Engineers Without Borders

La Ceiba Project Report

Rowan University

Fall 2007/ Revised Spring 2008
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Abstract

The town of La Ceiba in rural El Salvador is home to 465 people, nearly all of whom get their drinking water from shallow, hand dug wells. These wells are unprotected from the environment, and are contaminated with fecal coliform bacteria. Rowan University's chapter of Engineers Without Borders is currently working with this community to help the residents obtain clean drinking water. In this report potential alternative solutions are described and evaluated. Each alternative is described in detail and the pros and cons of each are discussed. General sizing and cost estimates are given, and each possible solution is rated based on the most common criteria for design. Finally, a matrix is generated which is used to choose the best design solutions for the people of La Ceiba. It was decided that the two best solutions to present to the people of La Ceiba were (1) a distribution system that included 15 community spigots and (2) providing each household with a biosand filter. To add to the effectiveness of future visits, it was also decided to educate the community residents regarding the correct use of Puriagua chlorine tablets and solar disinfection.

Introduction

Engineers Without Borders at Rowan University is designing a clean water system for the rural community of La Ceiba, El Salvador. This town is home to approximately 465 people. The main sources of water for the residents of La Ceibaare shallow, hand-dug wells by their homes and a river that runs through the town. The drawback of the wells and the river is the quality of the water. The water in the wells is contaminated because the wells are hand-dug, shallow and unprotected. The wells are impacted by nearby latrines, from overland flow during the wet season or via contaminated groundwater year round. The river is contaminated by animal and human waste. The water, without treatment, causes diseases such as diarrhea that, when untreated, can be deadly. The results of a survey of town residents conducted by the EWB team indicate that as many as 34 children have died in the past five years as a result of lack of clean water.

The average human should consume between 2 and 4 liters of water per day, depending on his or her weight, activity, and environment. Unfortunately, safe drinking water is inaccessible for 1.1 billion people in developing countries. Every hour, as many as 400 children under age 5 die from waterborne diseases. Increased longevity, lower infant mortality rate, and better health can all be achieved by reducing the amount of bacteria, sediments, and toxins in drinking water. There are many water treatment technologies available, but few are available to people in developing countries[1].

The ideal water supply option, if available, is to obtain water from an uncontaminated source. For the citizens of La Ceiba, the only such source is groundwater obtained from a protected well located a sufficient distance from latrines. If tied to a distribution system, this water would still need to be disinfected, to guard against contamination during distribution. If contaminated water must be moved, the best treatment options are filtration and disinfection. If correctly operated, filters can remove as much as 99% of bacteria and viruses in water, among other sources of disease. Small, granular materials such as sand can be used as a filter medium in community or household-scale filters. Drinking water can also be disinfected to a point where the number of organisms is so low that no infection or disease results when the water is ingested. This can be done chemically or by means of boiling or exposure to ultraviolet light[1].

A description for each method is given in this report, along with a brief explanation of how to size a system for a community. The pros and cons are provided and general cost estimating methods given, along with a list of resources for each alternative.

Background – Problem Definition

The towns of La Ceiba and neighboring Miramar are located inland off the Pacific Coast near the Guatemalan border. Miramar was initially included in the project scope, but has since been taken over by the Drexel EWB team. La Ceiba has an estimated population of 465 that will directly benefit from the work done by Engineers Without Borders.

The people of La Ceiba lack the expertise, means and resources necessary to implement a system that will provide clean water year round. Due to unclean drinking water, the community suffers from diarrhea, bloated stomachs and infections. Along with these, as many as 34 children have died in the last five years as a result of contaminated drinking water. The primary source of water for many villagers is shallow, hand-dug wells. The local river is used by the community for bathing and clothes washing, as well as by farm animals. For some families, those without a well, the only drinking water source is the same river.

In May 2007, a group of Rowan students in cooperation with Drexel University traveled to La Ceiba to collect data and gain a firsthand perspective of the problem. The group conducted a land survey of the entire community. This consisted of 200 points and 34 turning points. The group also performed a health survey of each household. The survey included questions regarding the amount of water used and how long it took to collect that water. On average, each household uses a total of 103 gallons of water daily. The effect of the unclean water on the health of the community is extremely important. This survey also included questions on the effect of the water on adults and children. The water quality of the hand-dug wells and river were tested for fecal coliform bacteria and chemical parameters.

In Fall 2007, students analyzed the data collected from both the land survey and health survey and researched water purification methods that could be applicable to La Ceiba. Cost estimates were made for each solution after it was sized based on the water demand and expected growth of the community. Steps were taken to estimate costs in El Salvadorean dollars. A distribution system was modeled in several configurations, and local contractors were found with the capability of drilling a new well. Fundraising was done in anticipation of another assessment trip to be taken during Spring 2008.

Materials and Methods

The program used to simulate various water distribution systems for the town is called EPANET version 2.0. This program is capable of performing extended period simulation of hydraulic and water quality behavior within pressurized pipe networks. The components of a water network include pipes, nodes (pipe junctions), pumps, valves, storage tanks, and reservoirs. The program is capable of simulating a network over a length of time. The program can simulate water flow, pressure at each node, height of the water in a tank, and even a chemical concentration if present in the network. The program can provide tables and graphs of the performance of all components after the simulation.

EPANET is beneficial to Engineers without Borders because it is a simple program to run, it simulates piping networks, and it's free. Surveying data from an assessment trip can be imported into EPANET by converting the data into a compatible file format. The surveying points become nodes in the program and piping can be connected to these nodes. A water supply system is simulated by adding the desired demands (water consumption) to nodes throughout the system and running the computer program. The user can access all the necessary tables and graphs to analyze the simulation. The user can change components of the network to improve the performance of the network. A tutorial has been created and is available with the software on the U.S. Environmental Protection Agency web site[2].

For the land survey, a Leica total station was used. The equipment was mounted on a tripod and data was collected using a handheld data collector. Two prism rods were used to shoot points.

Water Quality Assessment

pH - Hach Test Strip 27456-50 / color values=4-5-6-7-8-9

Nitrate - Hach Test Strip 27454-25 / color values=0-1-2-5-10-20-50

Nitrite - Hach Test Strip 27454-25 / color values=0-0.15-0.3-1.0-1.5-3.0

Total Alkalinity - Hach Test Strip 27448-50 / color values=0-40-80-120-180-240

Total Hardness - Hach Test Strip 274520-50 / color values=0-25-50-120-250-425

5 in1-Total Cl - Hach Test Strip 27552-50 / color values=0-0.5-1.0-2.0-4.0-10.0

5 in1-Free Cl - Hach Test Strip 27552-50 / color values=0-0.5-1.0-2.0-4.0-10.0

5 in1-Total Hardness - Hach Test Strip 27552-50 / color values=0-25-50-120-250-425

5 in1-Total Alkalinity - Hach Test Strip 27552-50 / color values=0-40-80-120-180-240

5 in1-pH - Hach Test Strip 27552-50 / color values=6.2-6.8-7.2-7.8-8.4

DO - Xplorer GIX (Pasco) PS-2002 - Pasco Scientific 699-06320 DO Probe

Turbidity - Xplorer GIX (Pasco) PS-2002 - Pasco Turbidimeter PS-2122 Probe

Temperature - Xplorer GIX (Pasco) PS-2002 - Pasco Port Temperature Probe

Conductivity - VWR SympHony SP40C (Calibrated at Rowan before trip)

Coliform Bacteria by Membrane Filtration - Hach Method 10029

- m-ColiBlue 24 Broth Broth (2ml/test taken from 100ml bottle)
- PALL Petri Dishes
- PALL 63077 GN-6 47mm gridded 0.45um presterilized filters & pads
- Hach Portable Incubator (35 C for 24 hr)

Water Quality Results

Water samples were taken from 7 wells and 2 river locations (upstream of La Ceibe and where the river intersects the main road through town). All of the samples were found to be contaminated with Total coliform and E. Coli bacteria. Many of the samples, even diluted 1 to 10 had too many bacteria to count, indicating the levels were over 2000 bacteria per 100 mL. The target concentration is zero. This water should be treated, or uncontaminated sources of water should be obtained.

Chemical parameters were obtained using strips, which have limited precision. The pH of the samples ranged from 6 to 7. This is acceptable for drinking water. Nitrate ranged from 1 to 2.5 ppm. Nitrite was 0, except for one well sample, which was 0.1 ppm. Drinking water standards in the US for nitrate and nitrogen are 10 and 1 ppm (as Nitrogen), respectively. Nitrate and nitrite level, then, are acceptable. Phosphorous ranged from 4 to 25 ppm. Unpolluted streams will typically have phosphorous levels below 0.01 ppm; however, there is no drinkingwater standard for phosphorous, as it does not have a health impact. High phosphorous levels can be caused by contamination from fertilizers and manure. Alkalinity is a measure of water's ability to neutralize acids and act as a buffer to maintain a constant pH. Hardness is a measure of the amount of divalent cations in a sample, which can impact the tendency of water to scale and consume of soap. Total Alkalinity ranged from 40 to 200 ppm as $CaCO_3$, while Total Hardness ranged form 70 to 190 ppm as $CaCO_3$. The Alkalinity and Hardness levels are acceptable.

Meters were used to measure Turbidity, Conductivity, and Dissolved Oxygen. Turbidity is a measure of the clarity of water (clearness). All of the turbidity levels were 0. The samples were taken during the dry season. River turbidity may be elevated during the wet season. Conductivity is related to the concentration of dissolved ions. A drastic change in conductivity can indicated the introduction of contamination into a river or groundwater. Conductivity ranged from 104 to 234 mS, a fairly tight range. Aquatic species, such as fish, need at least 5 mg/l. Dissolved Oxygen levels ranged from 3 to 6.2 ppm, with most samples at temperatures from 28 to 29^{o}C. The two river samples had DO levels of 5.6 and 6.1 ppm, sufficient to support aquatic organisms.

Toxic chemicals were not assessed. No new water sources are envisioned and the health assessment found no indication of diseases caused by toxins, such as arsenic.

Water Quantity

A citizen's survey was conducted during the first assessment trip to La Ceiba in May 2007. The citizen's survey provided important water data that was useful for sizing and cost estimation. The amount of water each household used per day was recorded along with what they used it for. After compiling the data from each household, it was calculated that the average household uses 104 gallons per day.

A factor of safety was applied to the town's water usage in order for each design to remain functional for years to come. This was done because the population of the community may increase or the current citizens may start using more water now that it will be readily available.

Proposed Solutions

Several alternatives have been analyzed as possible solutions to the water situation in the town of La Ceiba. Alternatives include no action, educating the people on water supply and treatment, providing extra jugs for improved household Puriagua use, individual household filtration systems, including biosand and ceramic pots, sunlight UV disinfection, a new latrine system, drilling new household wells, improvement of existing wells, and several public water supply and distribution systems.

No Action

Description

This alternative requires no work. It provides no solution to the water situation that the community of La Ceiba is facing.

Cost Estimate

This solution does not require any investment because no materials and/or labor are needed.

Pros/Cons

Pros	It does not require any effort or investment of money.
Cons	The community of La Ceiba will continue drinking unclean and water. Therefore the people in the community will continue to be sick, and children will continue to die unnecessarily. Some families will continue collecting water from the river, a time consuming activity. Due to lack of clean water, some people may abandon their homes and move to a town with clean, sustainable drinking water.

Education

Description

The purpose of educating the residents of La Ceiba is to provide them with information on water supply and treatment. According to the observations made during the first assessment trip and the community's responses to the health survey, it can be concluded that the community lacks appropriate knowledge about water treatment. To implement this solution the town would be provided with adequate information through workshops, conferences, and/or pamphlets. The list below shows some of the type of information that should be provided.

Type of Information

1. Types of water sources including rainwater, groundwater and surface water.
2. The quality of the water from different sources. This would include information on the water collected from the wells and the river.
3. Health impacts of water contamination and their implications
4. How to adequately treat water depending on the source and the financial limitations of the community.
5. Proper storage of water
6. Water conservation

Currently, in the town of La Ceiba, a solution of 5% sodium hypochlorite is provided by the Department of Health of the El Salvador. This solution is called "Puriagua" and comes in a 480 mL receptacle; it is available to the residents of the community at no cost. Table 1 is used to describe the proper use of Puriagua. However, based on our observations during the assessment trip, the people do not use Puriagua or use it improperly. Therefore, any education solution should include information on using Puriagua. Other simple treatments, such as boiling or solar disinfection should also be covered.

Table 1: Chlorine vs. Water Amount

Available Chlorine	Drops per Quart/Gallons of Clear Water	Drops per Liter of Clear Water
1%	10 per Quart - 40 per Gallon	10 per Liter
4-6%	2 per Quart - 8 per Gallon (1/8 teaspoon)	2 per Liter
7-10%	1 per Quart - 4 per Gallon	1 per Liter
Unknown	10 per Quart of filtered or settled water	10 per Liter
Unknown	20 per Quart of cloudy, murky or colored water	20 per Liter
Mix the treated water thoroughly and let stand for 30 minutes		

Pros/Cons

Pros	The application of this alternative would provide the community with useful tools in regard to the treatment of their water. As a consequence, the health of residents is expected to improve. Better community understanding may also help the community select and/or operate other solutions. The community must have a critical role in the development of clean water for their town or they will not take care of it or be able to maintain it. Also this is an alternative of relatively low cost when compared to a more complex system.
Cons	Some residents will not adopt the actions advocated by education. Thus, an education-only solution cannot be as effective as a town-wide solution, such as a public water supply and distribution system.

Future Expectations

Nelson Mandela said, "Education is the most powerful weapon which you can use to change the world[3]." That is the goal of this alternative. By educating the people in the community, their lifestyle may improve. Ideally, parents would to teach their children, and Puriagua (or other simple methods) would continue to be used to treat drinking water. The effect of teaching the current residents could be significant. However, it is unlikely that all residents would adopt the required practices. It is also unlikely that information would be effectively passed on to all of the children of the community. Therefore, the application of this alternative without other more active solutions is not recommended.

Cost Estimate

The cost of this alternative is based on the travel and printing expenses. Travel expenses range from $4,000 to $7,000 depending upon the number of students traveling. The cost for printing would be minimal. A cost estimate is given in Table 2.

Table 2: Cost Estimates for Education Alternative

Description	*Quantity*	*Unit*	*Cost/unit*	*Cost*
Traveling Tickets and related expenses	4-7	Person	$1,000	$4K to $7
Brochures	85	Household	$2.00	$170.00
Total				$4,170 to $7,170

Extra Jugs

Description

Providing extra jugs would help residents use Purigua correctly. The community uses the jugs to haul water from the local river or hand dug wells to their home. Some residents are not willing to wait the 30 minutes or so it takes to disinfect water with Purigua. With two sets of jugs, residents can have clean water in one set while disinfecting the next batch of water in the second. Combined with education, this alternative would provide residents with everything they need to treat their well or river water.

Cost Estimate

The cost of this alternative solution is small. Puriagua is provided by the government at no cost. The price of a 5 gallon jug (a canteros) is $3. Travel costs are as in Table 2. The cost of providing Canteros is given in Table 3.

Table 3: Cost Estimates for Extra Jug Alternative

Description	*Quantity*	*Unit*	*Cost/unit*	*Cost*
5 gallon canteros	4	each	$3	$12
Total	85	households	$12	$1020

Pros/Cons

Pros	If the community does the treatment correctly, they will have clean drinking water.
Cons	Some residents will not use the Purigua correctly, even with an extra jug.

Slow Sand Filters

Slow sand filters were not originally considered for the Fall 07 report. They deserve mention, because they are an EWB-recommneded treatment, and also to understand the mechanism behind another process discussed later: household biosand filters.

Slow sand filtration is a simple and reliable process to eliminate harmful contaminants from drinking water. With minimal power and chemical requirements, slow sand filtration is an appropriate form of water treatment in developing countries around the world. The process removes bacteria, cloudiness and organic matter from groundwater or river water, producing water that is safe to drink. It does not require pretreatment or extensive operator control. There are no disinfection byproducts in the water, so taste and odor are not affected. Close operator supervision is not necessary, and systems can be built using locally available materials and labor.

Description

Slow sand filters consist of a large tank containing a bed of fine sand which is initially 0.9-1.2 m thick (Figure 1). On top of this sand, a sticky deposit of bacteria and microscopic plants, called the schmutzdecke, forms a few millimeters thick. These micro-organisms form a layer in which particles are trapped, and organic matter is biologically degraded. As the shmutzdecke develops during the filtration cycle, it assumes the dominant role in filtration rather than the granular media.

Water passes through the layers in the tank by gravity. It begins resting on top of the filter bed, as the supernatant water stage. This layer is about 1-1.5 meters deep. Large particles will settle in this stage, while smaller particles may coalesce, aiding in their ultimate removal. Sunlight allows algae to grow on the surface of the water, which absorbs carbon dioxide, nitrates, phosphates, and other nutrients to form oxygen. This oxygen dissolves in the water and is used by algae as they consume organic matter[4].

At the surface of the filter bed, the schmutzdecke consists of threadlike algae, as well as plankton, diatoms, protozoa, rotifers and bacteria. These organisms trap, digest, and break down organic matter in the water that is passing through. Dead algae from the water above as well as living bacteria in the raw water are also consumed.

After passing through the biological cake on the surface, it reaches a layer of fine sand particles which trap sediment and aid in the removal of heavy metals. Biological activity takes place in the first 40 cm of the fine sand layer, but the majority of the activity is near the surface. After passing through the first 40-60cm of fine sand, almost all of the organic material has been removed, leaving the water with only simple inorganic salts in solution.

At the bottom of the filter bed is a layer of supporting gravel to provide the least amount of resistance for the clean water to reach the underdrain. This layer of gravel prevents fine sand particles from clogging the underdrain.

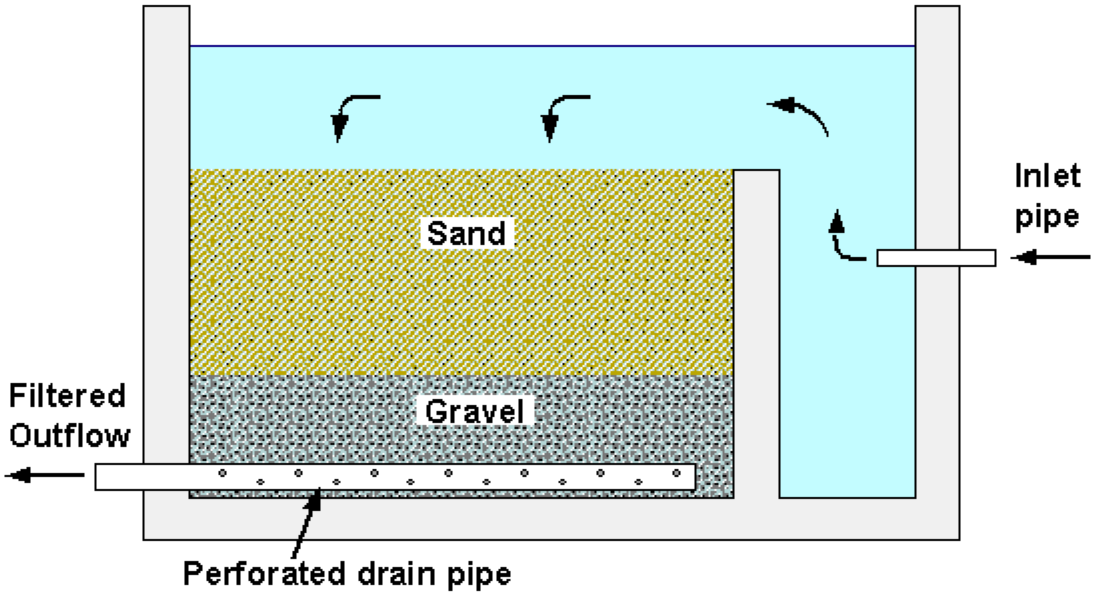

Figure 1: Slow Sand Filter

Operation and Maintenance

After a period of normal operation, the rate of filtration will decrease and the top layer must be cleaned. The decrease in filtration rate will be unnoticeable at first, but will increase more rapidly, signifying the impending cleaning that must be done. This is done by simply scraping off the surface layer to a depth of about 1 to 2 centimeters. This can easily be done by unskilled workers using hand tools or mechanical equipment[4].

When a new filter is commissioned, it must first be charged with filtered water, with all the outlet valves closed, introduced from the bottom to drive out air bubbles. The supernatant water must be high enough such that the surface of the filter bed is not disturbed by the addition of raw water. Top filling can now be done, at a rate of one-fourth the normal filtration rate. The filter must be run this way for several weeks, depending on the quality of the water. Cleaner water will take more time to develop a biological layer. This process can be sped up by the addition of biological material from a slow sand filter that is already in operation[4].

Sizing and Cost Estimates

Slow sand filter generally have a flux of water through the surface of 0.1 to 0.4 $m^3/(m^2\ hr)$[5]. This means in order to produce 1 cubic meter of water per hour, the surface of the schmutzdecke would have to be 2.5 to 10 square meters, depending on the quality of the raw water, and the gradation of the filter medium.

In 2002, engineers from the University of Guam performed a cost estimate for a slow sand filter to be implemented in a community in the Federal States of Micronesia. Table 4 is used to present their cost estimates for a 20 gpm system. The prices are adjusted for local vendors, and the estimate includes many costs which may not be needed depending on the site. Though their estimate represents a very conservative approach, it can be used as a benchmark for future estimates[6].

Table 4: Slow Sand Filter Budgetary Construction Cost Estimate (20 gpm capacity), provided by Masoud & Company (January 2003)

Description	*Quantity*	*Unit*	*Cost/Unit*	*Cost*
8" SCHEDULE 80 PVC PIPE	80	FT	$19.94	$1,595.00
8" PVC SCHED. 80 COUPLING	10	EA	$56.25	$562.50
8" PVC SCHED. 80 ELBOW 90 DEGREE	5	EA	$65.00	$325.00
6" SCHEDULE 80 PVC PIPE PERFORATED	240	LF	$25.00	$6,000.00
6" PVC SCHED. 80 COUPLING	8	EA	$31.25	$250.00
6" PVC SCHED. 80 ELBOW 90 DEGREE	5	EA	$40.00	$200.00
6" TO 8" PVC SCHED 80 REDUCER	8	EA	$62.50	$500.00
8" GATE VALVE BRASS	6	EA	$687.50	$4,125.00
8" SCHEDULE 40 GALVANIZED PIPE	80	LF	$29.11	$2,328.57
8" MJ 90 DEGREE ELBOW	4	EA	$225.00	$900.00
8" SOLID SLEEVE JOINT	8	EA	$225.00	$1,800.00
4'X4' SS WATER-TIGHT DOOR & FRAME	1	EA	$3,562.50	$3,562.50
MAGNETIC TAPE	1	LS	$250.00	$250.00
STRUCT. STEEL REINFORCED CONC. (3000 PSI, GRADE 40 STEEL)	70	CY	$312.50	$21,759.26
TRENCH BEDDING SAND	1	LS	$1,500.00	$1,500.00
GRAVEL BASE COURSE	18	CY	$45.00	$830.00
COMPACTION	1	LS	$1,050.00	$1,050.00
TRENCHING/BACKHOE/EXCAVATOR	1	LS	$6,300.00	$6,300.00
3/4" HOSE BIB	2	EA	$6.25	$12.50
LOCALLY MANUFACTURED SAND FILTER (commercial sand quartz @ $462/cy)	38	CY	$150.00	$5,688.89
LOCALLY MANUFACTURED GRAVEL FOR UNDERDRAIN	19	CY	$120.00	$2,275.56
PIZOMETERS	3	EA	$435.00	$1,305.00
WATER METERS 8"	2	EA	$1,250.00	$2,500.00
PIPE ADHESIVE, PLUGS, MISC. FITTINGS	1	LS	$500.00	$500.00
FENCE & GATE	400	LF	$56.25	$22,500.00
STAINLESS STEEL LADDER	2	EA	$1,800.00	$3,600.00
MISC. CONCRETE STRUCTURES, OPEN CHANNEL, WIER, ETC.	1	LS	$4,500.00	$4,500.00
SMALL TOOLS & MISC. EQUIPMENT	1	HR	$1,400.00	$1,400.00
LABOR	760	HR	$15.00	$11,400.00
SUPERVISION	95	HR	$30.00	$2,850.00
LAND SURVEYING DURING DESIGN AND CONSTRUCTION PHASES	1	LS	$2,500.00	$2,500.00
SITE SPECIFIC DESIGN AND CERTIFICATION	1	LS	$3,500.00	$3,500.00
CONSTRUCTION PERMITTING, FEES	1	LS	$450.00	$450.00

$118,819.78
$29,704.95
$148,524.73

This estimate includes, $12,350 in equipment rental, $14,250 in labor and supervision, and $22,500 in a protective fence and gate.

Pros/Cons

Pros	Slow sand filtration has large maintenance intervals. Systems make use of locally available labor and materials. There is no chemical requirement, and slow sand filters are very effective in removing particles and biological material.
Cons	Large filter bed areas are required for filtration. There is an electricity requirement if the water source or the distribution system is not gravity fed. Cost estimates may be very high depending on the complexity of the system. Requires long start up time, and is ineffective immediately after maintenance.

Bio-Sand Filters

In communities without the economic means to construct a large scale water treatment system, household treatment may be the only viable option. Household filters can be used in this way, and are commonly referred to as biosand filters.

Description

The removal of pathogens in a biosand filter occurs in the same way as in a slow sand filter, just on a smaller scale. The filter media in a biosand filter is typically around 56 cm in depth to allow maximum filtration, and to ensure all organic material is removed before the water reaches the outlet pipe (Figure 2).

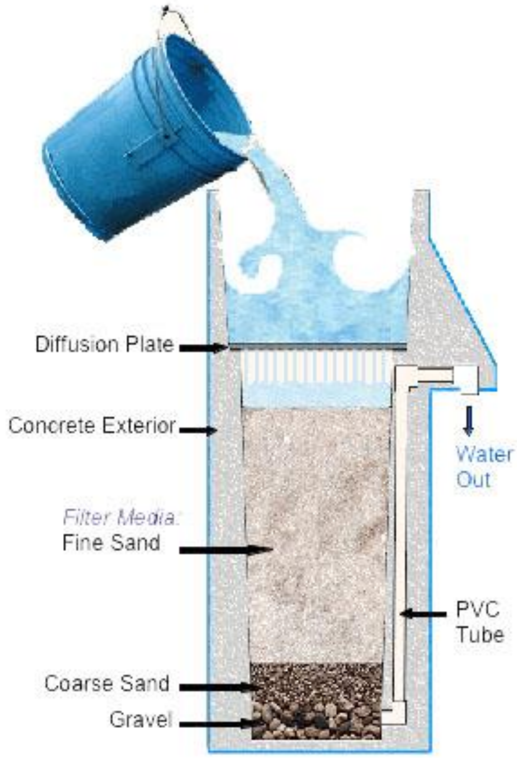

Figure 2: Diagram of a Biosand Filter (Source - www.deepspringsinternational.org)

The elements of a biosand filter are:

- **Lid (not shown in figure) –** Prevents Contaminants from entering the filter
- **Diffusion Plate –** Protects the biological layer from damage when water is poured onto the filter
- **Standing water layer (above fine sand) –** Keeps the biological layer alive during pause periods
- **Schmutzdecke (Not shown in figure) –** Biological layer on top of fine sand that consumes bacteria and other pathogens
- **Fine sand–** Traps organic and inorganic material at the top of the filter media
- **Course Sand–** Prevents fine sand from plugging underdrain gravel
- **Gravel (Underdrain) –** Promotes vertical flow of water into collector pipe
- **PVC Tube –** Conducts water from filter base to outside

Operation and Maintenance

In a new filter the biological layer typically takes 2 to 3 weeks to develop maturity. During this time, the removal efficiency and overall effectiveness of the biosand filter increases.

The surface sand should be stirred with fingers once a month. When the flow rate of water through the filter decreases, the surface of the sand should be agitated. Afterwards, the filter should be flushed by pouring a full filter's volume of water through it. The biological layer will quickly reestablish itself, returning the removal efficiency to its previous level[7].

Sizing and Cost Estimates

A typical concrete biosand filter can provide clean water for 6 to 15 people.

Concrete Biosand Filter:
The most commonly used biosand filter, because of its easy maintenance and long lifetime, is the concrete biosand filter. There is a startup cost because of the fabrication of the filter mold[8].
Cost[9]: *$30-$65*
Capacity: 35 liters per hour
Lifetime: *no known limit*
Materials needed for filter[10]:

- Portland Cement (10.5 kg)
- River Sand, dry without clay (30 kg)
- Ballast (gravel), 8mm to 10mm (40 kg)
- PVC 3 pcs elbow ½ inch (optional)
- PVC pipe (1/2 inch pipe, cut to 40mm length and a second piece of 560mm length)

Oil Drum Biosand Filter:
If there is an abundance of large plastic or metal containers, they can be recycled into water filters for a very small extra cost[11].
Cost: *varies*
Capacity: *varies, up to 150 liters total volume*
Lifetime: *no limit, however may need repair depending on construction*

Plastic Biosand Filter:
These are the cheapest type of biosand filter. The capacity and price varies depending on availability and size. They have a shorter expected lifetime than concrete filters[12].
Cost: *$1 for simple pitcher, up to $30 for tank*
Capacity: *varies*
Lifetime: *needs to be evaluated*

Cost estimates for various biosand filters are given in Table 5; however, initial purchase price depends on many factors and can vary widely. As education must accompany the introduction of household filters, there would be a cost for pamphlets. It is generally accepted that follow-up visits are also necessary, to ensure complete and proper adoption. Travel and pamphlet costs are as in Table 2.

Table 5: Cost Estimates for Various Household Biosand Filters:

Filter	*Quantity*	*Unit*	*Cost/unit*	*Cost*
Concrete	85	each	$65	$5525
Drum	85	each	varies	Varies
Plastic bucket	85	each	$30	$2550
Ceramic Filters (see next section)	85	each	$55	$4675

Pros/Cons

Pros	Effectively removes harmful contaminants. Household can still use local wells. Very low cost and local vendors make it widely available. Can be made out of recycled material. Very low maintenance. Virtually indefinite lifetime.
Cons	Small scale, will only provide water for 6-15 people depending on the size of the filter and the size of the filter medium. Plastic ones may break easily. Does not solve water supply problem. Extra work is required for the townspeople to fill the container with water first. Households that use the river as their source of water will still have to carry water jugs to home. At least one extra jug is required to collect the water.

Ceramic Pot Filtration

Description

A similar alternative for La Ceiba is household ceramic pot filters. Ceramic pot filtration involves making a ceramic pot that is infused with either saw dust or rice husks that combust during the firing of the pot leaving fine pores that work as filters. The pots are then coated with a layer of colloidal silver which acts as a bacteriacide. Water is poured into the pot which is placed on top of a receptacle. Filtered water passes through the pot and is collected in the receptacle. The water can be filtered at about 2 L per hour, and 98-100% of contaminates are removed[13]. The team could educate the community of La Ceiba on how to make these pots, if there is a suitable source of clay, and they could make them for themselves providing jobs and additional income to the community through the sale of filter systems and replacement filters. The filters are inexpensive initially and in replacement and easy to maintain with simple scrubbing of the filter[14].

Cost Estimate

Commercially available filters cost from $10 to 100 US depending on where the filter is manufactured and purchased[15]. A filter used to produce 20 liters/day for 3 costs only 0.046-0.46 US cents/liter. Filters can easily last more than 3 years, reducing the cost per liter further. Costs estimates are given in the previous section, Table 5[16].

Pros/Cons

Pros	Approximately a half gallon of water would be available for drinking every hour and would be 98-100% contaminate free. The townspeople would be able to make and sell filters for their own use and extra income to the town. Sickness would be decreased with lack of contaminates in the water they would be drinking. Filters only need to be replaced every two years, and are inexpensive for the townspeople. Serves dual purpose of treatment and safe storage.
Cons	Only enough water would be available for drinking purposes, and they would still need to have water for bathing and other purposes. Slow filtration rate of 2 liters per hour, cost approximately $6 -$12 per filter

Solar Disinfection

Solar disinfection (also referred to as SODIS) can be used at the household or town level. Water is treated by storing it in clear bottles while exposed to sunlight.

Description

Clear water can be exposed to sunlight to kill bacterial pathogens. UV radiation like that from the sun will destroy most fecal bacteria[1]. Clear well water can be contained in clear glass or plastic bottles and exposed to sunlight for a sufficient period of time to ensure its disinfection. Solar disinfection also imparts no taste or odor to the water, and there is no risk of overdosing with dangerous chemical or forming carcinogenic disinfection by-products. Since DNA is sensitive to UV light, there is a short treatment time for water. On a 100% sunny day only a 6 hour exposure time is required. For days with 50%-100% clouds, a 2 day exposure time is recommended[17]. Solar water disinfection has no adverse effects on taste or odor, so it should be more accepted by the people in La Ceiba compared to chemical disinfection. The effectiveness of solar radiation decreases with water depth, so the diameter of the container must not exceed 10cm. The effectiveness of the sunlight can be increased if the container is placed on a reflective surface. For this reason, plastic bottles are often placed on a corrugated metal sheet both for support, and to better disinfect the water[18]. More information can be found online at http://www.sodis.ch .

Figure 3: Clear plastic bottles full of raw water are placed on a corrugated iron sheet for disinfection by sunlight

El Salvador happens to be an ideal location for solar disinfection, because of the level of solar radiation in the tropical region as shown in Figure 4.

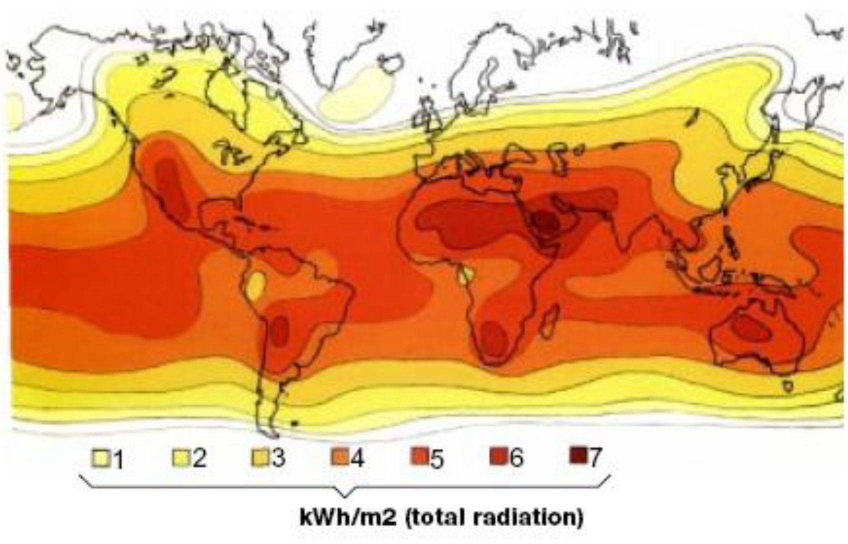

Figure 4: Solar radiation per day in different geographical regions

Operation and Maintenance

The material of bottles used can range from glass to PVC and PET plastics. The bottle must be no more than 10cm in diameter and it is recommended that the water have a turbidity level less than 26 NTU. The bottles must also be clear and not colored, with all labels removed. If excessive scratching occurs on plastic bottles, they must be replaced.

Sizing and Cost Estimates

Table 6: Cost Estimate for Solar Disinfection

Description	*Quantity*	*Unit*	*Cost/unit*	*Cost*
Plastic Bottles	4	each	$1.50	$6.00
Corrugated Sheet	1	sqf	$0.75	$0.75
Per Household	6	people	$6.75	$40.50
Subtotal	83	households	$40.50	$3,361.50
Total (+30% tax and shipping)				$4,369.95

Pros/Cons

Pros	Simple process, easy for the community to understand. Affordable. No power requirement. Can be made out of recycled materials. Can be used as an immediate water quality solution.
Cons	Requires clear water. Disinfection time depends on intensity of solar radiation. Does not change chemical water quality or remove heavy metals. Not useful for treating large quantities of drinking water.

Moringa Seed Treatment

Moringa Oleifera is a resilient tree that grows in tropical and sub-tropical environments. The seeds of this tree are a powerful coagulant, which has been used around the world to treat turbid or contaminated water. It is called “Teberinto” in El Salvadore.

Description

Moringa Oleifera is a natural and non-toxic organic polymer. It is known in the developing world as a medicinal plant that is also a source of vegetable oil. The tree produces fruit which are commonly referred to as “pods”. Each pod contains about 20 seeds, each having a diameter of 1-1.7cm and weighing 3-4g. These seeds can be used to treat raw water, as both a coagulant and an antimicrobial agent. The dosage rates depend on the level of turbidity of the water.

Table 7: Moringa Seed Dosage rates

Low turbidity	NTU<50	1 seed per 4 liters (4.225 qt) water
Medium turbidity	NTU 50-150	1 seed per 2 liters (2.112 qt) water
High turbidity	NTU 150-250	1 seed per 1 liter (1.056 qt) water
Extreme turbidity	NTU >250	2 seeds per 1 liter (1.056 qt) water

The seeds are shelled to obtain clean seeds and kernels, while discolored seeds are discarded. They are then ground up into powder and then mixed with a small amount of water to make a paste. The paste is mixed with 1 cup of water and agitated thoroughly to activate the coagulant, thus making a solution. This solution is filtered through a muslin cloth or mesh screen and added to the water to be purified. Rapid stirring must be done for the first minute, followed by slowly stirring the water for another 5-10 minutes. Then the water is left to sit for at least 1-2 hours. After the material settles to the bottom, clean drinking water may be decanted out of the container. While the mechanism for killing bacterial pathogens is not known, Moringa Oleifera has been known to remove 90-99.9% of the impurities in water[19].

Cost Estimate

Katayon et al specify that the cost of cultivating 1kg (340 seeds) of Moringa Oleifera Seeds is approximately 2 USD. If each seed treats 1-4 liters of water, the daily requirement to satisfy the 15 GPD of drinking water consumed per household is 15-57 seeds. This means that the yearly cost per household would be roughly $16.10-$61.00 (US). This seems economically feasible, assuming that they are locally available. This is still unknown, and the cost of planting these trees, and how quickly they produce seeds would still need to be determined[20].

Pros/Cons

Pros	Moringa Seeds are especially effective in removing cloudiness and turbidity from water. They may be used along with another method of treatment (such as solar disinfection, which is ineffective to turbid water) to speed up the disinfection time.
Cons	May not remove small microorganisms from water. Requires extra effort from community, and takes a long time to treat. May not be locally available. Instructions are not simple, and may take some time to master. Not needed in La Ceoba because water has low turbidity.

Latrine System

Description

Another alternative solution for La Ceiba is the installation of new latrines. Currently, most residents of La Ceiba use pit latrines. Liquid wastes from pit latrines can impact ground water, contaminating it with pathogenic microorganisms. The current latrines are located too close to drinking water wells (a typical rule of thumb is to locate latrines at least 10 m from wells, though other sources indicate that 15 m is the common rule of thumb). Furthermore, during the rainy season, the pits overflow, creating another route (overland) by which well contamination can occur.

There are different types of latrines that could be used in the town. Some of the types are ventilated improved pit latrines, double-vault ventilated composting latrines, and water privies. Pit latrines are the simplest form of latrine. Basically, they are a hole in the ground. Ventilated improved pit latrines are similar to pit latrines, however, they include a ventilation pipe that reduced the odor and fly and mosquito breeding in the latrine. Some variations of pit latrines are lined at the bottom with a layer of cement. The cement layer blocks any seepage into the surrounding soil. Double-vault ventilated composting latrines are further advanced. They collect the waste in a tank where it is then composted and used as a fertilizer. Water privies are basically water-tight tanks that collect the waste and send it to a drainage area or basin. By installing any of these types of latrines in the town, it would improve the current latrine situation, and, with proper location, installation and protection, could prevent overflow and seepage into the water supply.

Cost Estimate

Cost varies based on the type of latrine from the minimal cost of digging a hole that is unlined to the more advanced and more expensive systems like the double-vault ventilated composting latrines. Raised composting latrines are estimated to cost $600 (USD)[21].

Description	*Quantity*	*Unit*	*Cost/unit*	*Cost*
Latrine	1	each	$600	$600
Total				$51,000

Pros/Cons

By installing new latrines, the sources of water that are used, the river and the hand-dug wells, would be less contaminated from waste overflow and seepage. The new latrines would also be more sanitary without fly and mosquito breeding.

Pros	New latrines would be more sanitary for those using them and the community. There would be less contamination of the sources of water from seepage and overflow of latrines during the wet season.
Cons	Some types of latrines require drainage and waste removal which may come with an extra cost associated with them. Some types of latrines require drainage and waste removal which may come with an extra cost associated with them.

New Wells – Town and Household

Description

The citizens of La Ceiba are currently drinking from hand-dug low quality wells that provide bacteria filled water, a cause of many illnesses and deaths throughout the town. The nearby river is a main resource that the people use for washing dishes, bathing and watering livestock. Drinking water however is found primarily from their old wells. Modern wells could increase the quality of water that the people are drinking. The new well(s) would be sealed from sewage and surface runoff contaminating the water and would also be screened at the deepest possible level, reducing the possibility of contamination from groundwater impacted by the latrines. If a single town well is installed, it can be located far from latrines.

Cost Estimate

While creating a cost estimate for drilling a new well, there are a few different factors that must be taken into consideration. The most obvious factors are the cost per foot of drilling and cost per foot of casing. Other costs include mobilization of equipment, sealing materials, labor, development, pumping materials, pump, pump test, grouting, disinfection and testing. Some of those cost factors do not apply as a result of free labor from the citizens of La Cieba. Disinfection may or may not apply based on the quality of the underwater reserve. According to the USEPA, the total cost estimate for a town well ranges from $97 to $500 per foot to drill and finish with an average cost of $300 per foot. current design for the well has a depth of 70ft which results in a total cost of approximately $21000 in U.S. dollars. We have located a non-profit organization in El Salvador that will drill a town well for $5,000. Household wells in the US cost approximately $12/ft. Current well depths in La Ceiba vary from 11 ft to 70 ft. Table 8 shows the cost estimates for new wells, using an average depth of 45 ft.

Table 8: Estimates for New Wells

Description	*Quantity*	*Unit*	*Cost/unit*	*Cost*
Drilling Wells	80	eacg	$540	$45,900
Total				$45,900

Pros/Cons

Pros	While the cost of constructions a high quality well may be relatively expensive, the benefits of having reasonable modern well are also high.
Cons	Wells are too expensive to provide wells for each household, requiring people to walk to get water, unless a distribution system is also implemented. Most people would rather continue to use their old wells filled with contaminated water than walk to a distant new well to get higher quality water. Finally, the new wellscould be contaminated if latrines are too close (wells should be at least 15 m from latrines).

Future/Sustainability

A town well could provide significant improvement by providing high water quality to the town. A new town well provides a starting point for future designs. For example, we are currently working on designing a water distribution system for the town. That distribution system would draw its water from a town well.The water would be stored in a tank and be gravity fed to the town. The town well would be the keystone of further systems. Wells generally last as long as they are maintained.

Renovation of Existing Wells

Description

Reconstruction of the private wells in La Ceiba is another option for sanitary drinking water. The citizen's survey showed that most families get contaminated drinking water from private wells located near the home, and more than 50% of those people do not treat their water before they drink it. The people of La Ceiba are also reluctant to accept a solution that involves the water source being farther from the home. If the private wells can be reconstructed, the familes there would benefit from clean water without having to change their lifestyle[22].

Currently, the wells in La Ceiba are very wide, and they have no protective covering or lining to prevent contation from leaking in. Bacteria and microbes can reach the drinking water either by runoff directly into the well mouth or by passsing through the soil at the sides of the well. Figure 1 shows the current well construction and pathways for contaminated surface water to reach the clean groundwater.

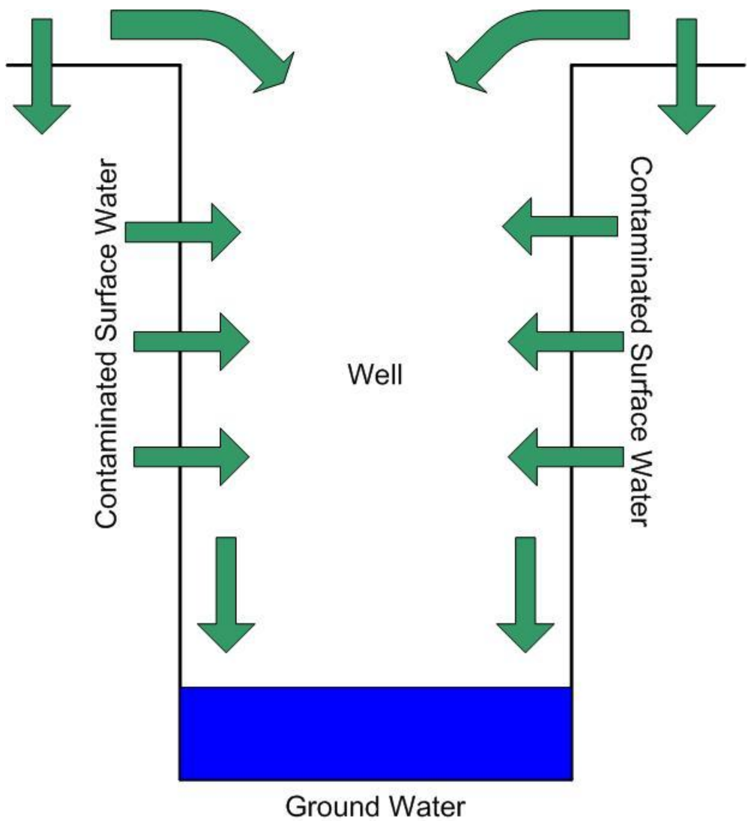

Figure 5: Current well construction and pathways for contamination

A simple solution to this problem would be to replace this layout with that of a shallow hand-pumped well, with a much smaller diameter. This would involve replacing the hand dug hole with a thin pipe, and filling in the well with soil, dirt, or sand. Doing this would prevent contaminated surface water from passing through the sides of the well entirely, and will protect the well opening from letting in other contaminants and insects. Figure 2 shows the proposed well construction, not including the hand pump at the top and wire mesh or PVC cut screen at the bottom.

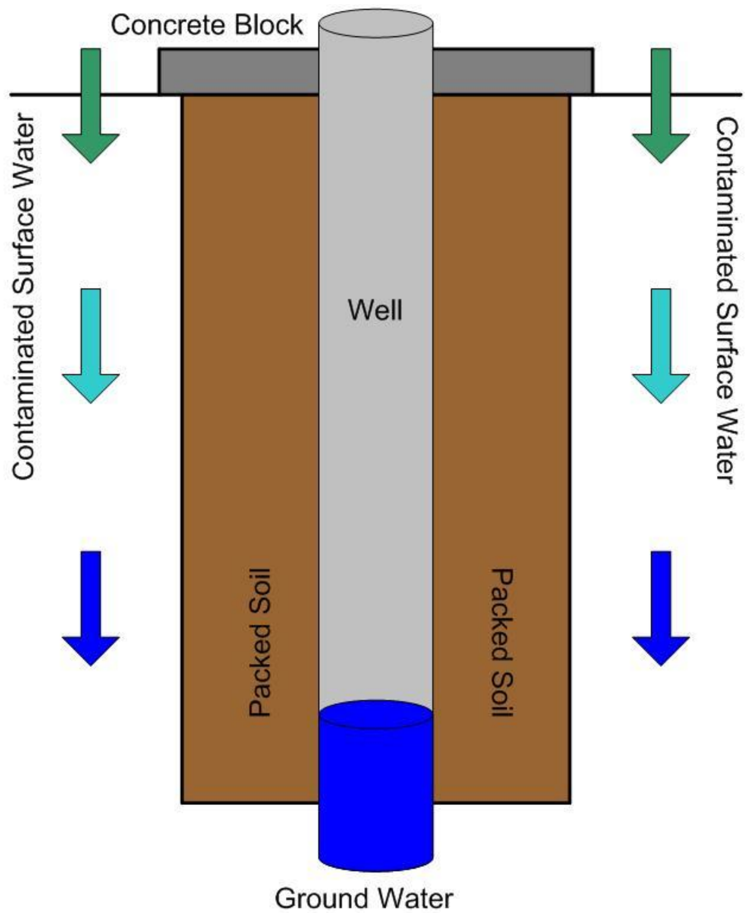

Figure 6: Proposed well reconstruction

Water from the surface would be filtered naturally through the soil before it reached the drinking water.

This water supply option is not without its drawbacks. The first and most important of which is the uncertainty of its effectiveness. There is no known literature of this process being used to remediate wells, therefore it is uncertain if doing this will prevent contaminants from reaching the groud water. This plan is also based on the assumption that the groundwater is inherently clean, and becomes contaminated when it comes in contact with dirty surface water[23].

When most wells are constructed, a hole is bored with a slightly larger diameter than the pipe or lining, and the extra space is filled with grout, made up of a cement or bentonite clay. This well would not have such grout, which could mean that contaminated surface water could use the space between the pipe and the packed soil as a shortcut to the clean ground water, as seen in figure 3. This is not nearly as big of a threat as in Figure 1, but it could be enough to compromise the well reconstruction effectiveness in eliminated contaminants from drinking water.

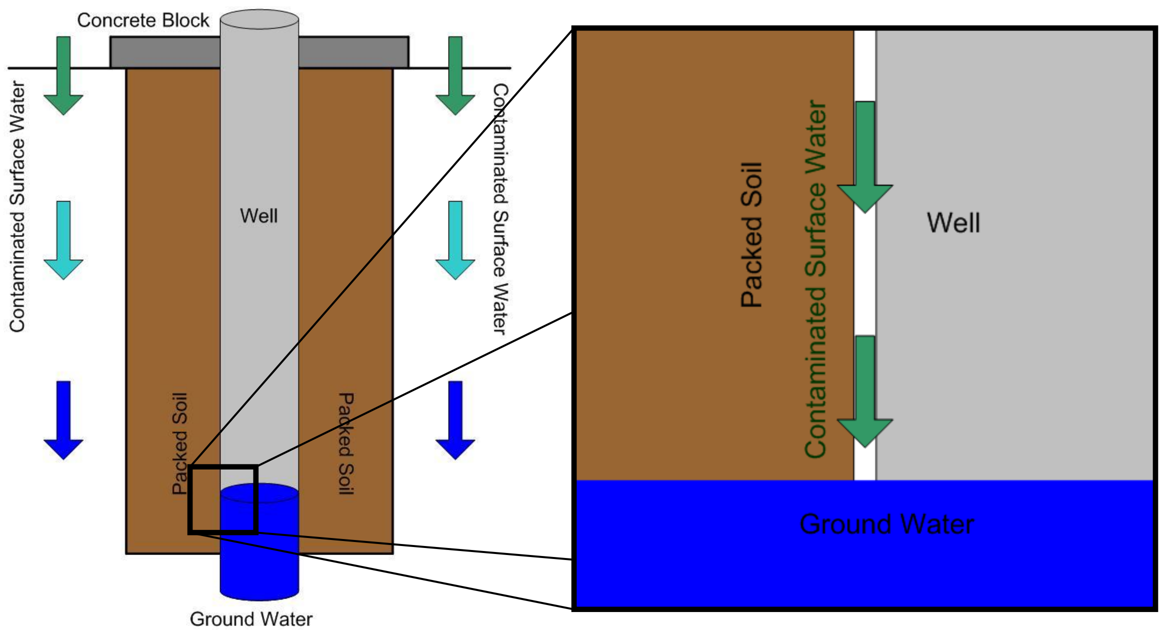

Figure 7: A zoomed view of the space between the well pipe and the soil

Further study is needed before this plan can be implemented. The most effective way to ensure that the families in La Ceiba take good care of their wells is to educate them on how to do so. It may be necessary to teach them how to cover the tops of the wells so that insects and bacteria cannot get it. In case of expansion, the people can be taught how to dig new wells and line them to a reasonable depth so that contaminated surface water cannot permeate through the sides of the well without being filtered through the soil.

Soil data must be taken to determine if the hand pump wells are suitable for the region. It is the consensus that the soil there has high clay content, but how much and the properties of that soil are still a mystery. Soil measurements, such as the grain size distribution, porosity, plasticity, and compaction characteristics may need to be taken to model the system and determine how well the system can supply clean drinking water to the citizens of La Ceiba. Many soil properties can be found based on the percent composition of clay, silt, and sand in a given sample. Figure 4 shows how soil can be categorized based on these compositions[24].

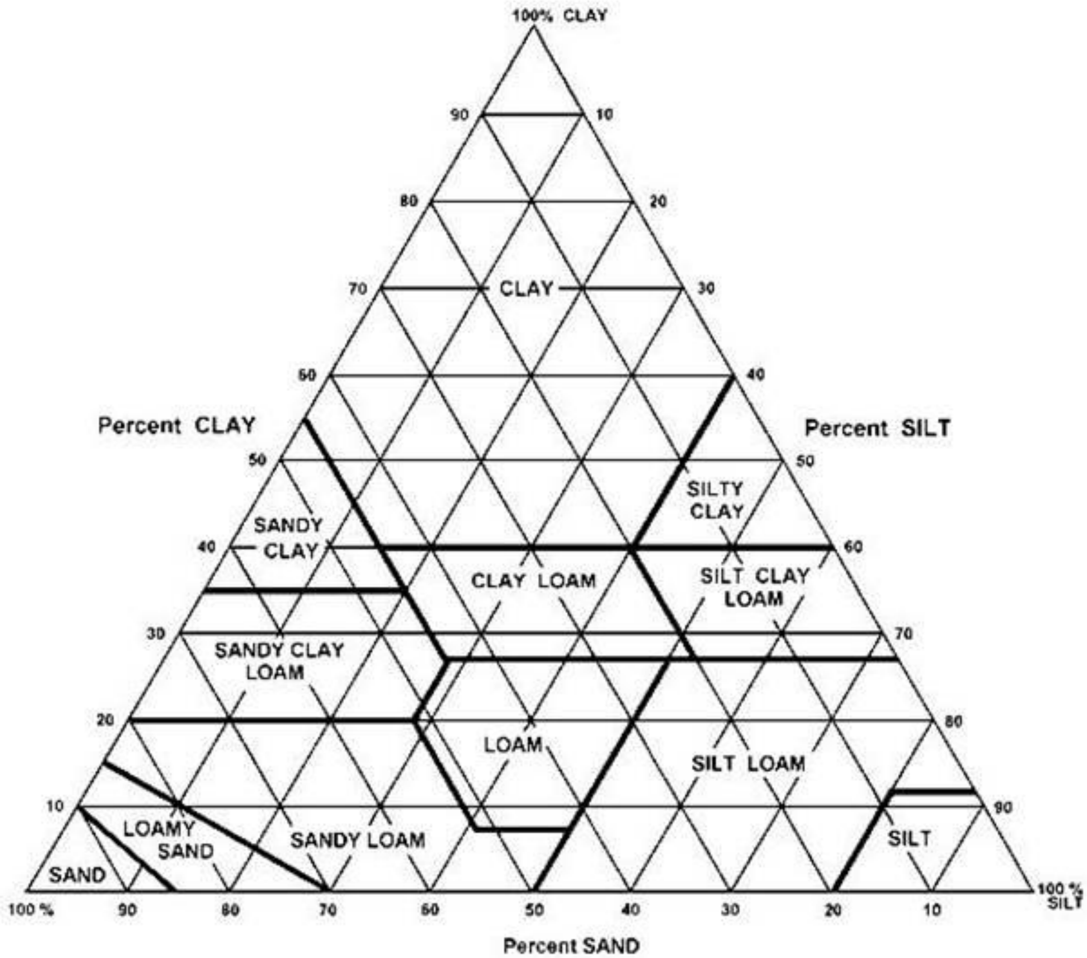

Figure 8: Percentages of clay, silt, and sand in the basic USDA soil textural classes

Sizing and Cost Estimates

A cost analysis was performed using a worst case scenario. The diameter and depths of the wells were estimated, and prices were based on conventional US prices for pipes, hand pumps, and soil (assuming it were not readily available)[25]. Tables 9 and 10 show that the capital cost does not change very much if a wider and deeper well is assumed.

Table 9: Cost estimation for 10' well 2' in diameter

Number of Households	83
Estimated Number of Wells	67
Gallons per day per household	103
average well depth (ft)	10
average well diameter (ft)	2
For 1.25" ID pipe	
cost per foot of pipe	$1.50
cost per well of pipe	$15.00
cost per well for pump	$79.99
cost per well for fittings	$16.99
subtotal	$113.48
with 30% tax and shipping	$147.52
For entire community	**$9,884.11**
volume of soil needed per well (ft^3)	15.71
total volume of soil needed (ft^3)	1052.43
cost per cubic yard of soil	$20.00
cost per cubic foot of soil	$0.74
total cost of soil (if necessary)	**$779.58**
Subtotal cost per well	$125.12
Total per well +30% tax & shipping	$162.65
Grand total	**$10,897.56**

Table 10: Cost estimation for a 15' well, 3' in diameter

Number of Households	83
Estimated Number of Wells	67
Gallons per day per household	103
average well depth (ft)	15
average well diameter (ft)	3
For 1.25" ID pipe	
cost per foot of pipe	$1.50
cost per well of pipe	$22.50
cost per well for pump	$79.99
cost per well for fittings	$16.99
subtotal	$120.98
with 30% tax and shipping	$157.27
For entire community	**$10,537.36**
volume of soil needed per well (ft^3)	35.34
total volume of soil needed (ft^3)	2367.98
cost per cubic yard of soil	$20.00
cost per cubic foot of soil	$0.74
total cost of soil (if necessary)	**$1,754.06**
Subtotal cost per well	$147.16
Total per well +30% tax & shipping	$191.31
Grand total	**$12,817.63**

Pros/Cons

Pros	Inexpensive, optimum benefit for community, no change to lifestyle, close to home
Cons	Effectiveness unknown, may not eliminate contamination entirely, reduced screened intervalwill reduce the water yield.

Distribution System

Description

The idea behind the distribution system is to find a source of water and create a network to deliver the water to the community. The team has come up with three different methods of distribution systems. The first one is a tank and faucet system that doesn't include a piping network. The second system is a community system which is the same as the first system but also includes a distribution system to parts of the community. The last system is the full distribution network that would supply drinking water directly to each house in the town of La Ceiba.

One Tank and Faucet System

Every distribution system includes the same source of water and tank design. This system is the simplest of the three and the easiest to install. The source of water we are looking at is groundwater which would require a well and pump. The well would be drilled down to the groundwater table and a submersible pump would be placed to pump the water from the ground to the tank above ground. Calculations have been performed to determine what pump size is needed based on the elevation difference between the estimated groundwater table and the top of the holding tank and the major and minor head losses. This system is designed to be able to add a distribution system on to it at a later date.

This system is the simplest and easiest to perform but it is distant from the majority of the community. Most of the community would not benefit from this system since other sources of water would be much closer than this clean source. Another implementation trip would have to be made to add a distribution system onto this system.

Community System

This system has the same water source, tank, and pump design as the first design but also includes a piping network to distribute the water to parts of La Ceiba. Calculations are being performed to create the best type of piping network consisting of spigots located about the community. There are a total of 15 spigots throughout the town and their locations were determined by the locations of the houses. We have an estimate of piping prices on the open area, but we haven't determined a more specific cost analysis since all of the calculations have not been performed.

This system is a cost effective design that supplies drinking water to a close proximity of the majority of houses in La Ceiba. The system may also be added on to provided water to more areas of the town at a later time. This system seems to be the best choice for the town of La Ceiba because it provides water to a large amount of the town and is cheaper than the full distributions system.

Full Distribution System

The full distribution system is a step up from the community system because it provides water directly to each house. This system is the much more expensive than the community system because it requires more spigots and piping. This system would take a long time to implement and require a large amount of fundraising. The team has decided to focus less on the full distribution system and more on the community system. The full distribution system could be a possibility after the community system is implemented.

Cost Estimates

Table 11: Cost Estimate for Distribution System with 15 community spigots

Description	Quantity	Unit	Cost/unit	Cost
*Pipe (2")	9500	ft	$0.50	$4,750.00
*Pipe (1")	0		$0.18	$0.00
Branch Piping (.75")	600	ft	$1.00	$600.00
T-fittings (2"-.75")	65	#	$16.89	$1,097.85
male adapter (0.75")	15	#	$0.30	$4.50
Valve (.75")	65	#	$15.00	$975.00
spigot	15	#		$0.00
spigot mount	15	#	$40.00	$600.00
Reducing Coupling		#		$0.00
Lock Boxes	15	#	$17.00	$255.00
Meters	15	#	$17.00	$255.00
				$8,537.35
Well and Tank System				
Tank (8000 L)	2	#	$1,250.00	$2,500.00
Pump (3hp)	1	#	$3,750.00	$3,750.00
Boring Well and mat.	1	#	$5,000.00	$5,000.00
PVC Cement	5	85 grams	$3.75	$18.75
Primer	5	32 fl oz	$19.25	$96.25
				$11,365.00
			Total Cost	$19,902.35

Pros/Cons

Pros	The community would not only benefit from the cleaner quality of groundwater, but the supply of water will be sufficient for all of their daily water needs, since it is estimated that this well will not dry up during the summer months. The energy cost would be minimal since the distribution system is gravity fed.
Cons	There would be a large labor effort to get the system in place. The community would have a monthly payment to cover the cost of maintenance and the salary of an employee needed to oversee the system. There is no local billing system in place so one would have to be set up. Education would be important with the complexity of the system.

Solutions Matrix

Each alternative is evaluated based on the following criteria:

- Quality – How well the alternative removes fecal coliform bacteria and produces clean water
- Total Quantity – How well the process provides water for ALL of the daily water needs of each household
- Drinking and Cooking Quantity – How well the process provides water for ONLY drinking and cooking purposes
- Monthly Cost – operation and maintenance cost estimate per household
- Employees – How many permanent positions will be needed to maintain the process
- Satisfaction – An estimate on how satisfied the community will be with the solution.
- EWB Cost – How much it will cost Rowan EWB. It should be noted that a total cost above $40,000 is not immediately plausible for EWB to implement, and a total cost above $100,000 will be nearly impossible for this size group to implement in the near future.

From these criteria, other qualitative factors can be estimated, such as the ease of implementation and the sustainability of each possible solution. These factors will be used to select a small number of alternatives for further study, after which a more in depth design will take place. The values given in the following Tables were developed from a brainstorming session of the Spring 08 La Ceiba clinic team.

Table 12: No Action

Criterion	***Value***	***Rationale***
Quality	0	No action will have no effect on water quality
Total Quantity	0	The community will continue to use contaminated wells, which may dry up during the dry season.
Drinking Quantity	0	The community will continue to use contaminated wells, which may dry up during the dry season.
Monthly Cost	0	There is no cost associated with their current well system
Employees	0	Currently there is no one in La Ceiba employed for the purpose of water supply
Satisfaction	0	The community would be very disappointed if no action was taken by EWB
EWB Cost	0	With no action there is no cost

Table 13: Education (Puriagua and Solar Disinfection)

Criterion	***Value***	***Rationale***
Quality	1	One or more people may be convinced to begin treating their water before they drink it
Total Quantity	0	It would be too much work and energy for each household to treat all of their water needed for washing, bathing, cooking, and drinking
Drinking Quantity	2	The quantity of water treated would be on a cooking and drinking scale of magnitude
Monthly Cost	0	Though there are no associated maintenance cost with education, the lessons learned from EWB can be passed on to future households.
Employees	0	There is no need for employees
Satisfaction	0	While education may be beneficial, it will likely not affect everybody, and the community is hoping for much more
EWB Cost	$1000	This cost is estimated for posters, pamphlets and associated educational materials

Table 14: Extra Jugs

Criterion	***Value***	***Rationale***
Quality	4	The community will be able to use the chlorine tablets already provided to them by their national government.
Total Quantity	1	Each household would likely not have the capacity to treat their full daily water requirement.
Drinking Quantity	4	Each household would easily meet their drinking and cooking water requirement.
Monthly Cost	0	The chlorine tablets are free to the community, so there would be no monthly cost.
Employees	0	No employees are needed since treatment is on a household level.
Satisfaction	1	The community has access to the chlorine tablets and is currently reluctant to use them. They do not like the taste of the chemically treated water, and want more convenience.
EWB Cost	$1020	This cost is estimated for providing each household with 4 five-gallon cantaros.

Table 15: Slow Sand Filters

Criterion	***Value***	***Rationale***
Quality	5	Slow sand filters easily remove all materials that would be harmful to humans
Total Quantity	2	A slow sand filter can be built to provide the water for all of the community's daily needs, but would have to be built to a size that rivals the area of the town itself. For this reason, the total water quantity is not feasible to achieve.
Drinking Quantity	5	The slow sand filter will most likely be designed to meet the drinking and cooking water requirements for the town.
Monthly Cost	??	The monthly cost of a slow sand filter would still have to be determined.
Employees	1	There will have to be at least one person in charge of cleaning and maintenance, even though constant supervision is not necessary.
Satisfaction	3	A slow sand filter will not necessarily solve the water supply problem.
EWB Cost	>$100k	The cost of a slow sand filter may be to great for Rowan EWB to implement

Table 16: Bio-Sand Filters

Criterion	***Value***	***Rationale***
Quality	4	Biosand filters are almost as effective as slow sand filters in removing contaminants
Total Quantity	1	Biosand filters are to be used mainly on a household level for drinking and cooking purposes.
Drinking Quantity	4	Drinking water requirements can easily be met for a family of 6 to 15 people, but periodic cleaning may hinder production.
Monthly Cost	0	Concrete biosand filters have an almost indefinite lifetime
Employees	0	There are no employees necessary, and biosand filters can be bought by local vendors
Satisfaction	3	The community would have to continue to use their current sources of water, and use the biosand filter to treat it. Does not address water supply problem.
EWB Cost	$5500	Worst-case scenario, not counting start-up cost

Table 17: Ceramic Pot Filtration

Criterion	***Value***	***Rationale***
Quality	4	The pores in the ceramic material filter out particles, and the colloidal silver is effective in removing microbial organisms.
Total Quantity	1	Too slow for the full 100 gpd requirement.
Drinking Quantity	4	While it does take time to filter through the material, one filter can provide a household with sufficient drinking water.
Monthly Cost	$1	Each year the ceramic filter would have to be replaced, which results in approximately a $12 replacement cost.
Employees	0	No employees required since treatment is on a household level.
Satisfaction	3	The community would have to continue to use their current sources of water, and use the ceramic pot filter to treat it. Does not address water supply problem.
EWB Cost	$3000	Cost varies, but is on the same order as biosand filtration.

Table 18: Solar Disinfection

Criterion	***Value***	***Rationale***
Quality	4	With the proper exposure time, all organic material would be neutralized.
Total Quantity	1	Not recommended for large scale water treatment.
Drinking Quantity	4	Provided enough bottles are available, solar disinfection can be used for drinking and cooking water purposes.
Monthly Cost	0	Save for the replacement of bottles, which can be recycled from soda bottles, there are no monthly costs.
Employees	0	No employees are needed since treatment is on a household level.
Satisfaction	1	The community would have to do extra work to their water before using it, and it does not address the water supply problem.
EWB Cost	$4,369.95	Estimation includes cost of a corrugated metal sheet to place bottles on.

Table 19: Moringa Seed Treatment

Criterion	*Value*	*Rationale*
Quality	3	While the treatment does remove particles in the water, it may not sanitize drinking water on a microbial level.
Total Quantity	1	Not recommended for large-scale treatment.
Drinking Quantity	4	One kernel of the Moringa Oleifera seed will treat up to 1 liter of water
Monthly Cost	0	Once the plant is set up and growing naturally in the community, there will be no cost of reproduction, and more may be planted.
Employees	0	There is no employee requirement.
Satisfaction	1	This may not be an immediate solution to the community, and it does not address water supply.
EWB Cost	TBD	The cost of implementing Moringa Oleifera trees is yet to be determined.

Table 20: Latrine System

Criterion	*Value*	*Rationale*
Quality	??	Effectiveness in lowering the water contamination is unknown, but expected to be significant.
Total Quantity	0	This alternative does not involve water treatment.
Drinking Quantity	0	This alternative does not involve water treatment.
Monthly Cost	0	Once the latrines are built, there will be little to no upkeep costs.
Employees	0	No employees are required.
Satisfaction	1	This does not address the water supply problem.
EWB Cost	$51,000	Cost estimate is for raised composting latrines.

Table 21: New Wells

Criterion	*Value*	*Rationale*
Quality	4	At a depth of 70-100 feed, the groundwater is assumed to be clean and safe to drink.
Total Quantity	3	During the dry season, the overall water supply may drop.
Drinking Quantity	3	As stated above, the wells may lose capacity during the dry season.
Monthly Cost	0	There would be no monthly cost associated with the presence of new wells.
Employees	0	No employees are required.
Satisfaction	3	The community would appreciate new wells, since many households do not have their own.
EWB Cost	>$100k	The drilling of one well is expensive, so the drilling of one well per household may be out of the scope of this project.

Table 22: Renovation of Old Wells

Criterion	***Value***	***Rationale***
Quality	??	The effectiveness of this kind of well treatment has not been determined by any sources.
Total Quantity	3	There would be no improvement in water supply than the wells currently used in La Ceiba.
Drinking Quantity	3	There would be no improvement in water supply than the wells currently used in La Ceiba.
Monthly Cost	0	Hand pumps are used, so there would be no monthly cost.
Employees	0	No employee is needed.
Satisfaction	2	The health of the community would improve, but the wells may still dry up during the summer months.
EWB Cost	$12,817.63	Estimation is shown in Table 10.

Table 23: Distribution System (15 public faucets)

Criterion	***Value***	***Rationale***
Quality	5	At a depth of 70-100 feed, the groundwater is assumed to be clean and safe to drink.
Total Quantity	5	A well with a large enough capacity pump will be able to provide enough water for all the community's daily needs.
Drinking Quantity	5	As stated above, the drinking and cooking water requirement would easily be met.
Monthly Cost	$1-$2	This is estimated for the electrical demand of the pump, and the salary of the employee needed to run the system.
Employees	1	An employee would be needed to keep the system running smoothly and perform routine cleaning and maintenance.
Satisfaction	4	The community would gladly accept this solution, but hopes to one day upgrade to household connections.
EWB Cost	$19,903	The cost estimation for this alternative is given in Table 11.

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Table 24: Distribution System (Household connections)

Criterion	***Value***	***Rationale***
Quality	5	At a depth of 70-100 feed, the groundwater is assumed to be clean and safe to drink.
Total Quantity	5	A well with a large enough capacity pump will be able to provide enough water for all the community's daily needs.
Drinking Quantity	5	As stated above, the drinking and cooking water requirement would easily be met.
Monthly Cost	??	The monthly cost for the full distribution system with household connections would still have to be determined.
Employees	2	With so many connections, it would be overwhelming for just one employee to supervise the entire system.
Satisfaction	5	This represents the best-case scenario for the town of La Ceiba
EWB Cost	~$50,000	An in-depth cost analysis has not been performed, but the cost is estimated at more than twice the cost of the public faucets.

Overall Matrix

Table 25 was generated to compare the alternatives to one another. Using this data, the best alternatives were selected based on the criteria discussed in the previous section. The top two solutions will be presented to the community of La Ceiba to determine which one will be implemented.

Table 25: Overall Solutions Matrix

Alternatives	***Quality*** *Zero Fecal*	***Quantity Total*** *100GPD*	***Quantity Drinking and Cooking*** *15 GPD*	***Monthly Community Cost*** *$/House*	***Employees***	***Satisfaction*** *1-5 (Happy)*	***EWB Cost***
No Action	0	0	0	0	0	0	$0.00
Education	1	0	2	0	0	0	$1,000
Extra Jugs	4	1	4	0	0	1	$1,020
Slow Sand filter	5	2	5	??	1	3	> $100k
Bio-Sand Filter	4	1	4	0	0	3	$2500 - $5500
Ceramic Pot Filtration	4	1	4	$1	0	3	$3,000
Solar Disinfection	4	1	4	0	0	1	$8,000
Moringa Seed Treatment	3	1	4	0	0	1	TBD
New Latrines	??	0	0	0	0	1	$51,000
New Wells	4	3	3	0	0	3	> $100k
Renovation of Old Wells	??	3	3	0	0	2	$12,818
Community Distribution 15 Public Faucets	5	5	5	$1-$2	1	4	$19,903
Full Distribution Household Faucets	5	5	5	??	2	5	~$50,000

The top two solutions appear to be the community distribution system with 15 public faucets and the household biosand filters.

The best solution that is economically feasible for Rowan EWB to implement is the community distribution system with 15 public faucets. While the community would like household connections, EWB cost limitations, as well as possible community costs, prevent that option from being considered at this time. The distribution system in general is the best for water quality and quantity, providing the full 100 gallon per day clean water requirement of each household. It has a low monthly cost, and will provide the best feasible satisfaction to the community, so it will be presented as one of the main solutions for La Ceiba.

On a household level, biosand filters appear to provide the significant benefit to the community at a much lower cost. With very little maintenance, low cost, and the ease of use, they will provide clean drinking and cooking water to the community, thus improving their quality of life. Biosand filters were chosen to be presented to the community over ceramic pot filters because they have no monthly cost as a result of their indefinite lifetime.

In addition to the presentation of the two best solutions to La Ceiba, it would be greatly beneficial to implement the education alternative as a supplement. This would reinforce the correct method of treating their water with PuriAgua tablets, so that the community would be able to have clean water from their wells or in the time before a permanent solution is implemented.

In March 2008, students from Rowan University's EWB chapter returned to La Ceiba, El Salvador for a second assessment trip. On this trip the entire town was resurveyed, this time including the location of wells and houses. Water depth measurements were taken for some of the hand dug wells around the community. Two separate meetings were had with the community to explain the potential design options. It was determined that the community was committed to the idea of installing a town well, with a pump, tank and community distribution system. The people of La Ceiba were informed of all associated costs and labor, and told which property they needed to acquire for the well and holding tank. The detailed design of the system is currently being completed. In addition to the decision to move forward with a distribution system, several families in the La Ceiba said they were planning on purchasing a biosand filter from a local vendor.

Conclusion

The community of La Ceiba has lived for years with contaminated water. They have had many child deaths in recent years, and want a source of clean water. The Engineers Without Borders Chapter at Rowan University assessed the problem in May 2007 and since then has been working diligently to bring a continuing supply of clean water to the community. Many water treatment alternatives were researched and evaluated based on what were decided to be the most important criteria for implementation. Cost estimates were made for each alternative to decide if there were any financial limitations. The evaluations for all of the alternatives were place on a table to perform an overall comparison. This comparison took into account the scale and effectiveness of each solution and the best options were selected.

The townspeople of La Ceiba were presented with two possible solutions: biosand filtration, and a distribution system with 15 community spigots. Given these options, the townspeople chose to proceed with the community distribution system. A detailed design is being performed and the system will soon be constructed.

Rowan EWB came to La Ceiba with years of experience in water supply, treatment, and distribution systems for developing countries. The approach used in this project follows the general engineering method of problem solving, and can be applied not only to EWB projects, but to other design problems. The methodical approach used here will prove to be beneficial for the citizens of La Ceiba. They will soon have a source of clean drinking water, which will improve their overall health, and thus their quality of life.

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