ME 423 ENGINEERING DESIGN VII

PHASE III – FINAL REPORT

Engineers Without Borders: Water Purification System

A SENIOR REPORT

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Abstract:

The objective of the group is to create a water purification system that provides clean drinking water for a theoretical community. The project is important because water pollution is a major world-wide problem. This system will offer a solution to a group in need. The following report includes different technologies that are on the market now. Some of the main technologies used in water purification systems include: carbon filtration, ultraviolet light filtration, reverse osmosis, ozone filtration, and sediment filtration. The group has documented the positives and negatives of each device and has put together concepts that they feel will purify the water. The group will purify the water according to the Environmental Protection Agency's definition of what is safe drinking water. To obtain the objective the group has put together a project management plan that divides the tasks amongst the group. The objective for design will be to optimize the system to provide clean drinking water at the lowest possible cost.

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Introduction

The water sanitation crisis is the greatest public health problem that the world is facing today. The good news is it is a problem that can be solved in the near future with the hard work of good engineers who have strong public support. The technology necessary to provide people in need with clean water already exists. It is merely a matter of finding a way to implement these technologies into the existing communities at a low cost and without disrupting the lifestyle of the communities being helped. It is the idea that is at the center of this project.

Objective

The objective of the group's Senior Design project is to design a Water Purification System that will provide safe drinking water to benefit a community in need. This will be done in the form of an Engineers Without Borders (EWB) research project. With a EWB research project, the system is designed for a theoretical situation and when EWB is ready to implement the project, the design is adapted by the organization to fit the need of the community that they find. In terms of this project, the group will create a specific design for a theoretical area in order to show how a water purification system design should be developed and also provide the information need for EWB to adapt that specific design to the widest array of situations possible. In keeping with EWB guidelines, the design would have to be able to be implemented at the lowest cost possible and it must be able to be maintained by the local population. It is this criteria that will direct the course of the project.

Impact and Significance of the Project

The decision to design a water purification system for the third world was based on the fact that water sanitation is such a large problem in the world today. The extent of this problem cannot be understated. According to the United Nations, an estimated 1.1 million people across the globe do not have access to clean drinking water. That represents roughly 18 percent of the world's population. This problem is expected to be exacerbated by an estimated worldwide population increase of 1 billion people by 2015, mostly resulting from developing nations. It has also been estimated that by 2025, two-thirds of the world's population will face moderate to severe stress on their water supply[1].

There are many causes for the shortages of sanitary water supplies. Part of the problem is simply the amount of consumable water available. Only 2.5 percent of the water on Earth is fresh water and 68 percent of that is frozen. Much of the remaining water is simply wasted. About 70 percent of available freshwater is used for irrigation for agriculture. Nearly 60 percent of that water is lost to evaporation or goes back into rivers. Furthermore, as much as 30 percent of the water supply in developing countries is lost due to leakage. That number can reach 40 to 70 percent in some major cities. A second cause for the water scarcity is an increased strain on the water supplies worldwide over the years. Water usage increased 600 percent in the 20th century while the total population increased 300 percent. That means that the per capita water usage rater doubled worldwide over that time. Additionally, in the United States, India, and China, water usage is outpacing nature's ability to replenish it[1].

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1 "Fact Sheet on Water and Sanitation." United Nations Water for Life Decade. 2006. 11 September 2007 < http://www.un.org/waterforlifedecade/factsheet.html>.

With the scarcity of water at such high levels, it is imperative to keep the remaining water clean. With that being said, roughly 90 per cent of sewage and 70 percent of industrial wastes in developing countries are dumped into water sources without treatment, polluting much of the usable water supply. This has resulted in a health nightmare that has had a tremendous human toll. More than 2.2 million people die every year from diseases resulting from unsanitary water conditions. Over 90 percent of those deaths are of children under the age of five. According to a report by the World Health Organization, two water-related diseases (diarrhea and malaria) ranked 3rd and 4th place in the cause of death among children under 5 years old. That represents roughly 17 percent and 8 percent of all deaths, respectively. In sub-Saharan Africa, where clean water is hard to come by, a baby's chance of dying from diarrhea is nearly 520 times that of a child in the developed nations[1].

The aim for this project is to make a contribution to the solution of this problem by building a water purification system for a town in Puerto Rico. Groundwater samples in the area detected chlorinated solvents in the water. The amount of chlorinated solvents detected has exceeded the federal Safe Drinking Water Maximum Contaminant Level. This is dangerous because chlorine can produce a by-product that is a carcinogen. If this project is successful, it will provide the people of this village with clean drinking water and, in turn, improve the public health of the area.

Theoretical Location

For EWB research projects, it is recommended to keep the design as general as possible in order to make it adaptable to the widest range of locations possible. For that reason, a specific location was not chosen as for where to design the project. Instead, a theoretical place was developed for which the design could be based upon. That would prevent the group from having to make a design to fit a specific place yet could not be used in many other situations. For this project, a theoretical village of 400 people was chosen. Those people would be divided into 60 homes. There water source was chosen to be a well of 300 ft. The 300 ft depth is based in the researched average well depth. The village was chosen to be located 1500 ft from the well. The water was decided to contain sand, soil, algae, fecal Coliform, trichloroethane, Total Trihalomethanes (TTHMs), Toxaphene, Trichloroethylene, and fungi. These contaminants were chosen from a list of possible contaminants in water that was compiled by the Environmental Protection Agency[2]. It was for these criteria that the water purification system was designed.

Water Testing

When designing a water purification system, it is necessary to first test the water that is targeted for purification in order to determine the type of system that is needed. There is no perfect technology that can remove every type of contaminant from the water. Each technology can only remove certain contaminants from the water. Multiple technologies would need to be linked together in a system in order to cover the various contaminants in the water. That is why it was necessary to research water testing in order to find a company that could test the water at the

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[2] "Stainless Adjustable Pipe Brackets." Reliner. 4 December 2007 <http://reliner.com/brackets/index.htm>.

location where the system will be implemented. The group found a company called Stevens Ecology[3] which would take a sample that they receive from the group and analyze it to determine what contaminants the water contains. After the analysis is done, the group will receive a report of the contaminants in the sample. The testing is only $95, so it could also be performed every six months to a year once the system is in place, to make sure the system is still functioning properly. With this testing is in place, the system will be able to be designed properly and function properly for a very long time.

Existing Systems

The group looked at what other water purification systems were out there that were made by non-profit organizations. The group hoped to use these systems as guides to determine the best ways to purify water with reduced costs. Being as this is an Engineers Without Borders project, it is crucial that the system is both low-cost and low-maintenance. The other non-profit projects provide examples of different ways to accomplish the goal of purifying water while still meeting the requirements of EWB.

There have been several Engineers Without Borders projects that deal with water purification. The EWB chapter at the University of Maryland - College Park has done water purification projects in Ecuador, Brazil, and Thailand[4]. They used slow sand filters in conjunction with chlorination in order to remove the sediment and bacteria that was found to be in the water in those locations.

Another EWB chapter at Seattle University designed and built a water purification system for a children's dormitory that they had previously worked on in Thailand[5]. Their design was based on a previous assessment by the California Polytechnic State University at San Luis Obispo that suggested using a 50,000 gallon water tank elevated 300 feet above the dormitory area as the water source. There was already an electrical system in place the so the only needed to design the filtration. The used a spin down filter, two sediment filters, a carbon filter and a UV filter to eliminate the e coli and Coliform that was contaminating the water.

The EWB chapter from the University of Arizona – Tucson Arizona designed a water purification system in Mafi-Zongo[6]. A water purification system consisting primarily of slow sand filtration was previously built there, but it was experiencing problems and not functioning properly. The chapter decided to use a horizontal flow gravel roughing filter to alleviate the conditions that were causing the problems with the slow sand filtration.

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[3] Stevens Ecology Analytical Laboratory Services: Water, Soil, Food, Atmosphere Testing." Stevens Ecology. 4 December 2007 < http://shop.stevensecology.com/main.sc>.

[4] "Project: Ecuador - Province of Azuay." EWB-USA. 2 November 2007. <http://ewb-usa.org/project_search.php?op=project&ID=312>.

[5] "Drinking Water System for the Children's Dormitory." Seattle University. 2 November 2007. < http://students.seattleu.edu/clubs/ewb/projects/mnkwater.htm>.

[6] "Project: Ghana - Mafi Zongo." EWB-USA. 2 November 2007. < http://ewb-usa.org/project_search.php?op=phase&ID=435>.

The EWB professional chapter from NASA Johnson Space Flight Center designed a water purification system for a hospital in Mugonero, Rwanda[7]. The hospital serves around 5,000 people at any given time. The chapter had previously built a 10,000 liter rainwater catchment system there and the required a system to filter that water. They went with a UV filtration system as the rainwater system where the water was coming from did not allow much sediment or other inorganic contaminants to enter the water supply.

Healing Waters, a non-profit organization working in the Dominican Republic created a system there composed of sediment filters, reverse osmosis, and UV disinfection[8]. They place this technology at contaminated water sources around the country and sell it to the people at below the market rate. The profits are then used for community development projects like job training and day care. This information provided valuable precedents to help the group to determine what methods of water purification systems were suitable for the capabilities of non-profit organizations.

State of the Art

Below is a chart of all the filter technologies on the market that the group performed research on and has considered as a possible filter for the water purification system. The information on this chart allows a different EWB group that is looking to implement the system to find the filters that are needed to treat the water. The chart provides the contaminants removed by each filter, the flow rate capabilities that the group was able to find, the maintenance required for each filter, and lastly the negatives of each filter.

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7 "Project: Rwanda - Kibuye." EWB-USA. 2 November 2007. <http://ewb-usa.org/project_search.php?op=project&ID=133>.

8 Program Expansion Scoping Study – Dominican Republic. Denver: Water For People, 2007.

Filter Chart

Name of Filter	**Contaminants it Removes**	**Flow Rate (GPM)**	**Maintenance**	**Negatives**
Ultraviolet Water Purification System	Bacteria / Viruses, Yeast, Mold Spore, fungi, algae, Fecal Coliform	0.25 to 5000+	Cleaning the quartz sleeve with the manual wiper once monthly or more frequently if the conditions dictate. Lamp replacement every 10,000 hours of operation approximately 14 months of continuous service.	The standard radiant does of the systems are 30,000 microwatt-sec/cm^2 which is enough to kill most but not all water-born bacteria. If ultraviolet purification cannot remove a microorganism in the water. Ultraviolet lamps are designed to operate for approximately one year, radiant output of the ultraviolet lights progressively decreases. Required pre-filtration to maintain effectiveness (the water must be pure water containing only microorganisms). Inability to remove endotoxin. The system should be close to point of distribution as possible.
Ozone	Filters trihalomethanes, organochlorine compounds, and deodorizes the water by removing geosmine and 2-methylisoborneol If used with GAC: removes agricultural chemicals, industrial waste, and reduces total organic carbon (TOC), methylene blue active substances (MBAS), chlorine, and potassium permanganate (KMnO4), destroys all types of microorganisms instantly (including ecoli), decomposes organic waste by oxidation, removes calcium carbonate by destroying the biomass glue bonding agent, removes legionella (the cause of Legionnaires disease), removes sulfide, removes bromide.	10.0 to 416,700	Low Maintenance.	The systems are expensive (1million GPD for $1M dollars), The system requires the use of a water softener, The system requires the water to be less than 45 deg C .
Chlorination	Destroys disease-causing bacteria, nuisance bacteria, parasites and other organisms. Chlorination also removes soluble iron, manganese and hydrogen sulfide from water	N/A (Usually for wells a 2-3 minute contact time is needed for continuous Chlorination)	The water must be continually tested on a regular basis	Only a temporary measure, not for permanent purification, nitrates are not removed from water by chlorination, chlorination causes a smell and bad taste to the water, may lead to the formation of Trihalomethanes (THMs) (more likely in surface water), Cannot be used with Carbon Filtration

Activated Carbon	Remove tastes, Removes Odor, Removes color, Inorganic Contaminants reduced to acceptable standards: Organic Arsenic Complexes, Organic Chromium Complexes, Mercury (Hg+2) Inorganic, Organic Mercury Complexes, Organic Contaminants: Benzene, Endrin, Lindane, Methoxychlor, 1,2-dichloroethane, 1,1-dichloroethylene, 1,1,1-trichloroethane, Total Trihalomethanes (TTHMs), Toxaphene, Trichloroethylene, 2,4-D, 2,4,5-TP (Silvex), Para-dichlorobenzene, Foaming Agents (MBAS).	5-150	Replace the filter every 9 months	Could be a breeding ground for microorganisms, the organic chemicals absorbed are a source of food for various types of bacteria.
Kinetic Degradation Fluxion (KDF)	Chlorine, lead, mercury, iron, and hydrogen sulfide, magnesium, chromium. Inhibits the growth of bacteria, algae, and fungi may reduce the accumulation of lime scale	N/A	Replace the filter every 8 months to 1 year.	Should be combined with other filtration methods to be fully effective (the filter is often combined with Carbon Filtration).
Reverse Osmosis (RO)	RO removes most sediments and particulates down to less than 0.005 microns, most microorganisms: bacteria, viruses, cryptosporidium, Giardia, most heavy metals, asbestos, chlorine, fluoride, a wide range of volatile organic compounds, pesticides, herbicides, removes bad tastes, bad smells, color, nitrate, sulfate, sodium, total dissolved solids, inorganic chemicals: salts, metals, minerals, aluminum, arsenic, barium, cadmium, chloride, chromium, copper, magnesium, iron, lead, manganese, mercury, nitrate, selenium, silver, sulfate, zinc, asbestos, turbidity, radium.	1500 GPD to 50000 GPD	The RO membrane must be periodically flushed with water. Some RO systems are equipped with automatic membrane flushing to clean the membrane. The membrane must be replaced every 2-3 years.	RO systems are not appropriate for treating water supplies contaminated by coliform bacteria. RO systems use a lot of water. They recover only 5 to 15 % of the water entering the system; the rest is discharged as waste water. Pre-treatment with water softeners, sediment filtration, and activated carbon pre-filters, and post filtration with UV, ozone, and a post activated carbon filtration is recommended.

Sediment Cartridge/Bag Filtration	sand, salt, loose clay, organic material, insoluble (not dissolvable) or suspended iron and manganese	50 to 2000	Regular replacement of the filter/cartridge is a criticalfactor in maintaining effectiveness and reducing bacterialcontamination of the filter.	Bacteria could potentially accumulate on the filter.
Slow Sand Filtration	Removes Giardia cysts, coliform and some bacteria, solids, precipitates, turbidity.	0.26 to 2.64	Replacement of the sand in the top layer, for the automated system replacing the sand containers, periodic backwashing.	Produces water at a slow rate, the filter performance progressively decreases over time.
Water distillation	Nitrate, bacteria, sodium, hardness, dissolved solids, organic compounds, heavy metals, and radionucleids.	800 to 6000 GPD	The boiling chamber of a distiller should be emptied more than once a week for continuous distillation. Must clean the distiller with an acid cleaner to remove mineral scale build up.	It is not economical to distill water for flushing toilets, bathing, washing clothes, and cleaning. Bacteria removed by distillation may colonize again on the cooling coils during inactive periods. Distillers have small capacities. Distillers with no gas vents, fractional columns, or activated carbon filtration will not remove volatile organic compounds. If the boiling chamber is not cleaned more than once per week the distiller's efficiency decreases.
Water Softener	Calcium, magnesium, 10ppm of iron, 10ppm of manganese	15 to 85	The softener must be back flushed with salt brine solution, for automated systems the salt brine solution will have to be replaced. The tank will have to e cleaned.	Sodium is added to the water. Water softeners may reduce the effectiveness of sewer system. Iron or Hydrogen sulfide in excess can make the softening system less effective, and pre-treating the water may be required.

Through a comparison with what current filters can eliminate in the water supply as to the information provided by the EPA[9] has found in them shows that in the situation that we are looking for, our filters eliminate 95- 99% of all contaminants in the water. The only contaminants found that are not able to be eliminated from the water are extreme conditions such as wastes from big petroleum or other chemical companies that pollute the water ways with harmful chemicals. Since our case we aren't designing our base system for these conditions; we

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[3] "Stainless Adjustable Pipe Brackets." Reliner. 4 December 2007 <http://reliner.com/brackets/index.htm>.

are more concentrated on poorer, rural areas, we won't need to filter out such contaminants that they produce. So we have fulfilled more then required by EPA to eliminate almost all harmful elements from water sources in the environment.

Conceptual Designs

The way in which the community currently gets its water would go a long way in determining what type of design would be needed for the water purification system. One area to look at would be how they are currently getting their water from the well. If they have an automated pump in place to get the water from the well, that system can still be used as long as the pumps are sufficient for the design. If the have a pipe sticking out of the ground with a manual pump attached, the design would merely remove the manual pump and attach the appropriate automated pump in its place. If they have well with a classical stone or a cement wall through which they drop a bucket, piping would need to be installed down the well and bracketed to the wall. For this design, the third option was chosen as that is the worse-case scenario with the largest cost for which the water extraction could be designed.

The next condition that would need to be determined is current distribution system in the targeted community. They would either have no plumbing, such as the previously stated situation of manually pumping water from the well, or they would have a plumbing system in place. If they have a plumbing system, a section of piping could be cut out and the filtration system put in its place. This would be the most cost-effective situation as no pumps and minimal piping would need to be purchased. If they have no plumbing, a pumping system would be needed to extract the water from the well and distribute it to the people. It is that case that was chosen for the theoretical village as it presented the greatest amount of opportunities for engineering design.

With the case settled, it then had to be determined what type of distribution to incorporate into the design. The first type that was looked at was to distribute the water to a faucet in each of the sixty homes in the village. This would require a 60 GPM flow rate for the system to be able to supply each house with 1 GPM of water if every house was using their faucet at the same time. The problem with this idea is its cost and logistics. Every filter has a limit on the flow rate at which it can effectively purify the water. At this flow rate, any effective system was found to cost $20,000, without factoring in the costs for thousands of feet of piping as well as pumps. The highest project budget that was seen on the EWB website was $25,000. When the price of the piping, pumps, controls, and other miscellaneous expenses were factored in, the total price was greater than the known EWB fundraising capabilities. Another problem was the logistics of providing plumbing for every home. That is a large-scale public works project that normally is done by government institutions. It was determined that EWB would not likely possess the resources to undertake an endeavor of this size and magnitude.

It was decided instead to pump the water from a well to a water tank within the town. That system would require smaller filters at much lower costs. Plus, it would require smaller pumps, less piping, and less controls. It would also be much more manageable for EWB to implement. While it would be ideal to distribute the water to each home, the financial limitations of EWB cannot be ignored. This distribution system can not be designed to US standards because the funding of a non-profit organization such as EWB is nowhere near the US government budget for public works projects, nor are their resources at that level. According to a report from Water For People assessing the water situation in the Dominican Republic, distribution tanks are commonly used by non-profit organizations to compensate for their relative lack of funding and resources while still providing adequate water purification[10]. This is important to keep in mind when evaluating the design. If the people were able to live with traveling to the well to get their water previously, then they certainly will be able to get their water from a tank in the middle of their village. The important thing is that their water would be safe to drink, cook with, and bathe in when they get it from the system from the chosen design.

Detailed Design

The final design was chosen to have two pumps in series that would pump the water from the well and through a series of filters into a storage tank. The user would open two valves at the outlet of the tank in order to extract water from the system. The flow of water into the tank would be controlled by a control system. The details of the design and the rationale behind them are listed below.

Before creating any water purification system, it is important that the water source for which the system is being created is first tested. Testing the water will determine the contaminants in the water. After the contaminants are found, a purification solution can be formulated and the filters can be chosen (Please see the above State of the Art section for the possible water purification filters).

For the case selected for this project, the filters chosen were a 100 micron sediment filter, a 25 micron sediment filter, a 5 micron sediment filter, a carbon filter, and an ultraviolet filter. The sediment filters were chosen because the well water contains sand and soil particles. The 100 micron filter would remove the sediment and soil particles larger than 100 microns which will help to prolong the life of the 25 micron filter by reducing the range of large particles that the filter would have to remove. The 25 micron filter would remove all the particles between 100 and 25 microns. This would help to prolong the life of the 5 micron sediment filter by reducing the range of large particles the filter would have to remove. The 5 micron sediment filter would remove the particles between 25 and 5 microns in size. That would prolong the life of the carbon filter by removing the particles larger than 5 microns and preventing the carbon filter from being used for particle removal. The 5 micron filter would be able to remove all the sand and most of the silt found in water.[11] The three sediment filters would also help make the water particle-free which would allow the ultraviolet purification filter function effectively. Any particles in the water could prevent the ultraviolet rays from reaching some microorganisms and therefore reducing the effectiveness of the ultraviolet purification[12]. The carbon filter was chosen because the water contains Triclorethane, Trihalomethanes (TTHMS), Toxaphene, and Trichloroethylene.

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[10] Program Expansion Scoping Study – Dominican Republic. Denver: Water For People, 2007.

[11] "Particle size." Wikipedia: The Free Encyclopedia. 15 September 2007 <http://en.wikipedia.org/wiki/Particle_size_%28grain_size%29>.

[12] "Ultraviolet Water Purification - UV." Home Water Purifiers and Filters. 15 September 2007 <http://www.home-water-purifiers-and-filters.com/ultraviolet-filter.php>.

Carbon filters can effectively reduce those contaminants until the water is up to drinking water standards[13]. The carbon filter would also help to make the water as pure as possible and allow the ultraviolet purification to function more effective. Lastly, the ultraviolet purification system was chosen in order to filter out the algae and the fecal coliform.

The deciding factor for the size of the filters was choosing a flow rate for the system. It was decided for the theoretical case that the people of the community would normally get their water by lowering a bucket into the well. With the chosen design, the people of the community would only have to open the valve at the outlet of the tank and the tank would then drain and push the water through the ultraviolet purification system and out to the people. The ultraviolet purification system has a flow rate limit of 12 gpm with a 1 in inlet and outlet diameters. This size system was chosen because it is a cost effective system that would be capable of handling the water flow from the tank while still allowing an adequate flow rate to meet the needs of the people. The three sediment filters have a service flow rate of 20 gpm and an inlet and outlet diameter of 1 in and the carbon filter has a service flow rate of 15 gpm and also a 1 in inlet and outlet diameter. The filters of the initial filtration system were chosen because they are still cost effective size yet are able to handle a higher flow rate than the ultraviolet filter. For the worst case scenario, the tank would be able to be refilled in a faster time than the water can flow out of the tank. This is due to the higher flow rates of the three sediment filters and the carbon filter in comparison to that of the ultraviolet filter.

Due to the 1 in diameter inlet and outlet of all the pumps, all the piping must also have a 1 in diameter. The well water is 300ft from the surface and the pipe from the water purification system was chosen to be submerged 20 ft in the water. That meant that 320 ft of PVC pipe would be needed for the pipe in the well. The pipe would need to be bought in 10 ft sections and for the well it would require 32 sections. This is due to the lengths of PVC available to purchase as well as the need to be able to transport the materials. For the section of piping connecting the pumps and filters before the storage tank, 9 ft of UV resistant PVC piping would be used. This type of piping was chosen to minimize the negative effects of the sun on the pipes. This section would also have 1616 ft of piping under the ground to allow the storage tank to be stationed within the village. The regular PVC pipe can be used in the ground, as well as in the well, because it would not be hit by the sun's UV rays. The piping used to connect the carbon filter to the storage tank would need to be bras pipe. The brass pipe is needed because the actuated valve used on the system requires the piping connecting to it to be threaded. This section would require 12 ft of piping.

To connect the pipe to the wall of the well, 1.5 in diameter brackets would be used. The brackets would be placed every 10ft of the pipe in the well, totaling 32 brackets in all. To connect the sections of PVC pipe, straight couplings would be used. At different points in the system, 90° elbows would need to be used for the piping to connect the system. There are six 90° PVC female elbows and two 90° Brass female elbows in the design.

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[13] "Activated Carbon Filtration." North Dakota State University. 11 November 2007 <http://www.ag.ndsu.edu/pubs/h2oqual/watsys/ae1029w.htm>.

Using the length of the pipes and the filters, the roughness of the pipes, and the pressure drop from the filters, pump calculations were performed and a pump was sized. The head required for the system was found to be greater than one pump could provide, and therefore the group went with two of the same pump placed in series. Using two pumps in series was a more cost effective measure than using one larger pump. The two pumps chosen were both 5 horse power single phase stainless steel pumps. The service flow rate for the system was calculated to be 15 gpm (Please see below in the calculations section for a more detailed explanation).

In order to control the flow of the water and to keep the storage tank full, a Water tank level controller would be installed on the tank. The control is installed at the top of the tank and a cable with a sensor at its end is inserted into a hole at the top of the tank. The sensor measures the level of the water in the tank and that information if relayed wirelessly to a controller that controls the pumps and the valves. The level controls will be set to where the system will shut off the pumps and close an actuated ball valve at the inlet of the storage tank when the water in the tank reaches 8ft in height. To receive water, the person using the system will open a PVC globe valve at the outlet of the storage tank and a second PVC globe valve at the water outlet point to retrieve the water. When the water in the storage tank reaches 4 ft, the level controller will turn on the pumps and open the actuated ball valve and the water would refill in the tank until the water level of the tank reached 8ft. At that point, the pumps would once again shut down and the inlet valve would again close.

Lastly, the group considered how to protect the system from possible vandalism or from physical damaged from natural sources. Part of the solution was to put the 1600 ft of PVC pipe that brings the water from the well to the people underground. That would protect that section of piping from nature and require someone to go through the effort of digging the pipes of in order to do any damages. To protect the filters, individual lockable cases will enclose the three sediment filters, the carbon filter, and the ultraviolet filter.

The system, itself would work as follows: The person looking to get water would go to the storage tank turn on the power for the ultraviolet light and then open the outlet globe valve for the tank. The person would then go to the end of the tank where the water would be flowing from and open the globe valve to receive the water. The reason the ultraviolet filter is at the end of the system is to ensure that the water that flows to the people is free from bacteria, algae, and fecal coliform. The belief is that when the water is in the storage tank it is stagnant and there is the potential for the bacteria to grow. To ensure that there is no bacterium in the community’s drinking water, the last possible step before the water is received by the people is for the water to flow through the ultraviolet filter. Once enough people get water and the tank level goes below 4 ft, the water level controller would open the actuated ball valve and turn on the pumps that would pump the water from the well through the 100 micron sediment filter, the 25 micron sediment filter, the 5 micron sediment, through the carbon filter, and into the storage tank. When the user is finished with the system, the procedure is to close the water outlet flow globe valve, then close the globe valve at the outlet of the storage tank, and lastly to shut off the power of the ultraviolet filter. This is because the ultraviolet filters require a constant flow of water to eliminate the possibility of the bulbs overheating so the bulbs would need to be immersed in water at all times[14]. The reason why the user will shut off the ultraviolet filter is to extend the life of the ultraviolet bulbs and to save electricity.

All the while, the group had to keep in mind the requirement of Engineers Without Borders for the system to be easy to maintain. For the three sediment filters the bags should be replaced every month. Please note that the price given for the sediment bag is actually for 20 bags at each purchase. The group would order two shipments of sediment filter bags. This would give the community forty bags which if they change every month would last the community three years and six months before new bags will have to be ordered. To maintain the carbon filter they would have to change the filter cartridge every year. To maintain the ultraviolet filter, the filter's quartz sleeve would have to be manually cleaned once a month with the manual wiper. The ultraviolet bulbs would have to be replaced every year. The actual life for the ultraviolet bulbs is approximately 10,000 hours, however the bulbs decrease in strength over time and therefore to ensure that the bulbs are still at an effective strength to successfully purify the water, the bulbs would be changed once a year. The last maintenance step would to test the filtered water every six months to a year (please refer to the testing section above). Continual testing would ensure that the system is successfully filtering out all the harmful contaminants and that the water is safe to drink.

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14 "Ultraviolet Sterilization Systems for Commercial & Industrial Applications." Aqua Technology. 11 November 2007 <http://www.aquatechnology.net/Ultraviolet_systems.html>.

The Maintenance Cost:

Part #	Qty	Description	Supplier	Price	Total Price	Yearly Cost
PO100G3S	1	100 micron Polypropylene Felt Filter Bags	Waterfilters.net	$69.99	$69.99	$3.89
PO25G3S	1	25 micron Polypropylene Felt Filter Bags	Waterfilters.net	$89.99	$89.99	$49.99
PO5G3S	1	5 micron Polypropylene Felt Filter Bags	Waterfilters.net	$89.90	$89.90	$49.94
BBL	1	10 micron Carbon Block	Pure Water Express	$78.00	$78.00	$78.00
05-1343	1	UV Lamps	Ultraviolet Water Purifier	$99.50	$99.50	$99.50
Testing	2			$95.00	$190.00	$190.00
Cost per year		$471.33				

Technical Analysis

Pump Analysis

The variables used in the pump calculations are listed below. The length used in the pump calculations includes the length of the pipes as well as the length of the filters. The roughness value is for PVC pipes. That roughness was also used for the brass piping section. Since that section is so small compared to the entire length of the system and the roughness values of the two materials are separated by only 0.000002 ft, that assumption was deemed acceptable.

$L = 1968$ ft

$\rho_{water} = 1.94$ slug/ft^3

$\epsilon = 0.000005$ ft

$g = 32.2$ ft/s^2

$D = 1$ in $= 0.083$ ft

$K_{elbow,PVC} = 0.5$

$K_{elbow,Brass} = 1.5$

$K_{Valve} = 8.2$

$\Delta P_{\text{Sediment Filter}} = 15$ psi

$\Delta P_{\text{Carbon Filter}} = 5$ psi

The following two equations govern pump calculations. The second equation was used for this analysis since the losses due to the filters were only available in pressure drop.

$$H = z_2 - z_1 + \frac{V^2}{2g}\left(f\frac{L}{D} + \sum K\right)$$

$$\Delta P = \rho g(z_2 - z_1) + \frac{\rho V^2}{2}\left(f\frac{L}{D} + \sum K\right)$$

A pump was chosen based on its pump performance curve and its expected performance in the system in which it would be inserted. It was expected that at least two of these pumps would be required for this system, but that was deemed acceptable since no pumps were found in the acceptable price range that would be expected to provide the required head and flow rate on its own. Since it was known that the head required for the system was greater than what the pump could provide, it was decided to use two pumps in series. An arbitrary elevation difference of 30 ft was used to get a system curve that could fit on the pump performance curve in the initial analysis.

$$\Delta P = (1.94 \text{ slug/ft}^3)(32.2 \text{ ft/s}^2)(30 \text{ ft}) + 3(15 \text{ psi}) + 5 \text{ psi} + \frac{(1.94 \text{ slug/ft}^3)V^2}{2}\left(f\frac{1968 \text{ ft}}{0.083 \text{ ft}} + 8.2 + 6(0.5) + 2(1.5)\right)$$

$$\Delta P = (0.0011 \text{ slug/in}^3)(32.2 \text{ ft/s}^{2)}(360 \text{ in}) + 3(15 \text{ psi}) + 5 \text{ psi} + \frac{(0.0011 \text{ slug/in}^3)V^2}{2}\left(f\frac{1968 \text{ ft}}{0.083 \text{ ft}} + 8.2 + 6(0.5) + 2(1.5)\right)$$

$$\Delta P = 62.75 \text{ psi} + 0.00055V^2\left(f\frac{1968 \text{ ft}}{0.083 \text{ ft}} + 14.2\right)$$

guess $f = 0.015$

moody chart $\rightarrow \mathrm{Re} = 4500000$

$$\frac{1}{f^{1/2}} = -1.8\log\left[\frac{6.9}{4500000} + \left(\frac{0.000005 \text{ ft}/0.083 \text{ ft}}{3.7}\right)^{1.11}\right]$$

$f = 0.0114$

$$\Delta P = 62.75 \text{ psi} + 0.00055V^2\left(0.0114\frac{1968 \text{ ft}}{0.083 \text{ ft}} + 14.2\right)$$

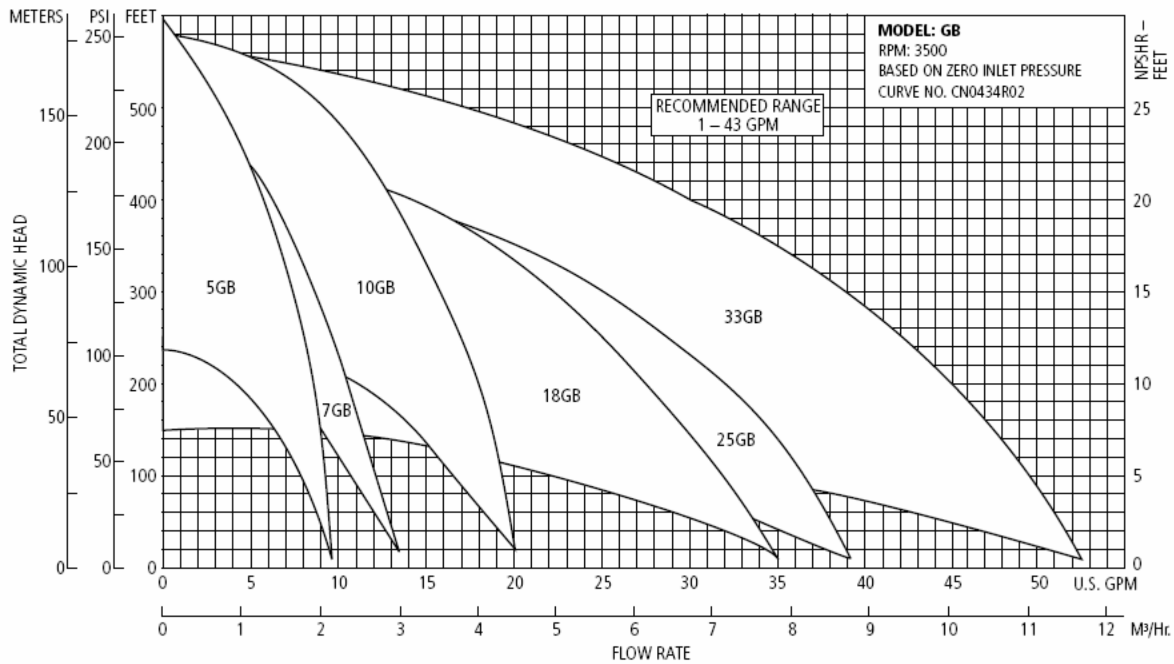
$$\Delta P = 62.75 \text{ psi} + 0.156V^2$$

$$\Delta P = 62.75 \text{ psi} + 0.0965Q^2, \text{ Q in in}^3\text{/s}$$

$$\Delta P = 62.75 \text{ psi} + 1.43Q^2, \text{ Q in GPM}$$

This equation can be used to compare the system with the performance curve of the pump.

PERFORMANCE COVERAGE 60 HZ, 3500 RPM



The point at which the system performance curve formulated from the equation above and the performance of the pump labeled 33GB intersect was determined. It is:

$$\Delta P = 235 \text{ psi}, \; Q = 11 \text{ GPM}$$

A parabolic formula was then formulated using the 240 psi level at which the curve begins and formulating the rate at which the pressure would need to drop in order to end up at 235 psi at 11 GPM.

$$\Delta P = 240 \text{ psi} - x(11 \text{ GPM})^2 = 235 \text{ psi}$$
$$\Delta P = 240 \text{ psi} - 0.0413Q^2$$

That equation is doubled to put two of the same pumps in series. That is set to be equal to the previous pressure differential equation that did not include the pump performance curve. The 307 ft elevation difference that the actual system will include is substituted into that equation and from that relationship, the flow rate was determined.

$$z_2 - z_1 = 307 \text{ ft} = 3684 \text{ in}$$
$$\Delta P = \rho g(z_2 - z_1) = (0.0011 \text{ slug/in}^3)(32.2 \text{ ft/s}^2)(3684 \text{ in}) = 130.49 \text{ psi}$$
$$\Delta P = 2(240 \text{ psi} - 0.0413Q^2) = 130.49 \text{ psi} + 1.43Q^2$$
$$Q^2 = \frac{480-130.49}{0.0826+1.43}$$
$$Q = 15.2 \text{ GPM}$$

The flow rate of 15.2 GPM meets the requirements of the system. It will provide the people with enough water to satisfy their daily needs and does not exceed the maximum flow rates of any of the filters. The efficiency of the system is calculated below.

$$bhp = 5 \text{ hp}$$
$$bhp_{(A+B)} = 5 \text{ hp} + 5 \text{ hp} = 10 \text{ hp}$$
$$\Delta P_{(A+B)} = 130.49 \text{ psi} + 1.43(15.2^2) = 460.88 \text{ psi}$$
$$Q_{(A+B)} = 15.2 \text{ GPM}$$
$$\eta = \frac{Q_{(A+B)}\Delta P_{(A+B)}}{550 bhp_{(A+B)}} = \frac{(15.2 \text{ GPM})(460.88 \text{ psi})}{550(10 \text{ hp})} \frac{1 \text{ ft}^3}{7.48 \text{ gal}} \frac{1 \text{ min}}{60 \text{ sec}} \frac{144 \text{ in}^2}{1 \text{ ft}^2} = 0.4086$$

The efficiency of 40.86 is not ideal but it is acceptable.

Project Budget & Bill of Materials

Part #	Qty	Description	Supplier	Unit Price	Total Price
PL44-61NAC15	3	Carbon Steel Filter Bag Housing	Waterfilters.net	$435.00	$1,305.00
PO100G3S	2	100 micron Polypropylene Felt Filter Bags	Waterfilters.net	$69.99	$139.98
PO25G3S	2	25 micron Polypropylene Felt Filter Bags	Waterfilters.net	$89.99	$179.98
PO5G3S	2	5 micron Polypropylene Felt Filter Bags	Waterfilters.net	$89.98	$179.98
BB Long	1	Single Big Blue Carbon Filter	Pure Water Express	$233.00	$233.00
S37C	1	Ultraviolet Water Purifier	Purest Filters.com	$995.00	$995.00

T434R	1	Aquameta Tank Level Pump/Valve Controller	Anadex Labs	$330.00	$330.00
00425391	1	Actuated Ball Valve	Motion Industries	$254.00	$254.00
4738T13	6	90 deg PVC Female Elbow	McMaster-Carr	$2.48	$14.88
9152K15	2	90 deg Brass Female Elbow	McMaster-Carr	$33.53	$67.06
48855K13	194	10' Dark Gray Unthreaded PVC Pipe	McMaster-Carr	$7.14	$1,385.16
5065K15	5	5' Dark Grey Unthreaded UV Resistant PVC Pipe	McMaster-Carr	$25.48	$127.40
4596K54	189	Dark Gray PVC Straight Coupling	McMaster-Carr	$3.26	$616.14
4512K51	2	3' Brass Pipe 1" pipe size	McMaster-Carr	$58.97	$117.94
4512K57	3	2' Brass Pipe 1" Pipe size	McMaster-Carr	$39.35	$118.05
0005-040	1	3000 Gallon (Low Profile) Fresh Water Poly Tank -LB	Water Tanks.com	$918.57	$918.57
33GBS50144	2	5 hp Single Phase SS Pump	ITT Goulds Pumps	$1,700.00	$3,400.00
47535K23	2	PVC Globe valve for 1" pipe size	McMaster-Carr	$60.76	$121.52
AN4032PL	3	Enclosure with 2 Padlockable Latches	Vynckier Enclosure System Inc	$852.20	$2,556.60
AN3325PL	1	Enclosure with 2 Padlockable Latches	Vynckier Enclosure System Inc	$645.63	$645.63
PS5030A	1	FRP Polysafe Enclosure with Standard Door	Vynckier Enclosure System Inc	$1,362.49	$1,362.49
1.5SS40	32	1.5" Bracket 1.900" OD	Reliner	$28.05	$897.60
Total Price		**$15,965.80**			

Prototype

For the next semester, the group will develop a prototype that will attempt to develop indicator to signal when the carbon and sediment filters each need to be replaced. As they are, the filters have no way of indicating exactly when they need to be replaced. They have estimations in their respective specifications about how long they can last, but much of that depends on the flow rate at which the system is run and the volume of contaminants that are removed from the water. In order to stay under the $600 budget for prototypes, the group will attempt to come up with creative ways to test their designs without having to buy the actual filter. Part of that could be only purchasing the filters themselves and not the housing. Another option would be to develop sensors that could determine the water quality coming out of the system to determine if the filter is still effective. In that case, the filters would not need to be purchased as the sensors are independent from the filters. If successful, these features could then be incorporated into the final design.

Summary and Conclusion

The design that was developed over the past semester would be able to provide a community in need with water for years after its implementation. The system would be able to accomplish that task with minimal cost and maintenance in compliance with the criteria of Engineers Without Borders. The system design is versatile enough to where it can be adapted to fit a wide variety of situations. This raises the likelihood that the system would be able to meet the needs of EWB wherever they decide to implement their system. The above steps could be a useful guide for any EWB chapter looking to develop a water purification system for a community in need.

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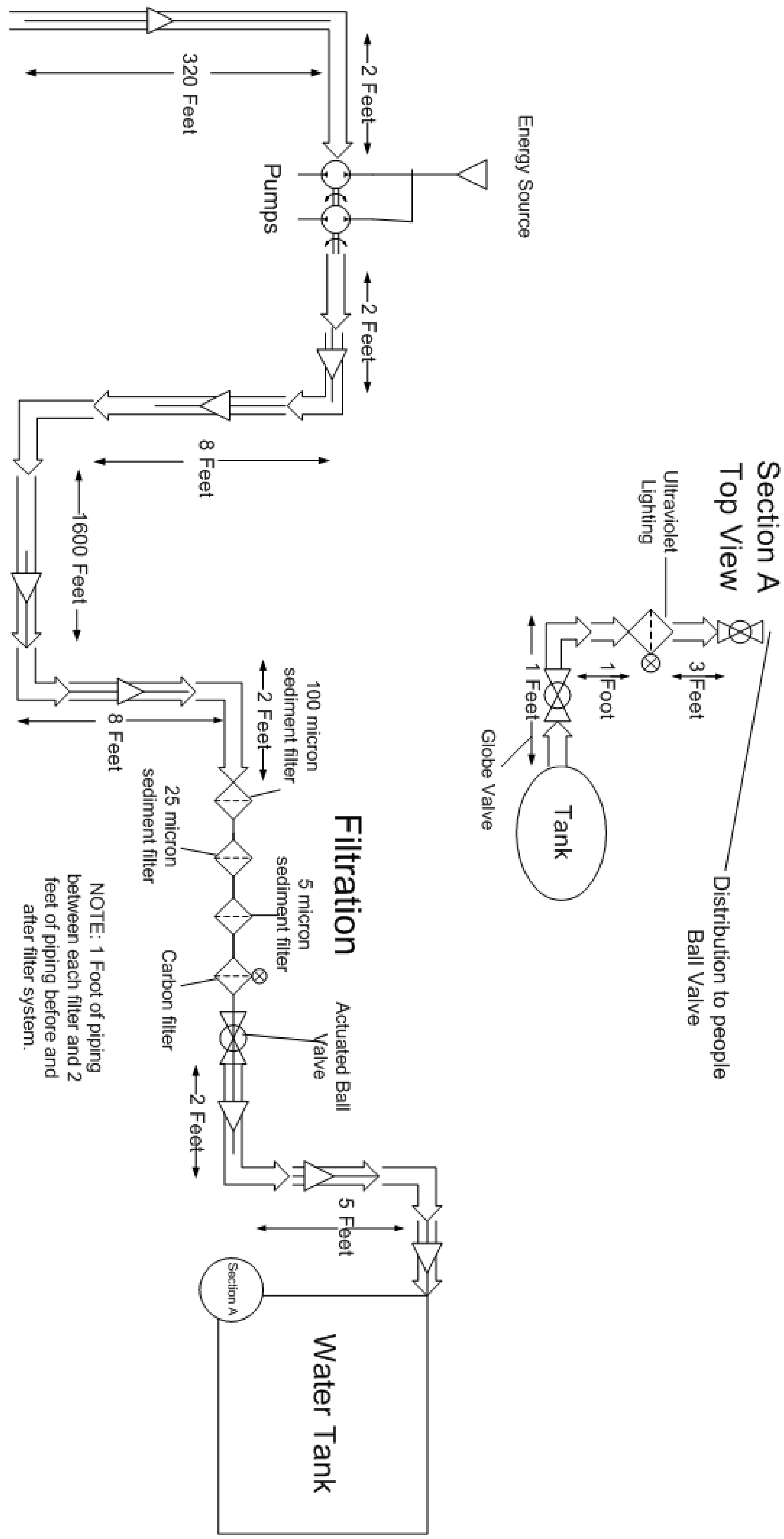
Appendix A: Design Schematic



Appendix B: Nugget Chart

ME 423 *Phase III Nugget Chart* – Engineering Design

Title: Group 10 Water Purification System

Team Members: Kim Fellenz, Abdul Karim Dawan, Jonathan Da Silva, Kevin Gonzalez Emanuel Rios

Advisor: Professor Fisher

Project #: 10 **Date:** 12/6/2007

• Project Objectives

(Same as before, modify if necessary. Give specifications and performance expected.)

The objective is to design a water purification system that will rpovide safe drinking water to communities in need.
Specifications: Flow Rate = 15 Gpm.

• From Technical Analysis to Engineering Design

Using the technical analysis the group was able to determine the correct sized pumps for the system. It was determined that the group would use two pumps in series to increase the head of the system.

• Prototype Plan and Purchase Requisition

• Major Results Obtained in the Semester

The group was able to create a water purification system for a theoretical community that receives its water from a well source. The system contains a 100, 25, and 5 micron sediment filter, a carbon filter, and an ultraviolet filter. The project is an EWB research project and can be used as a guide line for any EWB chapter looking to develop a water purification system for a community in need.

Drawing and Illustration of Final Design