the buried pipes to the float valve in the water storage tank. Currently the tank design is 1.94m tall, H.tank. Very small head losses will also result from shear on the walls of this pipe leading up to the storage tank, equal to 0.006m. Compared to the losses being created by the coiled tubing, this is minor.

Flexible tubing is available in India and could be connected to the distribution system with brass barb fittings. The threads of the barbs have to be 1/2'', however the barb size could be almost anything, giving greater flexibility in the size of tubing that can be used. The coiled tubing is to be located in street level boxes outside each house compound. It is unrealistic to have one box at each household with coiled tubing because each box would have to kept under lock and key as to not be tampered with. As a result, it is suggested to design a central box near a cluster of homes that contains multiple coils, so the water operator can inspect the boxes and keep track of minimal keys.

**Fig 23.** Brass barb

The additional head loss in the system necessary to equalize flow is found in the coil of flexible tubing located between the distribution system and the household water storage tank. The Spring 2014 AguaClara team derived equations for the length of flexible tubing necessary to provide the average headloss to equalize flow at each point in the distribution system (See equation 1.) However, after looking further into this equation, there was a reporting error and the length of the coiled tubing is actually defined by Equation 5, where the head loss term is not squared, instead multiplied by 2g.

$$L_{Tubing} = \frac{2g * h_{f.tubing}\left(\pi \frac{D_{Tubing}^2}{4}\right)^2 * D_{Tubing}}{f_{factor} * Q_{Tubing}^2}$$

**(5)**

Coiling will produce different frictional effects in the tubing (Tse et al, 2011) thus a correlation factor is used to correct for the difference. Headloss through a straight tube assuming laminar flow is defined by the equation: $h_L = f_s \frac{L}{d} \frac{U^2}{2g}$ **(6)**, with a Reynold's number of $Re_d = \frac{Ud}{\nu}$ **(7).** The correlation factor $\frac{f_c}{f_s} = 1 + 0.033 \log(De)^4$ **(8)**, fc, can be used to replace fs in the head loss equation that describes losses in a straight tube, to correct for the differences in the curved tube. Due to time limits this semester, the effect of coiling on the friction factor still needs to be added into the calculation of the length of tubing.

To determine roughly how long the coiled tubing at the household should be, the entire headloss necessary to obtain maximum and minimum flows within 80% of each other, through the system, is needed. This includes both the distribution system losses and the household losses. At the end of the semester, there was not enough time to integrate the mathcad code between the distribution team and the household team, so basic estimates of the necessary parameters were made to get a rough idea of how long the tubing should be made.

The total head loss equation, Equation 9, from the Oceanids fall 2014 design was taken and adapted to the information from the distribution team. The distribution team reported that they calculated 2.8m of head loss through the distribution system, the majority of this from elevation differences from the maximum and the minimum house. Compared to the elevation difference, head loss due to shear on the pipe walls(h.Lvillagemax in equation 9) is relatively minimal; the value calculated by the Oceanids team for 1km of piping was 0.01m. As a result, the total headloss equation used a very small number for the loss due to the pipe walls, 0.05m and 2.8m as the elevation, h.elevation.

$$H_{total}(\Pi_Q) := \frac{-0.5h_{Lvillagemax}\cdot\Pi_Q^{2} - 0.5h_{elevation}\cdot\Pi_Q^{2} - 0.5h_{Lvillagemax} - 0.5h_{elevation}}{\left(\Pi_Q^{2} - 1\right)} \tag{9}$$

With a $\Pi c$ =0.8, the Htotal=6.5m. From here, the total head loss equals the headloss through the distribution system, plus the head loss at the household level. Again, the distribution team says there was 2.8m of head loss in the distribution system, so there needs to be approximately 3.7m of headloss at the household level. While all of this is educated estimation, these numbers allowed us to set up a mathcad code and determine approximate tubing lengths. All inputs in the code are variable and able to change to reflect when the distribution system and household level codes are joined.

Knowing the total headloss needed, H.household, at the household level, equation 10 was developed. The desired household flow rate of 0.021L/s was used in all terms; the only unknown is now the length of the tubing, and the diameter, which can be chosen to determine the length. The h.major term is calculated based on the shear of the ½" pipe walls leading the 2m into the storage tank and is .006m, as outlined above.

$$H_{household} = h_{f.tubing} + h_{orifice} + h_{bends} + h_{major} \quad \textbf{(10)}$$

$$h_{f.tubing} = f_{factor}\left(\frac{L_{Tubing}}{D_{Tubing}}\right)\frac{\left(\frac{Q_{Tubing}}{A_{Tubing}}\right)^2}{2g} \quad \textbf{(11)}$$

The terms were all rearranged to calculate the length of the tubing based on standard tubing inner diameters from McMaster-Carr. The tubing diameter had to be less than 0.5in, or the diameter of the pipe leading to the household level to produce the desired amount of losses in a small amount of tubing. The length results are tabulated below for 3.7m of headloss at the household.

**Table 2**. *Calculated lengths of flexible tubing*

| **3.7m of Headloss at Household** | |
|---|---|
| **ID of Plastic Tubing** | **Length of Tubing** |
| **1/4" = 0.0064m** | **25.9m** |
| **3/16" = 0.0048m** | **6.68m** |
| **5/32" = 0.004m** | **2.82m** |
| **1/8" = 0.0032m** | **0.98m** |
| **3/32" = 0.0024m** | **0.25m** |
| **1/16" = 0.0016m** | **0.035m** |

**TANK DESIGN**

It has been determined that an ideal tank size is 600L of water at the household level. 600L provides a family of five with 120L per capita of water each day (20% factor of safety built into the flow rate, a happy person needs 100L of water per day). Original designs had the tank being constructed out of brick or concrete, a construction material that can be made locally and is very common. While brick or concrete is still an option, discussions with AguaClara LLC engineers in the field suggested using high density polyethylene (HDPE) drums as water storage tanks, instead of building out of brick. The recommended, most common, brand is Sintex, an Indian plastic company based in Kalol, Gujarat, that makes cylindrical, vertical, water storage tanks in a range of volumes and dimensions. The tanks also include manholes for easy access for cleaning. By choosing the HDPE drums, it allows opportunity for households to increase the volume of water they're storing at their home if the household grows in size, without rebuilding the water storage tank. A price quote has been requested from Sintex for water storage tanks like the one seen in the figure below, multiple times, with no response.


**Figure 24.** *This is a an example of a water storage tank on the Sintex website.*

Sintex provides dimension information and the volume options for their tanks in a pdf form on their website, so there is opportunity for families to upgrade their tank sizes easily (http://www.sintex-plastics.com/pdf/building_&_construction/sintex_water_tanks.pdf: also an image in the appendix). Families can upgrade to 750L volume tanks until the diameter of the tanks became larger (1000L, diameter =1.1m) and stands need to be adjusted to accommodate larger tanks.

Since these tanks come pre-fabricated, it is necessary to fabricate the stand to put them at a higher elevation for free flowing water from the taps. The stand needs to be wide enough to accommodate the diameter of the cylindrical water tank. A Sintex 600 L tank has a diameter of 1.04 m, thus the top of the stand needs to be at least 1.04 m wide and 1.04 m long, but in reality wider than this to factor in expansion of the tank size and stability. Sintex 600 L tanks are 0.905m tall.600 L of water weighs 600 kg, approximately 1320 lbs. In addition, the HDPE tank will also have a weight (~100kg) that needs to be supported by the elevated stand. When considering both cost, available construction materials and stability for fabricating an elevated stand at each household, a brick structure seems to be the most practical. The stand will be built at ground level with four brick walls forming a closed rectangle. The dimensions of the width and length need to be greater than 1.04m, with room for a bigger tank if necessary. Using standard brick dimensions, the length of the stand will be 1.14m and the width of the stand will be 1.25m. The height of the stand can be adjusted with additional layers of brick, but with 15 layers of brick, the height of the stand will be 1.035m. The original design chose 1 m for the height of the stand as a reasonable number for a sink level. However, in the field, the height of the stand, and thus the bottom of the tank and tap, can be raised or lowered with additional layers of brick based on the families preference.

From here, there are two options for supporting the tank on top of the brick walls. Three wooden planks can be put across the brick walls with a layer of plywood on top that covers the entire brick structure. Lumber yard 2x4 planks should be able to support the weight of an approximately 700kg container. However, since the grade of construction material in rural India is unknown, it is recommended that the inside of the rectangular stand be filled with a fill, such as dirt or gravel and then bricked over the top layer. This is a very stable arrangement and would be to support the weight of the water storage tank.

To build the stand (at the current dimensions) and brick over the top, 170 bricks are necessary . Bricks cost approximately $100/1000 bricks, so the cost of such a stand would be $17 for the bricks, plus additionally for labor and fill. All things considered, this is a very inexpensive option for elevating the storage tank. The figure below (Fig. 25) provides a scaled view of the tank design done in Sketchup. The Mathcad file that details all of these designs can be found on the google drive under the file name “*village supply household infrastructure edit1.xmcd”.*

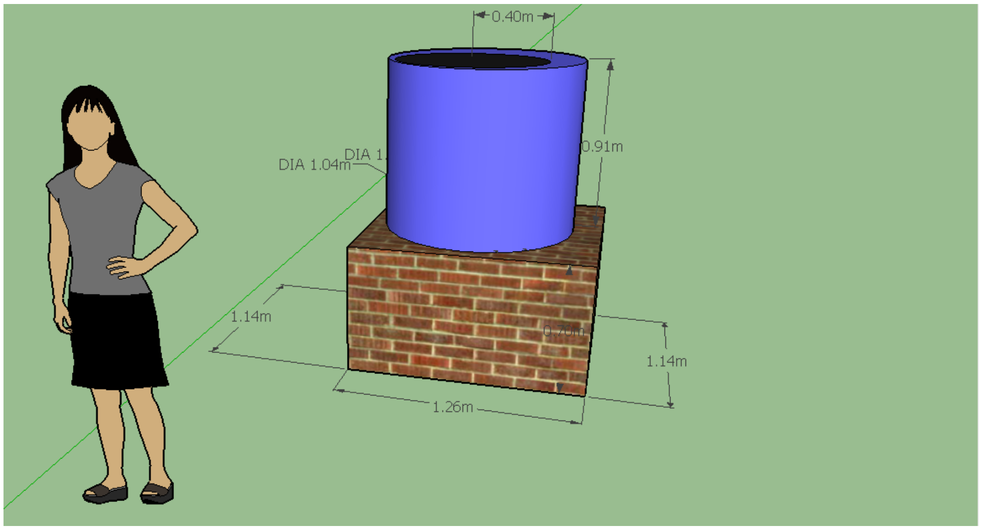


**Figure 25:** *Scaled model of current tank design in sketchup. Brick base with HDPE water tank on top.*

**SINK DESIGN**

According to information provided by Maysoon Sharif in the Gufu Village there are no set dimensions for the current sink design in place. Though some designs have platforms for washing dishes, filling buckets of water and cleaning clothes, as of now not all of the tap systems are equipped with areas for these tasks. Though there is room for a bucket under the current tap, often the lack of space forces families to continuously wash their dishes in the same container of dirty water - creating a large contamination issue.

When designing the system, we evaluated not only daily water related tasks but the current need to crouch down multiple times a day to simply access water. Additionally, we considered the runoff of water from the platform to nearby agriculture and aimed at creating a means to more conveniently supply water to greater areas of land.

The new proposed design for the sink and tap system consists of a dual platform and elevated sink. This design allows individuals to access drinking water easily from the elevated tap, and gives those who prefer to wash their dishes from a standing position the ability to do so. However, the design also allows those accustomed to more traditional washing methods (ie “squatting”) to do this daily chore on the platform. The design also allows for versatility in the way individuals choose to wash their clothes. The large platform area allows for two or more clothes to be washed at once, and eliminates the need to transport water to a separate area for this chore. A smaller washboard is built into the elevated portion of the system to the left of the sink to allow individuals who are more comfortable washing clothes while standing to do so.

Roughly half of the platform is flat to provide a comfortable even surface to stand on when at the sink, while the other half is slightly tilted downwards. The left and bottom edges of the platform are to be lined with open piping (not displayed), adjacent to the slanting primary structure, to allow for water to collect into a small pipe in the bottom left corner that is approximately one foot above ground level. Ideally, individuals may place a bucket under the pipe containing the aforementioned grey water to collect water that may potentially sustain a village garden.

Figures 26 and 27 located below, the small box atop the elevated platform indicates the lower tap system, while the upper tap is expected to be directly above the sink basin. Lastly, a step should be constructed to the right of the system to allow for easy access on and off the platform.

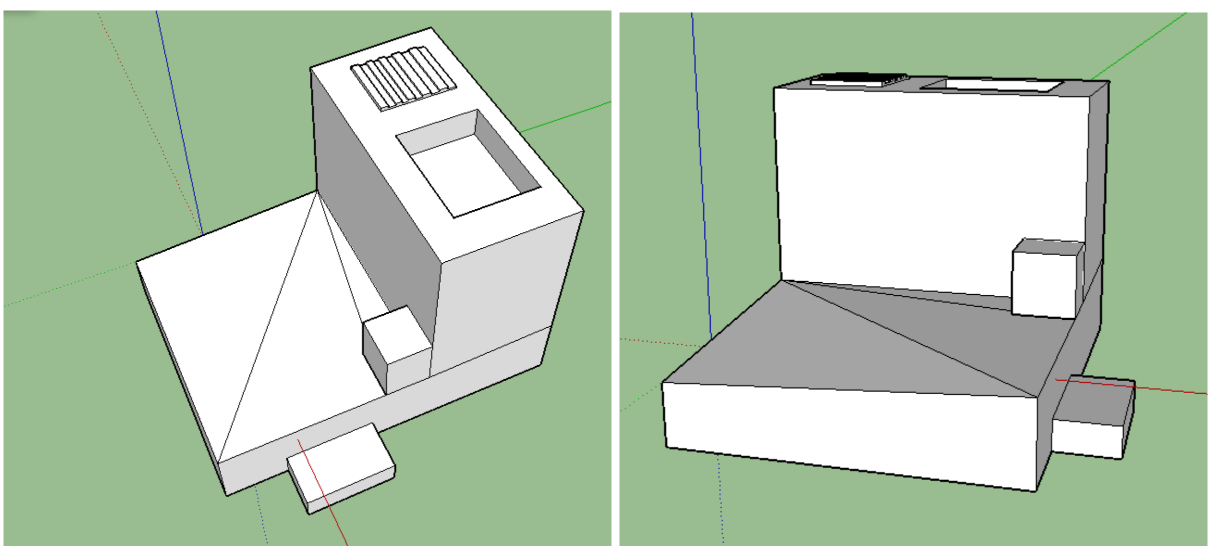


**Fig 26** ***(Left)*** *Birds eye view of the proposed sink system consisting of an elevated sink and washboard, and a lower platform and tap for more traditional use.* ***27 (Right)*** *Frontal view of proposed sink design.*

As suggested by May, stringent dimensions for the design would be impractical to determine as each system would have to be altered for the household specifications. However, roughly, the design would have to ensure approximately a foot of room below the tilted portion of the platform to allow for consolidated grey water collection, and would need to have an elevated portion approximately one meter above the platform to allow for comfortable dish washing. The primary source of water flow to the sink would be diverted to both the upper and lower tap systems. Lastly, though typically behind the stink, the position of the storage tank will vary from household to household based on the available area outside and in between households.

## CONCLUSIONS

### PRESSURE REGULATORS

With reference to the pressure regulators, after several discussions, the main conclusion is that this device is very useful in very steep villages or places with a high change in elevation. However, for the Gufu village we are not going to include them in the design due to the relatively flat terrain.In that case, the best option is purchase the pressure regulator from an Indian company because it would be cheaper than an international company.

**Figure 28 (right):** *Example of pressure regulator that would fit our design.*

The pressure of the water coming in would be determined by the Distribution Team, we only could regulate the pressure that would go into the coiled tubes. After some research, the appropriate pressure would be around 30 psi. As for the size, we would establish a size of ½ or ¾ inch. We decided to choose a relatively small size because, in case that the Distribution Team picks a bigger size, we can always create a reduction pipe between both systems. The materials that we would recommend are a combination of plastics and metals to make the price as low as possible. The price would depend on availability of the devices in India but we estimate that it would be around $40.

With reference to the type of pressure regulator, after considering the conditions, one-stage pressure regulators are definitely enough for this project and the best option would be one with a handle and a pressure indicator so the adjustments are easier and faster for the operator in charge of the controls.We considered a homemade pressure regulator, however, we realized that it was not feasible.

In order to create the necessary head loss to control and regulate the pressure coming into the house level system we would need to create a device with several tubes, some of them more than three meters high, which would not be likeable idea to install.

**SINK DESIGN**

After researching the current standards of sanitation and methods of cleaning, it was determined that a revised sink design would allow for optimal comfort, versatility and health. The new sink design contains an elevated portion with a built in washboard and sink basin for small clothes washing and basic dish washing - eliminating the need to kneel while conducting daily chores. However, due to the comfort in tradition, the system also contains a platform for traditional clothes washing methods with an associated tap. The sink has a sloping platform to allow grey water to flow into bucket that can be used to sustain surrounding agriculture.

**FLOAT VALVE**

A good choice for the float valve used inside of the storage tanks is from US Plastics, part #23184. It is a PVC float valve with a ½ inches tank mount,, a 3 inch rod, a 4x5 inch oval ball and a 0.25 inch orifice diameter. The maximum flow rate that the valve provides is 0.47 L/sec, at 20 psi pressure which is quite over our desired of 0.021 L/sec. An individual valve costs $22, if more are ordered at once, the price falls.

**STORAGE TANK**

The household level storage tank will be an elevated HDPE plastic water storage container, 600L in volume, to provide the average household with enough water a day. By using HDPE tanks, there is room for upgrades in size and the tank material provides a very hygienic environment to store water. Sintex Plastics sells these tanks and provides them in a wide range of sizes. The platform to elevate the HDPE tank, will be constructed out of bricks, a common material in rural villages. The bricks will make up four walls, and then it is suggested that the inside be filled with dirt or a rock fill and then the top bricked over, to create the most stable stand. The dimensions of a stand built to hold a 600L tank, using standard brick dimensions, are 1.14m in length, 1.25m in width and 1.035m high with 15 layers of brick.

**COILED TUBING**

To create the necessary 3.7m of headloss to equalize flow in the distribution system, a range of lengths of tubing were found, using standard tubing inner diameters from McMaster-Carr. Very small diameter tubes resulted in very short lengths, while larger diameter tubes resulted in longer lengths, which is intuitive. The most realistic inner diameter tubing to use would be 3/16”, 5/32” or 1/8” which result in lengths of 6.68m, 2.82m and 0.98m, respectively. These are manageable amounts of tubing to store in a box at the street level, however, the 2.82m or 0.98m may be most desirable, but it all depends on the available materials.

## Future Work

In order to make more finalized decisions regarding sink design, we need to know the opinion of the population of the village. We suggest doing a survey asking about different design options that would be desirable for the sink. The designs that we have proposed are realistic and feasible but we cannot choose without the input from the village. Moreover, the survey could include questions about the greywater namely how the villagers would prefer handling it, and how they would like it stored. Once all of this information is gathered, a more customized sink design can be chosen. Additionally, water from the sink could be more efficiently recycled for purposes other than agriculture, again, depending on the needs of the villagers. As we have already researched and discussed the use and storage of grey water, a potential next step would be to integrate this information into the household infrastructure.

Future teams also need to determine how to best regulate flow and create headloss throughout the village. This semester the team considered coiled tubing, an elevated household storage tank (~1-2m), and a float valve orifice to do so. However, the equity design at the household level is highly integrated into the distribution system subteams’ design and the two codes that have been developed this semester must be integrated to arrive at an optimal solution. Estimations of losses through the system can give us a general idea of design specifications, but connecting the codes will turn estimations into justifiable numbers.

Once this is completed, and flow rates throughout the distribution system are determined, the pump subteam will know the optimal pump to use. The code developed this semester also needs to be generalized; the equations need to apply to any village, not just the example village, Gufu, that we are given information for. The design needs to be more flexible; more easily scaled up and down.

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Village Source to Environment. Spring 2014 AguaClara Team.

AguaClara Code: Fluids Functions. Mathcad.
AguaClara Code: ExpertInputs. Mathcad.

# Appendix

## SINTEX WATER TANKS

**RANGE & SPECIFICATIONS:**

Series CCWS Cylindrical Vertical Tanks with Closed Top

| Code No. | Capacity (Litres) | Dimensions (mm) | | |
|---|---|---|---|---|
| | | Dia. | Height | Manhole Size |
| CCWS 20.01 | 200 | 740 | 605 | 280 |
| CCWS 27.01 | 270 | 740 | 755 | 280 |
| CCWS 30.01 | 300 | 740 | 870 | 280 |
| CCWS 37.01 | 375 | 860 | 765 | 280 |
| CCWS 40.01 | 400 | 860 | 865 | 280 |
| CCWS 50.01 | 500 | 1030 | 740 | 400 |
| CCWS 50.02 | 500 | 910 | 960 | 400 |
| CCWS 60.01 | 600 | 1040 | 905 | 400 |
| CCWS 70.01 | 700 | 1030 | 1080 | 400 |
| CCWS 75.01 | 750 | 1030 | 1100 | 400 |
| CCWS 100.01 | 1000 | 1100 | 1225 | 400 |
| CCWS 150.01 | 1500 | 1350 | 1265 | 400 |
| CCWS 175.01 | 1750 | 1390 | 1350 | 400 |
| CCWS 200.01 | 2000 | 1350 | 1600 | 400 |
| CCWS 200.02 | 2000 | 1410 | 1570 | 450 |
| CCWS 250.01 | 2500 | 1500 | 1720 | 450 |
| CCWS 300.01 | 3000 | 1500 | 2020 | 400 |
| CCWS 400.01 | 4000 | 1800 | 1850 | 510 |
| CCWS 500.01 | 5000 | 2000 | 1940 | 510 |
| CCWS 500.02 | 5000 | 2000 | 2000 | 940 |
| CCWS 600.01 | 6000 | 1800 | 2730 | 510 |
| CCWS 600.02 | 6000 | 2000 | 2200 | 510 |
| CCWS 750.01 | 7500 | 2000 | 2880 | 510 |
| CCWS 1000.01 | 10000 | 2000 | 3650 | 510 |
| CCWS 1000.02 | 10000 | 2550 | 2480 | 510 |
| CCWS 1500.01 | 15000 | 2550 | 3550 | 510 |
| CCWS 1500.02 | 15000 | 3000 | 2800 | 510 |
| CCWS 2000.01 | 20000 | 2550 | 4600 | 510 |
| CCWS 2000.02 | 20000 | 3000 | 3320 | 510 |
| CCWS 2500.01 | 25000 | 3000 | 4050 | 510 |