

Drinking Water Issues in Rural Colombia

FINAL SEMESTER REPORT

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I. Executive Summary

This report is a documentation of work completed on slow sand filter designs to be implemented in the rural highlands near Barbosa, Colombia. This project was initiated in January 2011 as a partnership between the Kimberly-Clark Company, Purdue Global Engineering Program (GEP), and the city of Barbosa. The initial goal was to design and install bench-scale slow sand filter units to treat drinking water for students in rural communities surrounding Barbosa. Prototypes were designed, constructed, and installed in three schools, where a noticeable improvement in water quality was seen. This past year, the project has continued under GEP and Purdue Engineering Projects in Community Service (EPICS). New design criteria for the redesign of the initial slow sand filter included replacing the gravel support layer with a solid porous media, replacing piping hardware, and reducing overall cost. These goals were achieved by installing a Porex support plate, (typically used in rapid sand filters), using smaller diameter piping, and replacing piping fittings.

Unfortunately, even after treatment with the slow sand filters, the water is still unsafe to drink. Currently, the schools boil the water to disinfect it before consuming, but in the process use large amounts of heating fuel. In order to improve the overall quality of the water treatment system, two disinfection techniques were explored. A UV disinfection system was designed and is currently being tested. The second disinfection method involves the use of a series of pleated filters to physically remove pathogens from the water. Primary removal occurs in a 0.2 μm filter but a 1 μm pre-filter can be used first to extend the life of the smaller (and costlier) filter. Both disinfection systems would include chlorine disinfection target pathogens which are resistant to UV or are not removed by the pleated filters. By utilizing two disinfection methods, a safety factor is provided if one system fails.

To meet the needs of community members around the schools, a large-scale slow sand filter system was designed. A pilot-scale continuous flow filter was constructed and operated, identifying design constraints, and allowing data to be gathered on filter performance. It was determined an 8 hour hydraulic retention time is sufficient to produce high quality water. An on-site conceptual design was created consisting of a pair of sedimentation basins for pre-treatment, a pair of large slow sand filters, and a storage basin. The design was completed with the goal of minimizing cost while still meeting the needs of the community. A total cost of \$19,537.04 was estimated, a 55% reduction from a previous design completed in spring 2011.

This summer, an onsite workshop will be held to train teachers from other schools in the Barbosa area on how to construct their own bench-scale filters using the new design. Further work will be done in assessing disinfection options and directly comparing the effectiveness and feasibility of the UV and pleated filter systems. More information needs to be collected on water use in these communities and other on-site conditions to improve and finalize the current conceptual large-scale design.

II. Introduction to Slow Sand Filtration

Purpose and Function

Slow sand filters are inexpensive water treatment devices that can be constructed and used even in remote locations. They require few materials for construction, no electricity during operation, and only very basic maintenance. The “filter” is composed of medium sand, layered on different diameters of coarse sand and gravel.

Figure 1 shows the basic structure of a slow sand filter. Highlighted in blue is the layer of medium sand, red is the coarse sand, and yellow is the layer of gravel. The setup of the filter consists of two buckets sitting on top of one another. Each bucket has the sand and gravel layers, with tubing transferring the clean water from the top bucket to the bottom, where once it filters through, the completely filtered water will exit from the bottom bucket.

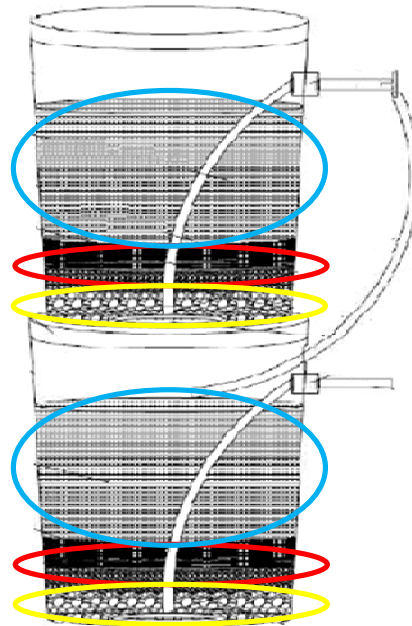


Figure 1. Point-of-use SSF Schematic

The large surface area of the sand efficiently removes inorganic particles present in the influent water (by attachment), and acts as a substrate for the growth of microorganisms. This in turn consumes dissolved organic materials. In addition, a large fraction of any pathogenic protozoa, bacteria, or viruses in the untreated water, are retained in the filter through attachment to the sand. Retention of these microorganisms for long periods of time eventually leads to their inactivation or death. Slow sand filters should not be confused with rapid sand filters.

Rapid Sand Filters (RSFs) process pre-treated water at a rate of ~ 21 m/h (21 m^3 of raw water per m^2 of filter surface area hourly). This is a larger amount of water than a slow sand filter can process, but produces a higher clogging rate. To inhibit biological growth on the sand particles, the influent water to RSFs is generally pre-treated by chemical flocculation and settling, and by chlorination. After several days, sometimes weeks, the hydraulic pressure difference across an RSF increases due to clogging. When this occurs, automated backwashing must be performed. Due to pretreatment and backwashing requirements, RSFs are one of many processes implemented within treatment trains for drinking water treatment plants in larger communities. They require some automation, are more complex in design, and therefore are not suited for small-scale communities or individual household due to the higher maintenance needs, (Fewster, 2004).

In comparison, slow sand filters (SSFs) are operated intermittently or continuously at much lower flow rates per area, typically at or less than 0.4 m/h (or $\text{m}^3/\text{m}^2 \times \text{hr}$). SSFs characteristically contain fine to medium sand to provide a large surface area, permitting extensive contact of water and sand and attached

organisms. The large surface area and the high hydraulic retention time [$\tau = V/Q$, where V is volume (m^3) and Q is flow rate (m^3/hr)] provide sufficient time and contact for the organic materials in the water to be mineralized by the attached biological community, decreasing clogging over extended periods of time. After prolonged use, slow sand filter designs build-up inorganic materials between the sand grains, requiring cleaning of the sand layer. The time period between cleaning events depends on the influent water quality.

The uppermost 1-3 cm is often referred to as the *Schmutzdecke*, or “*slime layer*”. Because the dissolved concentration of organic molecules is highest at the top of the filter, this is where microorganisms tend to accumulate. Gradually a zone of rich biological activity is formed. The density of this layer provides a more efficient filtration zone for materials present in the influent water, including other microorganisms. The *Schmutzdecke* biological zone is not truly a distinct and cohesive layer, but rather a dense population that steadily develops within the upper region of the sand (Fewster, 2004). Even though the majority of pathogen removal takes place in the *Schmutzdecke*, research performed on continually operated SSFs shows that biological activity is distributed throughout the top 40 cm of the sand bed, becoming less dense with depth. Below a depth of 30-40 cm, the level of bacterial activity drops to a level that is dependent upon the filtration rate (Fewster, 2004).

There are two ways slow sand filters can operate, by applying a continuous and uninterrupted flow of water, or by adding water to the filter bed at periodic intervals. The influent water provides both food and oxygen to the biological community in the filter. Continuously operated filters, designed with water retention times of at least several hours, depend on uninterrupted use to maintain biological stability. In comparison, intermittently operated slow sand filters are designed to function without a continual flow of water into the filter, and thus have retention times of 24 hours or more. During the periods of time with no water flow, the organisms within the biological zone receive additional oxygen through the diffusion of oxygen into the shallow level of standing water. The level of standing water is important in controlling the diffusion of oxygen and the development of the *Schmutzdecke* (Fewster, 2004). In order for SSFs to remain effective, the resident microorganism community must be sustained through a constant (sometimes intermittent) supply of organics (i.e., food), oxygen, and moisture. The sand bed must therefore be kept saturated with water at all times.

Slow sand filters are remarkably simple in both material requirements and construction. They consist of an open container filled with specific depths of granulated media, often arranged into several discrete layers of increasing grain size. The biologically active sand layer is situated at the top, and gravel (or other water collection system) is at the bottom. A porous pipe or tube is placed in the gravel layer, to convey the filtered water from the container. This drainpipe, often regulated by a valve or by adjusting the level of water in the container, carries the filtered effluent water to a ventilated reservoir.

The specific properties of the media (sand) are relatively unimportant as long as it is chemically inert and of an effective uniform size; sand is typically the most economical and readily available material used (Manz, 2008). Similarly, the material and shape of the container are subject to discretion. If the container material is resistant to corrosion, and the vessel is of an appropriate size, it can be used. Smaller filtration systems normally use a plastic or metal drum, whereas larger-scale applications have a concrete-lined bed installed in the ground. The grain size and total depth of the filtration medium may vary between designs; a more detailed discussion of these design parameters follows in later sections. Generally, finer material and deeper filter beds provide for more effective filtration; however these require that a greater hydraulic head be applied to maintain adequate flow of the water through the SSF (Huisman and Wood, 1974).

Operation and Maintenance

Operation and maintenance of SSFs are relatively simple. While water must be continuously (or frequently) added in order to oxygenate the filtration bed, the amount of water added varies depending on the size and design of the system (Fewster, 2004). If sufficiently turbid water is put through the system, the top layer of sand will eventually become clogged with clay and other large particles. As this happens, the flow rate of water through the system will decrease. While this actually increases the effectiveness of the filter, it may reduce the flow rate of the filter to below a suitable level for daily use. One method of clearing the debris from this layer of the filter is to remove all of the sand from the SSF and wash or fully replace it, and then rebuild the filter bed. This is not practical due to the high labor and time requirements of such a task. Further, this method forces the entire biological layer to rebuild itself, leading to significant down time before the filter is functioning at an optimum efficiency (Fewster, 2004). A second approach involves removing only the top few centimeters of media for replacement or cleaning. The specific amount of sand removed depends on the size and design of the filter. This method, over the first, requires considerably less labor and a shorter period of time for the filter to re-establish the Schmutzdecke. The third method is called wet harrowing (Fewster, 2004). Wet harrowing involves blocking the effluent pipe of the system if necessary, ensuring an adequate water depth above the sand, and then stirring the water by hand without touching the media layer. This causes the debris clogging the top layer of the filter to be suspended in the water. The water is then drawn off of the top removing the debris along with it. This may be repeated a few times if necessary. The advantages of this method include low labor input, and non-disruption of the Schmutzdecke, both critical factors for SSF effectiveness. This leads to almost no downtime for the filter. Backwashing (reverse flow of water through the filter bed) should never be used for a biological sand filter (Fewster, 2004). Cleaning agents and other chemicals should never be added to the filter. Such chemicals will destroy the biological layer, which is necessary for the slow sand filter to operate,” (citation of Spring 2011 document).

III. Project Background

The main overarching objective of the project is to develop an economical and effective drinking water treatment process for rural communities in Colombia. The project first began in January of 2011 when the Kimberly-Clark Corporation, a paper products manufacturer, sponsored a student project in conjunction with the Global Engineering Program at Purdue University. With a facility in Barbosa, Colombia, Kimberly-Clark was looking to improve drinking water quality for some of the schools in the surrounding area. In most parts of the world, naturally filtered groundwater is a key water source. However, in some regions, like Barbosa, groundwater resources are unavailable, not economical, or inefficient to pump treated water from the base of the mountain to rural areas in higher elevations. In these regions, the treatment of surface water through slow sand filtration has been shown to be the cheapest, simplest, and most effective means of improving drinking water quality.

Previous Work: Point-of-use Filter Design

After the initiation of the project, a team of students was able to come up with a design for point-of-use filters to be utilized in schools outside of Barbosa. The initial design incorporated inexpensive and easily obtainable materials. The main structure of the filters consisted of 5-gallon plastic pails. In order to reach a sufficient sand depth for proper filtration, each unit consisted of a stack of two pails. By having the filter split into two pails, rather than one large container, the units could be easily moved. In each pail, food-

grade plastic tubing carried the filtered water from the bottom gravel layer up to an outlet in the side of each pail near the top. Inside each bucket were medium grain sand and a coarse gravel layer at the bottom. The level of the water above the sand was determined by the location of the outlet in each bucket. This design allowed the sand to be fully saturated at all times which is a key aspect for proper function of the slow sand filters.

While this design was successfully implemented in three small schools in Buga, Graciano, and Las Bugas, there were several possible improvements that were identified after the filters were re-evaluated in the summer of 2011. The cord grips that were used to run the tubing from the inside of the bucket to the outside were not sealing correctly, producing some water leaks. Also, it was noted that sieving out different sizes of sand and gravel was extremely tedious and time consuming. With one of the goals of the project being to produce the filters in high quantities, improving the efficiency of construction was essential.

With these improvements identified, the fall semester of 2011 was dedicated to evaluating new hardware options and redesigning a base layer to enable the removal of the gravel completely. By removing the gravel layer, the intention was to cut down construction time and increase the sand depth, thus improving the overall effectiveness of the filters. To keep the cost of the filters to a minimum, a \$5.00 goal was established to replace the gravel layer. In order for the filters to function properly for an extended period of time, the new base layer was expected to be robust, as it would be under the pressure of the water and sand in the 5 gallon pails. It was to fulfill the responsibilities of the gravel layer: preventing sand from flowing out while allowing water to pass through.

The student team from fall of 2011 was able to come up with a new prototype that utilized a porous aluminum plate that was wrapped in both a coarse mesh and a fine mesh. Because the plate was rather thin, it needed to be braced off of the bottom of the pail, forming a reservoir for the filtered water to collect. Supports were constructed of excess tubing, and held the plate less than an inch above the bottom of the pail. The prototype was constructed and tested throughout the semester. After extensive testing, it was determined that there were several areas in which the design could be improved. These improvements will be discussed in detail in a later portion of this report.

Previous Work: Scale-Up Design

A large-scale slow sand filter could provide clean water to the roughly 40 families that make up each community. A pilot scale continuous-feed slow sand filter has been built at Purdue and is currently being evaluated for filtration efficiency and design parameters. A successful design will then be scaled-up to be built in-line with current water infrastructure, providing approximately 36,900 L of clean water each day. The sand filters currently operating in Colombia are batch systems. In batch systems, a set amount of water is directly poured into and collected from the filter over a given time period (in this case, 10 liters each day). A continuous flow system operates by similar biological filtration mechanisms; however a continuous source of water will feed into the filter by means of a pump or in this case the gravitational flow of a mountain stream. Certain devices must be designed to promote independent sustainability, but the main advantage of a continuous flow sand filter is the ability to operate with very little manual labor. The continuous flow system capitalizes on the free flowing fresh water source located near the intended construction site, and providing enough water to support approximately 160 people. Designs for the final system take into consideration the unpredictable flow of incoming water, a pre-filtration settling chamber, an overflow mechanism, adjustable flow controls (valves, wires, etc.), and a large storage tank. The proposed three-tiered filter design will be explained later in 'Filter Design'. These considerations will maintain an appropriate hydraulic retention time and hydraulic head without disrupting the

Schmutzdecke. An overflow system especially unique to continuous flow systems will direct excess water back to the water source (mountain stream).

At least two SSFs will be built in parallel, providing adequate filter area and back up if one filter is under maintenance. A continuously fed slow sand filter will meet the needs of the community while minimizing cost of implementation and maintenance. A rapid sand filter has the potential to operate 50 times faster than a slow sand filter however it requires an equivalent 50 times more maintenance and relies on backwashing to clean the filter, an unrealistic method (Huisman, 16). To clean a slow sand filter, the top 1 to 2 centimeters of filter media (most commonly sand) is scraped out, freeing the filter of any suspended particles or colloidal material that may have collected during operation.

IV. Spring 2012 Semester Goals

Redesign Team

In the initial construction of the prototype, it was noted that tubing supports took a considerable amount of time to put together. The goal of cutting down construction time was met, but there was still room for improvement. The filter functioned properly over the initial weeks of operation, consistently producing effluent water with turbidity levels of less than 1 NTU. After a longer period of testing, it was found that the effluent water was becoming discolored. The hypothesized cause was the porous metal plate in the bottom layer design. Another recommendation was looking at smaller diameter tubing, tees, and cord grips to reduce the overall cost even further. With these results and recommendations, a new team of students in the spring of 2012 set out to make the necessary improvements on the point-of-use slow sand filters, and prepare for an on-site workshop in the summer of 2012.

Scale-Up Team

In the fall of 2011 the scale-up team designed and built a pilot-scale continuous SSF in anticipation of designing a SSF built into the mountain landscape located outside of Barbosa, Colombia. The system will be built in-line with existing water infrastructure, relying on the flow of the mountain stream to provide a constant flow of influent water. The filtered effluent water will exit the SSF system and enter a centralized storage basin that can provide further disinfection and access to clean water for the community. The future community-scale filter will be a continuous flow system, unique to the area and its topography. This semester, spring 2012, the team treated 600 L of Wabash River water over a period of three months, intent on evaluating the effectiveness of our most important design constraint, retention time, (initially chosen to be 8 hours.)

0.2 μ m Filter Team

While slow sand filtration has been proven to be an effective means of removing solid particles and some pathogens from water, it is still essential that the effluent water be disinfected to ensure that it is in fact safe to drink. The goal of the 0.2 μ m Filter Team was to explore the various types of filter cartridges including ceramic, pleated, depth, and membrane filters as a secondary method for disinfection. Each of these filters can remove different types and sizes of pathogens in the water. The filter cartridges have different benefits and disadvantages in water disinfection that will be explored in depth.

UV Disinfection Team

The students and teachers in the rural mountains outside of Barbosa, Colombia, face difficulty accessing clean drinking water. Without a way to retrieve clean water from Barbosa, the only alternative is to treat surface water from the surrounding local area. In previous semesters, the Water Resource Management team has designed, built, and deployed slow sand filters in these schools. Although these satisfy the customer's need, the teachers still have to boil the filtered water to disinfect it. The objective of the UV disinfection team is to design a UV disinfection system that can eliminate the need for boiling the sand-filtered water. It will have to adequately inactivate giardia, cryptosporidium, and viruses in the water when used in conjunction with chlorination.

After thorough research and understanding of UV disinfection and inactivation applications, the UV Disinfection team has established a goal to design and test an economically feasible UV disinfection unit. This will serve as an alternative to the current method of disinfection for rural schools in Colombia, which involves boiling filtered water. UV disinfection would be a more efficient and less expensive method.

To begin, an extensive research study analyzing the effects of UV radiation as a method of biological inactivation was completed. An overview of these findings is discussed in the background section of the report, including the study of EPA UV recommended guidelines, various electronic components of design including housing, bases, and ballasts. Based on the criterion of cost, UV output, and size, the team will select the optimum lamp and associated fixtures. After receiving these parts, a prototype will be constructed. The team will continue the semester by performing an actinometry experiment using potassium ferrioxalate, measuring the intensity and effectiveness of the selected lamp's UV radiation. The system will then be verified with EasyGel using water from the bench scale slow-sand filters and the scale-up models. The semester will culminate with a thorough review of test results and cost analysis.

V. Case Studies, New Literature, Methods, and Approaches

Case Studies: Continuous-flow Large Filters

The ease of construction, operation and affordability has made slow sand filters successful in many rural communities similar to the partnered communities in Colombia. Large-scale slow sand filters have been designed and built in several of these communities. This section investigates two cases and evaluates the design constraints, unique mechanisms/design processes, and overall cost of the project.

Kenya

In 2010, a team from Purdue University collaborated with Moi University, and Aqua Clara International, to build a biosand-filter reactor that would reduce fluoride concentration in the water supplies of a school in Eldoret, Kenya (Blatchley et al., 2010). The non-continuous slow sand filter delivered approximately 1000 liters of potable water each day and cost \$450.00, the result of a linearly scaled-up pilot filter.

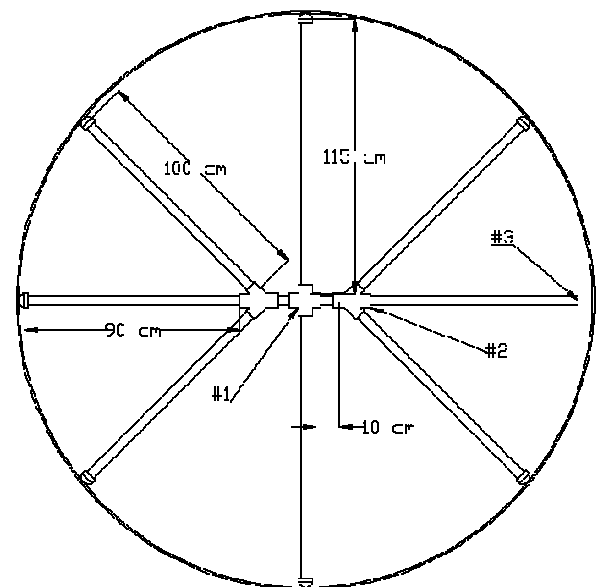


Figure 2. Underdrain system of PVC pipes placed at the base of the filter, directing filtered water and reducing non-vertical flow (Blatchley et al., 2005).

The design featured a 5000 L HDPE tank with influent and overflow pipes to ensure a 1000 L tank holding capacity, with overflown water returning back to the water source. A valve on the influent pipe controlled flow rate and directed water into a ‘distribution bucket’ that allocated the inertia of the incoming water. The distance between the overflow and effluent pipes was found by dividing the volume of water delivered each day by the surface area of the tank.

Two design options were presented to ensure the tank receives no more than 1000 L/day. (1) A valve on the effluent pipe is closed until 1000 L is pumped into the filter, or (2) an automatic pump shuts off after 1000 L. An underdrain system (Figure 2) was constructed with 1.5-inch PVC pipe and fittings (#1, #2, and #3 in Figure 2) that divided the tank into 8 equal areas to reduce non-vertical flow in the filter.

The final design was the assumed linear scaling of pilot filters built at Purdue after plug flow was verified. The test columns were six-inches in diameter and filled with gravel, course sand, and a varying third layer upon which the filters were evaluated on three varying filter medias: (1) “dirty” fine sand with an ACX layer, (2) “clean” fine sand with an ACX layer, or (3) “clean” sand without an ACX layer.

“Clean” refers to industrially processed sand and “dirty” refers to non-industrial-processed sand. The ACX layer is a brass alloy that can be used as a disinfectant.

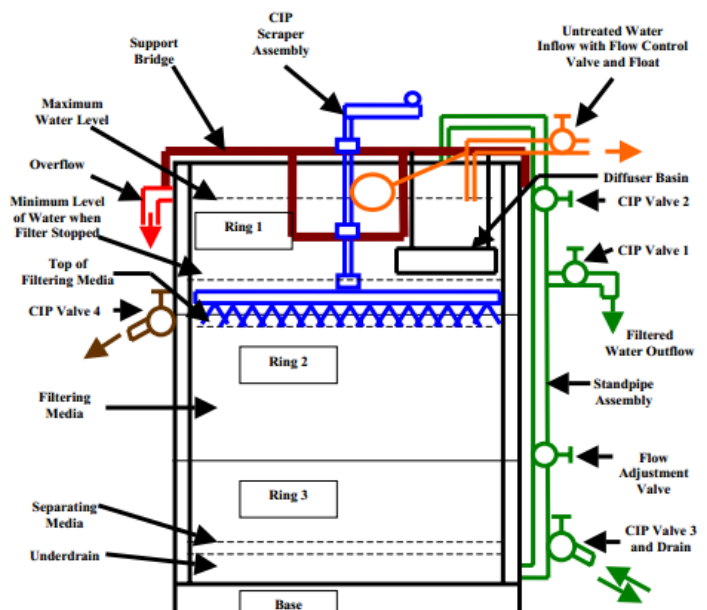
The following method summarizes the scale-up procedure:

1. Determine required (L) water needed
2. Verify plug flow (the velocity of the water is constant across any cross section)
3. Determine surface area needed (ratio of pilot filter cm² SA/L water produced)
4. Find tank diameter & size that gives SA
5. Tank height * Tank diameter = Tank surface area
6. Keep media height of pilot filters constant
7. Tank volume – media volume = volume available to hold water (options include multiple tanks)
8. Calculate amount of each media layer needed based on linear scale-up factor

The pilot filters tested at Purdue were successful in reducing viable coliform concentration to less than 5% presence in one month, and turbidity to levels below the USEPA recommended 0.3 NTU. This study suggested the use of, “entirely natural and rurally available materials,” to reduce system cost without compromising performance and ensuring a sustainable system that empowers the user permitting flexibility in construction, operation, and maintenance (Blatchley et. al., 2005).

Bangladesh

A community scale water treatment plant was designed to serve 1000 people living in a small Bangladesh community (Manz, 2005). Dr. David H. Manz used pre-cast concrete rings to design a large-scale biosand filter serving 200 families in a small community in Bangladesh. The water treatment plant consisted of separate tanks for (1) raw water storage, (2) biosand water filtration, (3) wastewater storage, and (4) treated water storage. Multiple biosand filters would operate in parallel, receiving water from the raw water storage and delivering it to treated water storage tanks. Valves were used to control the water flow and direction between tanks.



8 **Figure 3.** Biosand filter design with three concrete rings and base stacked vertically with pipefittings, valves, overflow, and scraping mechanisms (Manz, 2005).

An independent biosand filter (see Figure X) was designed to run for 10 hours each day producing a maximum of 600 liters per hour. Each filter used three rings (44.5 inch internal diameter and 12-14 in height) and included a concrete base with sand and gravel filter media. The use of locally produced concrete rings, versus a single concrete cylinder, allowed for easier assembly and flexibility in the size of a filter, through adding or subtracting a concrete ring. The rings stack on top of one another with notches cut in designated edge spots that form circle pipe fittings. The pipe fittings are sealed with concrete mortar.

Maintenance on each biosand filter was required at a reduced flow rate of 300 liters per hour, (50% reduction). A large-scale design with multiple filters operating in parallel allowed the full system to continue operating even while one filter was out for maintenance.

The design of the biosand filter required focus on the local production of concrete rings in Bangladesh, averaging a cost of \$3 USD per ring. The system including valves, filter media, floater valves, etc. cost a total of \$150 USD and was able to produce 600 liters of water each hour.

Conclusions

The goals of both case studies researched match the project goal of large-scale distribution at an affordable cost and effective, sustainable, filtration mechanisms. The under drain mechanism, ACX disinfection layer, stackable ring design, and other characteristics of referenced designs are useful to the design of the Colombia community scale filter.

Literature Review

Waterborne diseases including cholera and dysentery are responsible for approximately 2 million deaths each year. A high percentage of this number consists of children living in developing countries (World Health Organization, 2011). These diseases are caused by pathogenic microorganisms that are transmitted in contaminated fresh water. The use of traditional filtration and chlorination for drinking water treatment is effective at removing bacterial pathogens like *Vibrio cholerae* (responsible for cholera), *Salmonella typhi*, and *S. paratyphi* (responsible for typhoid fevers) (Huq et al. 1996).

Bacterial and virus contaminants range in size, resistances to disinfection methods, and concentrations based on location. Each of these factors needs to be taken into account when choosing a primary and secondary disinfection method. Traditional filtration methods are efficient at reducing turbidity in water and removing color from water. However, surface waters may contain other pathogens that are environmentally persistent and resistant to disinfection. One example is the oocysts of *Cryptosporidium parvum* (Peter-Varbanetes et al., 2009). *Cryptosporidium* is a protozoan parasite of 3-7 μm in diameter that have spherical oocysts. Some of the most important *Cryptosporidium* species are *Cryptosporidium parvum* and *Cryptosporidium hominis*. They are genetically distinct, differ in host range, and have potential to cause human infection (Cummins et al., 2010). The medium of exposure to *cryptosporidium* is ingestion of the oocysts in water and food, or by direct contact. Patients with acute infected feces could contain up to 1×10^7 oocysts per gram (Chappel et al., 1999). Infections with *Cryptosporidium* species have been reported in developed and developing countries including the United States and the United Kingdom. It has been observed that effective oocysts removal can be achieved through filtering water (Richardson et al., 1991).

For a primary treatment method, slow sand filters are an easy and effective way to remove suspended at least 90% of solids from water; more than 65% of the remaining BOD, and over 95% of coliform

organisms (Ellis, 1987). They are cheap and simple to construct, which is why developing countries are better suited to adopt slow sand filter technology. Rapid sand filters are another primary method of filtration to disinfect water. They remove pathogens from water, but require frequent maintenance due to clogging. The technology to replicate rapid sand filters is more complicated than slow sand filters.

This paper serves as an exploration into the various types of filter cartridges including ceramic, pleated, depth, and membrane filters, as a secondary method for disinfection. Each of these filters can remove different types and sizes of pathogens in the water. The filter cartridges have different benefits and disadvantages in water disinfection that will be explored farther. Chlorine, Ozone, and UV treatments are other secondary disinfection options that have been explored in water quality testing. Each method has several advantages and disadvantages that need to be taken into consideration when selecting the most effective method for secondary disinfection in Colombia.

Research: 0.2 μm Filters

Filtration Overview

Filtration is used to remove microorganisms and suspended solids in drinking water. This process involves the circulation of water through a porous media or membrane. Media layers can be sand, anthracite, or membranes with varying pore sizes (Betancourt and Rose, 2004; Cummins et al., 2010). Sand is found in many filtration systems including slow sand filters, rapid sand filters, and mixed media filtration. The anthracite filtration method is often combined with varying particle-sized sand for filtration. This is called dual media or tri-media filtration (LeChevallier et al., 1991).

Slow Sand Filters are a cheap and relatively simple primary method of removing larger suspended solids (Langenbach et al., 2009). Particles become trapped in the pores of the sand and the filtering from the Schmutzdecke. The Schmutzdecke is a biological layer in the top of SSF that helps reduce turbidity and color present in water. The Schmutzdecke is the formation of the fine layer of sand at the top of the SSF and the biological particles that have been removed. This is the first step in pathogen removal of water. Any chemical pretreatment to the influent of the SSF will disrupt the formation of the Schmutzdecke, hindering its performance (Cummins et al., 2010).

Rapid sand filters are another primary method used to remove suspended solids and other contaminants in drinking water. Rapid sand filters require frequent backwashing because filters become clogged due to microbial growth, air bubbles, deposition of particles, and precipitation from iron, manganese, chalk, and calcite. To achieve a desired performance of pathogen removal, filter heterogeneity is not desired. Heterogeneity in a filter is caused by variation in media size with an uneven distribution of biofilms and particles. Because rapid sand filters require frequent backwashing and maintenance, it is not a technology that could be easily adopted in developing countries like Columbia (Lopate et al., 2011).

It has been observed that rapid sand filters and granular activated carbon filters have a high probability compared to dual and mixed media filters in allowing oocysts to pass through (LeChevallier et al., 1991). The more effective removal of oocysts observed in the dual and mixed media filters are from the larger potential the filters have in trapping the oocysts (Cummins et al., 2010). According to Harrington, filtration can result in a 1.7–3.6 log₁₀ reduction of oocysts depending on the filter media used (2001). Water treatment facility use of mechanically pressurized filtering systems, are becoming more popular. These filtration systems include microfiltration, ultrafiltration, nanofiltration, and reverse osmosis. Depending on the type of filter media they can be depth, pleated, or surface filters. Some of the most commonly used materials are cellulose, polypropylene, nylon, ceramic, and membrane.

Low-pressure microfiltration filters have pores ranging from 0.1 to 10 μm . However, ultrafiltration membranes have lower permeability than microfiltration filters because of their smaller pore sizes ranging from 0.002-0.1 μm (Betancourt and Rose, 2004). The more common range of pore sizes in water treatment processes range 0.01 to 0.5 μm which is over one order of magnitude smaller than the *Cryptosporidium* oocysts' size. Microfiltration and ultrafiltration reduction ability is around 4-6log10 (Jacangelo et al., 1997). Based on the information provided, the use of microfiltration and ultrafiltration filters within a range of 0.01 to 0.5 μm is accepted to remove all *Cryptosporidium* oocysts.

Filter Cartridge Types

According to Brown, pleated membrane cartridges have up to a 53% superior performance and deposition of suspended solids than flat sheet cartridges impacting the clean water flux of the cartridge (2009). Brown suggests that the better performance of the pleated filters is due to the fluid/particle accessibility into the pleat structure. Two important characteristics in pleated filter performance are based on pleat packing density (PPD) and pleat height (hp).

Depth filters have a relatively thick media that requires the fluid to travel through a tortuous route from the upstream surface of the filter to the downstream surface. As the fluid maneuvers throughout the process, decreasing sizes of all pathogens become trapped and adsorbed as the matrix of fibers become tighter. Depth filtration is used to remove cells and debris by physically capturing the debris in the narrow pore spaces. Positively charged depth filters lead to high efficiency removal of negatively charged DNA, viruses, and endotoxins (Charlton et al., 1999). These filters are typically used in combination with surface filters providing a cost-effective process (Reis et al., 2007).

Ceramic filters are an effective way to remove pathogens from water because it is cost efficient technology. Ceramic filters can be produced from materials found in nature, (i.e. clay, soil, and fine organic materials such as saw dust or rice hills). When the natural material is fired the organic matter is burned away and leaves behind small pores. The sizes of pathogens removed from the water are based on the pore size of the ceramic filter and the surface charge it has. To provide a more effective disinfection method the filters are coated in silver to ensure that smaller pathogens capable of seeping through the filter are removed through the silver coating. The greatest disadvantage of a ceramic filter is that over time the silver coating wears off and disinfection is not as effective (Bielefeldt, 2010).

Membrane filters are made from a variety of base polymers including polyethersulfone (PES), polyvinylidene fluoride, nylon, and polypropylene (PP). These filters are able to remove microorganisms by size exclusion and protein aggregates by both size exclusion and adsorption (Reis et al., 2007).

Filter Specifications

Not only do the various filter cartridge types come in different sizes, they are rated differently. Each of these classifications affects the pathogen removal in water. Drinking water standards can help guide the selection of the filter size, type, and ratings. The filter must be capable of removing the pathogens including viruses and bacteria present in the water where filtration takes place.

Filters can be found in pore sizes ranging from 0.02-100 μm . The size of the filter selected for disinfection is determined by the pathogens present and in need of removal. Pathogens can range in size, so different filter sizes will need to be selected for effective removal (Bielefeldt, 2010). The microfiltration membranes have pores that range from 0.1 to 10 μm . Pore sizes for microfiltration and ultrafiltration range from 0.1-0.5 μm , which is at least one order of magnitude lower than the size of the protozoa. When selecting a filter for disinfection, the filter size should be an order of magnitude smaller than the pathogen to be removed (Betancourt and Rose, 2004).

Nominal and absolute are the two types of ratings a filter can have. When a filter is nominally rated, it will effectively remove between 80% and 90% of the particles at the specified size. An absolute rating of a filter means at the specified size it will remove between 98% and 99.98% of the particles. As the percent removal efficiency is increased more particles will be removed from the water at the selected filter size. For drinking water standards an absolute rated filter is optimal, because it is able to remove more contaminants from the water (Parker Hannifin Corporation, 1994).

Protozoan Types/Particle Removal

There are several types of pathogens that can be found in water, all of which range in size, (Table 1). The sizes of the protozoa are important when selecting the correct size and type of filter needed for disinfection. If a proper removal technique with the correct filter size and type is not used, consumption of the water can become produce illness because of pathogens that not removed (Bielefeldt, 2009).

Table 1. Diameters of Typical Pathogens

Pathogen	Diameter (µm)
Escherichia coli	~ 1 x 3
Cryptosporidium parvum	4 - 7
oocysts	~ 4.7
Giardia cysts	9.3 x 12.2

Cryptosporidium and Giardia are common pathogenic protozoa found in water. These protozoa can be transferred through drinking water and then found in the gastrointestinal tract (Hsu and Yeh, 2003). The removal requirements for the two, as well as other protozoa, bacteria, and viruses are dependent upon the concentration of the protozoa to be removed. It has been observed that Giardia is more resistant to disinfection than bacteria. However, both Giardia and Cryptosporidium can be removed through conventional disinfection treatment and slow sand filtration. In Colombia, some of the prevalent parasites found in elementary school children were Ascaris lumbricoides, Hymenolepis nana, Trichuris trichiura, Blastocystis hominis, and Giardia lamblia (Gomez, 2005). Each parasite has unique effects on the people of Colombia. These parasites range in size, and therefore will need to be explored to determine which filter size is necessary for removal.

Ascaris lumbricoides, often referred to as roundworm, is one the most common infections in the world, especially in children 10 years of age and under. Because climate conditions favor transmission of the infection, Ascaris lumbricoides is more commonly seen in tropical and subtropical areas where there is inadequate sanitation because of the warm and wet climate. Roundworms can measure to be 40 cm in length and 6 mm in diameter and are often transmitted through ingestion of food or water. The eggs of these parasites are resistant to chemical treatment, but can be removed through filtration or boiling of water before consumption (Zaman, 2005).

Another common parasite in Colombia is Hymenolepis nana. It is a short tapeworm favored by warm climates. The worm measures to be between 15 and 40 mm in length and 0.5 and 1.0 mm in diameter. The egg diameter of these worms ranges anywhere between 30 and 47 µm. The eggs are not resistant to heat and are transmitted mostly by hand and mouth, but could also be transmitted through food and water.

Trichuris trichiura are found frequently in warm areas with inadequate sanitation similar to *Ascaris lumbricoides*. They are 3-5 cm long, and the females lay 5000-7000 thick-shelled, yellow-brown eggs per day. Their eggs can remain viable for months or years (Kayser, 2005). Humans can be infected with *Trichuris trichiura* by ingesting contaminated soil, food, or water with their eggs. Children aging from 3 to 9 years old are the majority affected.

Blastocystis hominis is a protozoan ranging from 6 to 40 μm in size. Their mode of transmission is by contaminated food or water. They are relatively resistant to environmental conditions; however they could die if exposed to direct sunlight (Gunther et al., 2006).

Secondary Disinfection

Even though filter cartridges can act as a method of disinfection, there is a need for secondary disinfection in some cases. The most popular types of secondary disinfection methods are: chlorine, ozone, and ultraviolet (UV) disinfection. Each of these has advantages and disadvantages.

Chlorination is an effective method for further disinfection of drinking water. It is the leading candidate because of chlorination's inexpensive cost and simple implementation using hypochlorite species. Chlorine is effective at disinfection because it can easily adhere to the cell wall of pathogens. Once attached to the cell wall, chlorine (the hypochlorite solution) is able to diffuse into the cell. Once the small molecule of hypochlorite is diffused into the cell, it is able to inactivate the microorganism by the dysfunction of the internal enzyme group (Wang et al., 2012). Chlorine as a disinfectant can remove up to 90% of the oocysts present in drinking water (Betancourt and Rose, 2004).

There are also disadvantages when using chlorine as a disinfection method. Chlorine is not able to remove *Cryptosporidium* from water. Since *Cryptosporidium* is resistant to the effects of chlorine, another disinfection process is needed to remove it from drinking water. Chlorine also produces disinfection byproducts, including haloacetic acids and trihalomethanes, which has become a more recent health concern (Li et al., 2011). These byproducts exhibit carcinogenic behavior in humans (Wang et al., 2012).

Ozone is another method of disinfection for drinking water, which is highly effective against all groups of microorganisms and capable of treating high volumes of water. An advantage to ozone is that few byproducts are produced. Although ozone has strong advantages, it also has disadvantages. Ozone can produce bromate if bromide is present in the water to be treated, which is harmful if consumed. Its effectiveness is reduced in colder temperatures of water (Betancourt and Rose, 2004).

The third method of disinfection to be explored is ultraviolet (UV) disinfection. UV disinfection does not rely on any additional chemicals and has highly successful inactivation of protozoa results. These protozoa include *Cryptosporidium* and *Giardia*. The UV disinfection requires minimal contact time and does not form any byproducts. However, UV lamp dosages are difficult to measure in practice and the turbidity of the water interferes with the dosages (Betancourt and Rose, 2004). This means if the water being treated has a high turbidity, the dosages will not be transmitted equally.

An optimal dosage of chlorine must be used, with pathogen removal, chlorination to be considered a method for disinfection. If too much chlorine is added to water it can be harmful for human consumption, but if too little is used there will be pathogens in the water that can make humans sick. A study was completed to find the optimal dosage of chlorine between these two potentially harmful levels. They used a chlorine solution prepared from deionized water and hypochlorite species (Li, 2011). By varying the initial dosage used, ranging from 0.1-5mg/L, and calculating the survival of the bacteria in water, they

found that the optimal dosage of chlorine to effectively remove *E. coli* was 0.5 mg/L in a 200 mL solution of microorganisms in deionized solution.

The optimal ozone concentration was found in the same experiment from Li (2011). In the experiment, ozone was produced from Fischer's 52 ozone generator. By sparging ozone that contained oxygen through deionized water, and cooling it in an ice bath, the solution was made. It was found with initial ozone concentrations from 0.5-5 mg/L that the optimal dosage of ozone to remove *E. coli* from water is 3 mg/L in a 200 mL solution of microorganisms in deionized solution (Li et al., 2011).

In an experiment conducted to determine the optimal dosage of UV irradiation that will disinfect water, two water samples that were collected from two different waste water treatment plants. The experiments used low-pressure lamps with emission around 253.7 nm. The first step was placing a 20 mL sample from the first wastewater site under the UV lamp and calculating the optimal dosage. The efficiency of disinfection by UV irradiation deals with particle sizes as well as turbidity. The increase in the dose of UV resulted in inactivation of particles in the water. This study showed that in order to remove a large percentage of pathogens from the water the UV dose needed to be around 12-16 mJ/cm². The dosage will be different for each sample because of the amount and types of contaminants in the water (Wang et al., 2012).

Summary

Based on the needs of Colombia and the results of the disinfection analysis, it has been determined that pleated filters should be used for final filtration. Due to their increased surface area, pleated filters will remove more pathogens. Their price is a little higher than other filter types, but the longer life expectancy outweighs the cost of the filter. Depth filters are effective in removing larger sized pathogens and are more cost efficient. When using a higher rating for pathogen removal, depth filters should be chosen. It is crucial to use absolute ratings when selecting a filter for final disinfection, because it can remove 98% - 99.98% of the pathogens at the stated micron rating as opposed to the 80% - 90% removal of nominally rated filters. A small enough rating to remove all of the pathogens present in the water being treated must be used. Because no filter has the capability to remove all pathogens and viruses, it is necessary to combine filtration disinfection with a secondary form of disinfection to avoid clogging. A secondary form of disinfection will also prevent any microbial activity and viruses from appearing in the effluent. The lifetime of a filter can be determined by the size and amount of pathogens in the water, therefore it is important to use multiple forms of disinfection (i.e. chlorination combined with different filtration sizes).

For secondary disinfection purposes, chlorination is an effective step in the disinfection process. Chlorination combined with filtration can effectively remove *Giardia* cyst and other pathogens that may be present in the water in Colombia. Directly following chlorination, the selected filter is a 1 micron absolute depth. This filter was chosen because it is inexpensive and capable of removing 98% - 99.98% of pathogens and *Cryptosporidium* oocysts at the 1 micron level. After the 1 micron filter, there will be a final filter of 0.2 micron absolute pleated filter. The 0.2 micron pleated filter will remove the pathogens that were able to flow through the 1 micron filtration process. The 0.2 micron pleated filter will further eliminate any remaining pathogens at the selected size. It was chosen at an absolute rating in order to ensure the most efficient removal of pathogens possible. The pleated filter was selected due to its increased life expectancy and surface area for maximum pathogen removal.

Research: UV Disinfection

Disinfection Overview

The research necessary to form a basis of this project falls under two categories: UV application and

electrical construction. The ultraviolet research pertains to the properties associated with the use of UV light as a means of water disinfection, while the electrical research deals with the proper use and selection design of germicidal lamp systems.

Ultraviolet light has a wavelength ranging anywhere from 100 - 400 nanometers. UV light used for germicidal applications is generally between 200 and 300 nanometers. Mercury vapor lamps produce light of a wavelength 254 nanometers, making this the most common output wavelength. (U.S. EPA, Section 2.2.1, 2006)

For germicidal applications, UV serves as an inactivating agent. Unlike other methods of disinfection, UV prevents the microorganism from reproducing by harming nucleic acids such as deoxyribonucleic acid and ribonucleic acids (DNA and RNA). Because these control reproduction, the microorganism can no longer infect the host (U.S. EPA; Sections 2.3, 2.3.1; 2006). The level of inactivation depends on factors like the UV output wattage of the lamp, the transmittance of the material, the distance from the source, intensity of UV to reach the water, and the time of treatment. According to Cabaj, total dose is the most relevant factor when determining effectiveness of UV treatment (1998). Dose is defined as the product of intensity and duration of exposure. However, both a high intensity used for a short amount of time and a low intensity used for a long amount of time produce the same effect. Intensity is a property of UV light, measured in units of watts per meter squared. Intensity can also be modeled as a function of power, distance from source, and absorbance of the media (U.S. EPA, Section 5.4.4, 2006). The Beer-Lambert Law (Equation 1) relates light attenuation to transmittance,

$$T = I/I_0 = e^{-\alpha l} \quad (1)$$

Where:

T = transmittance of a substance
 I = intensity of transmitted light
 I_0 = intensity of incident light
 l = path length through substance
 α = Napierian (base e) absorption coefficient for water

By rearranging the Beer-Lambert Law and estimating I_0 as the total wattage over the surface area of a cylinder with a radius r , the following equation applies (U.S. EPA, Section 5.4.4, 2006). :

$$I(r) = \frac{P}{2\pi r} e^{-\alpha \cdot r} \quad (2)$$

Where:

$I(r)$ = UV intensity at a distance r from the line source (mW/cm^2)
 P = UV power emitted per unit length of the line source (mW/cm)
 r = Radial distance from the line source (cm)
 α = Napierian (base e) absorption coefficient for water (0.015 cm^{-1})

The results from this model show that several outside factors influence intensity, and must be considered when designing the system.

Specific dose levels have varying levels of effectiveness on different microorganisms. Inactivation is described in terms of log inactivation.

$$\text{Log inactivation} = \log_{10} \frac{N_0}{N} \quad (3)$$

N_0 = Concentration of organisms before treatment

N = Concentration of organisms after treatment

Generally a higher UV dose results in a greater log inactivation. A summary of doses required for specific log inactivation relevant to the project is provided in the table below (U.S. EPA, Section 1.4.1, 2006).

Table 2. Log Inactivation of Target Pathogens

Target Pathogens	Log Inactivation							
	.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
<i>Cryptosporidium</i>	1.6	2.5	3.9	5.8	8.5	12	15	22
<i>Giardia</i>	1.5	2.1	3.0	5.2	7.7	11	15	22
Virus	39	58	79	100	121	143	163	186

According to the EPA (Section 3.1, 2006), it is recommended that at least a 2-log *Cryptosporidium* inactivation is achieved. It has also been shown that the required dose for virus inactivation is much higher than that of both *Cryptosporidium* and *Giardia*. Because most viruses can be deactivated using chlorination, it may not be necessary to design for a high virus inactivation by the system.

Electrical Components

Many components are necessary to create a UV system. Several types of UV bulbs for germicidal purposes are available for consumer use. The most common variations are low pressure mercury vapor lamps classified as low pressure high output, and medium pressure (U.S. EPA, Section 2.4.2, 2006). Other lamps are available, such as LED, but the cost is restrictive. Mercury lamps have a high germicidal UV output because the majority of light produced is at 254 nanometers. Each lamp also has several other features which dictate output, lifetime, and power requirements.

Bulbs can be of cold cathode or hot cathode classification. This term refers to the type of the electrode in the lamp (American Air and Water, 2002). Hot cathode bulbs work like standard fluorescent lamps and are more common. Cold cathode bulbs are instant start and generally have a longer life.

Lamp life is affected by both lamp design and the number of times the lamp switches on over the course of the lamp's life. The lamp output decreases as the lamp ages (U.S. EPA, Section 2.4.2, 2006). The lamp's life in hours is the total amount of time it operates at least 70% of the original UV output (Willette, 2002). The most common specifications are outlined in the following table (U.S. EPA, Section 2.4.2, 2006):

Table 3. UV Lamp Specifications

Parameter	Low-pressure	Low-pressure High-output	Medium-pressure
Germicidal UV Light	Monochromatic at 254 nm	Monochromatic at 254 nm	Polychromatic, including germicidal range (200 – 300 nm)
Mercury Vapor Pressure (Pa)	Approximately 0.93 (1.35×10^{-4} psi)	0.18 – 1.6 (2.6×10^{-5} – 2.3×10^{-4} psi)	40,000 – 4,000,000 (5.80 – 580 psi)
Operating Temperature (°C)	Approximately 40	60 – 100	600 – 900
Electrical Input [watts per centimeter (W/cm)]	0.5	1.5 – 10	50 – 250
Germicidal UV Output (W/cm)	0.2	0.5 – 3.5	5 – 30
Electrical to Germicidal UV Conversion Efficiency (%)	35 – 38	30 – 35	10 – 20
Arc Length (cm)	10 – 150	10 – 150	5 – 120
Relative Number of Lamps Needed for a Given Dose	High	Intermediate	Low
Lifetime [hour (hr)]	8,000 – 10,000	8,000 – 12,000	4,000 – 8,000

With the application of an UV bulb there is a need for a ballast, or a current controlled current source. Due to the high input voltage and high input current the ballast works to prevent the bulb from draining too much power. A representative at 1000bulbs.com explained that at first the voltage and current are relatively high in order to start the bulbs, but then drop to a lower “operational setting.” This ensures efficiency and prevents the bulb from overheating and prematurely failing.

A device which controls the input source to the ballast, using time, is a requirement. Once turned on this device would allow the ballast to draw power and operate the bulb. After a set amount of time, the device would switch off so the ballast does not receive any power. Timers work in this exact fashion and conduct product efficiency.

Colombia has the same standard voltage output as the United States. Standard pins allow the use of a typical extension cord to go from a wall outlet to the ballast. These are relatively inexpensive and available in many locations. Cutting extension cords, (not plugged in), is a simple and effective way of connecting the ballast to the wall.

The initial prototype design had no timer and needed another way to control the input. This is what led to the switch method for the design. Turning the circuit on and off, while timing it with an outside timer was the process used. Eventually a timer will be purchased and implemented in place of the switch.

Case Studies: Solar Water Disinfection

Solar Water Disinfection, better known as SODIS, is an extremely basic form of batch water purification designed by the Swiss Institute for Aquatic Science and Technology (EAWAG). It is widely recommended by the World Health Organization, UNICEF, and the Red Cross.



Figure 4. SODIS bottle design (left), SODID bag design (right)

SODIS utilizes the UV rays from sunlight to inactivate waterborne bacteria. The device uses non-turbid water, similar to the water used in the Water Resource Management project. Figure 4 shows the basic devices are extremely basic and feature very few parts, making it inexpensive and easily transportable.

The two models are different in some aspects, but function in the same way. They are left outside in the sunlight for at least 6 hours during which the UV sunlight inactivates the bacteria. Both models have the ability to better the process by incorporating “Solar Sleeves” to increase UV reflection and heating potential. The first model utilizes bottles to store the water. Bottles are easy to transport after SODIS is accomplished. They can also be easily cleaned, and are very durable. The disadvantage to using a bottle is the “bacterial paradise” that exists under the cap.

The second model uses bags to store the water. The bag is easy to transport before SODIS is applied; “you can deliver 120 liter bags in the space of one two liter bottle” (Orfan, 2010). The second advantage is cost. Bags are typically less expensive than bottles and have an equally effective design. However, bags may tend to leak and are difficult to transport after SODIS is achieved.

In conclusion, SODIS is a proven and highly endorsed method of water disinfection. It provides an inexpensive method for UV disinfection. The disadvantages to SODIS disinfection are the reliance on sunlight, the minimum 6-hour required amount of time to achieve solar disinfection, and the inability to produce a large amount of disinfected water.

UV Water Disinfection System

This system utilizes a flow through system to achieve water disinfection. The system itself is extremely adaptable. From plug-in options to solar cells, there are many variations for the design. All the designs share a common mode of operation, seen in Figure 5. After system setup, the bulb is turned on, followed by filling the loading pail with water. Stouter claims that the system requires less work than the SODIS system needs (2011).



Figure 5. UV Water Disinfection System

There are numerous advantages to using the UV Water Disinfection System. It has a high clean water yield and can disinfect a large amount of water in a short timeframe. It also has a high quality of disinfection. Since the system uses a proven flow through system, it provides an extremely accurate UV germicidal lamp that has been proven to disinfect water accurately. Compared with the SODIS system, the initial costs are high because of this. Also, the construction time for a UV Water Disinfection System is greater, and maintenance costs may prove to be higher than SODIS maintenance. The UV Water Disinfection System is an expensive device and includes a high investment in initial building stages, but it uses external power to drive a high quality UV light that provides disinfection of water at speeds much greater than SODIS.

Actinometry Research

Actinometry is used to measure light intensity during irradiation. The potassium ferrioxalate actinometer is widely used by photochemists. It is most useful in the range of 254-500 nm (Leifer, 1930), and at a concentration of 0.15 M. The potassium ferrioxalate actinometer will form a red pigment when cryptosporidium, giardia, and viruses are inactivated throughout the water sample.

Modeling was completed, using the Beer-Lambert law, to calculate preliminary measurements of the intensity, dosage, and irradiation time necessary to complete full inactivation of water.

Table 4. Beer-Lambert Law Calculations

Inputs	
UV Output (W)	5.5
Safety factor	0.1
Radial distance (cm)	38.1
P_L (mW/cm)	244.444444
α_e (1/cm)	0.015
Pi	3.14159

Table 5. Preliminary UV Disinfection Measurements

Time (min)	Time (s)	I(r) (dimensionless)	Dosage
0.5	30	0.576602335	17.29807006
1	60	0.576602335	34.59614012
2	120	0.576602335	69.19228023
3	180	0.576602335	103.7884204
4	240	0.576602335	138.3845605
5	300	0.576602335	172.9807006
6	360	0.576602335	207.5768407
7	420	0.576602335	242.1729808
8	480	0.576602335	276.7691209
9	540	0.576602335	311.3652611
10	600	0.576602335	345.9614012
11	660	0.576602335	380.5575413
12	720	0.576602335	415.1536814
13	780	0.576602335	449.7498215
14	840	0.576602335	484.3459616
15	900	0.576602335	518.9421018

VI. Results

Point-of-Use Slow Sand filters

During the semester of Spring 2012 the slow sand filter redesign team sought out to make massive improvements in the functionality, ease of construction, and cost of previous SSF designs. The team identified several primary design aspects that needed to be analyzed. Table 6 shows the initial organization of design criteria that facilitated the design process.

Tubing Size

The redesign team decided to focus on tubing size at the start of the semester. A variety of different tubing options on McMastercarr.com were looked up and evaluated. It was found that the least expensive type of tubing, which met all of the team's design requirements, was the same as the tubing used in the original SSF design: *Flexible Low-Temperature White EVA Tubing*. Once the team made this identification, they conducted research using the McMastercarr.com catalog to generate an understanding of the price variability of cord grips and compression tees, in relation to the outer diameter of the tubing. The team concluded that as the outer diameter of the tubing became smaller, the price of the corresponding fittings and the price of the tube itself decreased.

Based on this observation the team decided to place an order for a new set of tubing and tube hardware at two different outer diameters. Two sizes were ordered in anticipation that the smaller tubing would lack the rigidity required to withstand the internal pressure forces of the filter. The sizes chosen were based on estimations of how large the inner diameter of the tubing needed to be in order to prevent clogging due to potential discharge of sand from the filter. This was estimated to be one quarter of an inch. Form A-1 in the appendix details the order.

When the hardware arrived the team found that the tubing with the smallest outer diameter met the requirements for rigidity. Since this size presented the least expensive option, the team chose to use it in their final prototype.

Table 6. Slow Sand Filter Re-Design Matrix

Slow Sand Filter Re-Design Team Design Matrix		
Components to Be Evaluated	Design Criteria	Reasons for Re-Evaluation
Tubing	1. Tube walls must be strong enough to withstand pressure from the weight of the sand and water mixture in the filter as well as any other extreme forcings that the SSF may encounter.	Derived from a recommendation made in last semester's project report; reconsidering the size of tubing used in the SSF could lead to large cost reductions as the price of several hardware components are dependent on the size of the tubing.
	2. The material of the tubing selected must be compliant with the United States Food and Drug Administration (FDA) standards for food safety.	
	3. The material must also be UV resistant and withstand a temperature range similar to the extreme temperatures on this planet.	
	4. Tubing must also have a bend radius that is 14" or less. (Height of a standard 5gallon bucket is roughly 14", if the tubing is intended to curve elliptically from the bottom of the bucket to the outer edge, a safe estimation is a bend radius of 14")	
	5. Tubing must have an internal diameter that is large enough to avoid clogging from sand. ID \approx 1/4"	
Support Layer	1. Must be structually sound and rigid enough to withstand the weight of the sand for five years	Upon evaluation of last semester's design, it was found that the supports for the pizza plates were arduous and time consuming to construct. Pizza disc caused discoloration in effluent water.
	2. Must be non reactive with water and compliant for use in drinking water	
	3. Supports must be easy to assemble and disassemble	
	4. Cost of entire support layer must be approximately \$5.00 or less.	
	5. Media must be porous enough to avoid generating preferential flows	
Diffuser Plate	1. Must sufficiently diffuse inflowing water so that the schmutzdecke is not disturbed	Last semester's team did not design a diffuser plate.
	2. Must be approximately \$2.00 or less	
	3. Must be made from readily available materials in rural communities	
	4. Must be easy to use, easily constructed, removed and replaced (Filter Maintenance)	
	5. Must be compliant with regulations for safe drinking water	
	6. Must last for at least five to ten years	

Support Layer

After reading last semester's report, the team decided to re-evaluate the design of the "pizza disc" support plate. Of particular interest was the construction process which entailed cutting and fitting many short segments of tubing as "legs" to support the pizza disc. The team found the procedure to be meticulous and time consuming. This was not ideal considering the client's need for a simple and quick to construct SSF. The team decided that a substitute for the pizza plate supports was necessary.

In addition to the tube legs requiring replacement, the team noticed that the assembled slow sand filter using the "pizza disc" design was producing discoloration in the effluent water. The hue of the water seemed to be metallic, and after a quick discussion, it was hypothesized that the aluminum pizza discs were eroding. In order to verify their hypothesis, the team placed a pizza disc at the bottom of an empty five-gallon bucket and filled it with about two inches of water. Periodically team members picked up the bucket and shook for the purpose of aeration. After a few weeks the team noticed the same discoloration in the test bucket as in the effluent water. With turbidity removal rates being a primary function of a SSF, having a component that caused coloration of the water was a design flaw that needed to be fixed.

Having established the source of the problem, the team sought to find a substitute for the pizza disc, as well as redesigning its supports. A chart detailing the problem solving process is listed below. In the end,

all of these ideas were not pursued because the team discovered a simplified design option for the entire support layer.

Table 7. Support Layer Problem Matrix

Support Layer Problem Matrix			
Component being Evaluated	Problem at Hand	Solution Criteria	Possible Solutions
Pizza Disc	Material of the disc is eroding and causing discoloration of effluent water.	Must be non reactive with water and compliant for use in drinking water	Use food grade paint, waterproof paint to coat the pizza disc
Tube "Legs"	Construction of tube legs is time consuming and arduous.	Must be structually sound and rigid enough to withstand the weight of the sand for five years	Use a "deep dish" pizza disc and set it upside down so that its edges provide the necessary support.
			Set the pizza plate on one of the following: a metal or plastic ring, marbles, shredded tubing

In the fall of 2011 a sample piece of *Sand Bed Filter Support*, from POREX[®], was received by the Scale Up team. This plate, a rectangular segment of heat pressed polyethylene beads, was thought to be too expensive to be used in the SSF. This semester the Redesign team re-evaluated the feasibility of using the plates and found it to be cost effective. Each plate measures 38.5" x 11.5" x .688" cost roughly \$10.97. If the team could make at least three support layers from each plate, the complete price of the assembled support layer would meet the \$5.00 cost criterion.

Several cut-outs of the original plate were discussed and the team agreed to pursue a circular design that matched the diameter at the bottom of the 5 gallon bucket ($d = 10''$). Before attempting to construct the top portion of the support layer, the team went to the Artisan and Fabrication Lab in Armstrong Hall at Purdue University and tested how the plate would cut using various tools. The team used a water jet at several settings and found that the plate had the cleanest cut when the jet was put at the material setting to cut lead. The team then used a band saw and found that it provided the cleanest cut possible out of all the different methods. With this knowledge the team discussed design options again. With further brainstorming, the idea for a square plate design came up. A 7" square supported by four rectangular pieces, arranged in a hollow 7" square, would fit at the bottom of the bucket and potentially save time and money. The team evaluated their options based on the criteria listed in the chart below.

Table 8. Porex Plate Support Layer Design Decision Matrix

Porex Plate Support Layer Design Decision Matrix			
Design	Tools Required for Construction	Construction Cost (Qualitative)	Number of Support Layers Constructed Per Plate & Waste Generated
Circular Cut-Out ($d = 10''$)	Requires either a water jet or someone skilled enough to cut a circle with a band saw.	Using a water jet would be more expensive than a band saw. Skilled labor would have to be hired to operate the band saw in the method requested.	Only three support layers could be cut out of one filter plate. A considerable amount of waste would be generated.
Square Cut-Out ($L = 7''$)	Band Saw	No exterraneous cost. Skilled labor is not required as only a few straight cuts need to be made with this design	Five support layers could be cut out of one filter plate. No waste would be generated.

The square design was pursued because it took less time to construct, was simple to assemble, generated no waste, and was the least expensive option. This design also catered to the client's need for ease and simplicity of construction. Another benefit is that the chance for preferential flow decreased. It was speculated that over time the pizza disc design might form flow paths through the holes in the pizza disc as the polypropylene mesh layered above it began to stretch and sag. With the square filter plate design, these flow paths would be of less concern due to the media's homogenously distributed small porosity. With a sealed support made of the same material, seen in the 7" square design, any water flowing in between the filter plate and the bucket would inevitably have to flow through the filter.

Now that the majority of the support layer had been created, the team had to decide on the connection the rectangular supports to the square plate and how to integrate the assembled block with the SSF's tubing network. The team looked at waterproof glues, caulking, cable ties, and staples before turning to stainless steel finishing nails to connect the square plate to its supports. This option provided the strongest connection between all the pieces and was inexpensive. For a connection to the tubing network, the team decided to mimic last semester's design. Complete instructions for assembly of a SSF unit are listed below.

Slow Sand Filter Assembly

Material required for a 2 bucket unit:

- 2 5-gallon buckets with 2 lids
- 11.5"x35" sheet of polypropylene beads
- Roll of polypropylene woven mesh
- 16 stainless steel finishing nails
- 18lb tensile strength fishing line
- Power drill with 1/8" and 5/8" drill bits
- White EVA tubing, 50" total will be needed
- 1 tube T
- 2 cord grips
- 2 zip ties
- Sand: total volume of approximately 15 L, with diameters ranging .25-.85mm
- 2 plastic washers
- 2 O-rings

Instructions:

1. Cut two 17" pieces and one 13" piece of white EVA tubing. Scissors can be used to cut the pieces.

2. Using a 5/8" drill bit, drill a hole 10" from the bottom of each of the pails (4 inches from the top of the pail). It will be necessary to remove a section of the bottommost flange using a utility knife (Figure 6)

3. Drill an additional 5/8" hole in one of the buckets approximately 13" from the bottom of the bucket, it should be located a quarter of the bucket away from first hole. This will be the bottom bucket of the filter.

4. Install a cord grip bulkhead fitting to each of the buckets. Cord grip fittings attached to bucket shown in Figure 7.

5. Feed a piece of tubing through the cord grips, each need to be tested for leaking. Fill up the bucket with water and thoroughly check for water leakage (Figure 8).

6. Cut 7"x7" squares from the sheet of polypropylene beads (the entire sheet will make 5 squares). A bandsaw should be used to make the cuts then a sander can be used to smooth the ends. The rest of the sheet will be used to make 20 1"x7" strips. Leave half of the strips as is and cut the other 10 to 1"x5"

7. Using the 8 nails, secure two of the 7" strips and two of the 5" strips under a polypropylene square. Use two nails per strip. (assembled plate in Figure 9)



Figure 6



Figure 7



Figure 8



Figure 9

8. Cut 18"x 9.75" rectangles of the mesh, one rectangle needed for each square of polypropylene.

9. Using the 1/8" drill bit, drill a small hole approximately 1" from the end of one side of both 17" pieces of EVA tubing.

10. Mimicking wrapping a present, wrap the mesh rectangle around the square and strip plate. Be sure to cover the entire plate, with some overlapping. The square will be the top of the plate with the strips the bottom. While holding the top layer of mesh in place, drill a 3/8" hole in one corner 2" from each side through the top layer of mesh and polypropylene square.

11. Still holding the mesh in place, feed the drilled end of the 17" EVA tubes through the mesh and plate. The tube only needs to go through the plate enough for the drilled hole to show. Then push the zip tie through the hole, secure it, and cut the extra tie off (Figure 10).

12. Replace the mesh so that it's in the original arrangement with special attention to securing the ends (Figure 11). Use a generous amount of fishing line to firmly secure the mesh in all regions (Figure 12).

13. Place the assembled plate in the bottom of the bucket; insert the top of the tubing through the cord grip of the bucket (Figure 13).

14. Repeat steps 9-12 for the second bucket

15. While holding the assembled plate in the bottom of the bucket, add about 1/4 bucket of water, then add the sand until it is just below the cord grip (do this for both buckets).

16. Stack the top bucket on top of the bottom bucket and attach the middle connector of the T-cord grip to the outer section of the tubing for the top bucket. The bottom connector should then be attached to the 13" piece of tubing with the other side fitting in the hole in the bottom bucket. Attach the 3" piece to the top of the connector. (Figure 14)

The final product is shown in Figure 15.



Figure 10



Figure 11



Figure 12



Figure 13

Figure 14





Figure 15

Scale-Up Team

A bench-scale slow sand filter (SSF) was designed and built in the lab. This pilot filter is held in a large PVC pipe 4-foot in length and 6-inches in diameter. This filter is designed to operate under a continuous regime of inflow water, provided by a FMI QD RH1 water pump, and will provide a continuous flow of filtered effluent water. The filter media consists of 65 inches of sieved sand, 8 inches of medium size gravel and 6 inches of coarse gravel, which the water will travel through. The filtered water will exit through a barbed male pipe elbow into a funnel and finally effluent reservoir. The vertical distance (Δh) between the overflow pipe and outflow pie is the hydraulic head and is used to control the flow rate through the filter. The siphon overflow system is included to divert the extra water fed into the filter back to the source reservoir. Figure 16 presents a diagram of the prototype filter design and description of some of its components, and Figure 17 shows a picture of the prototype filter built in lab.

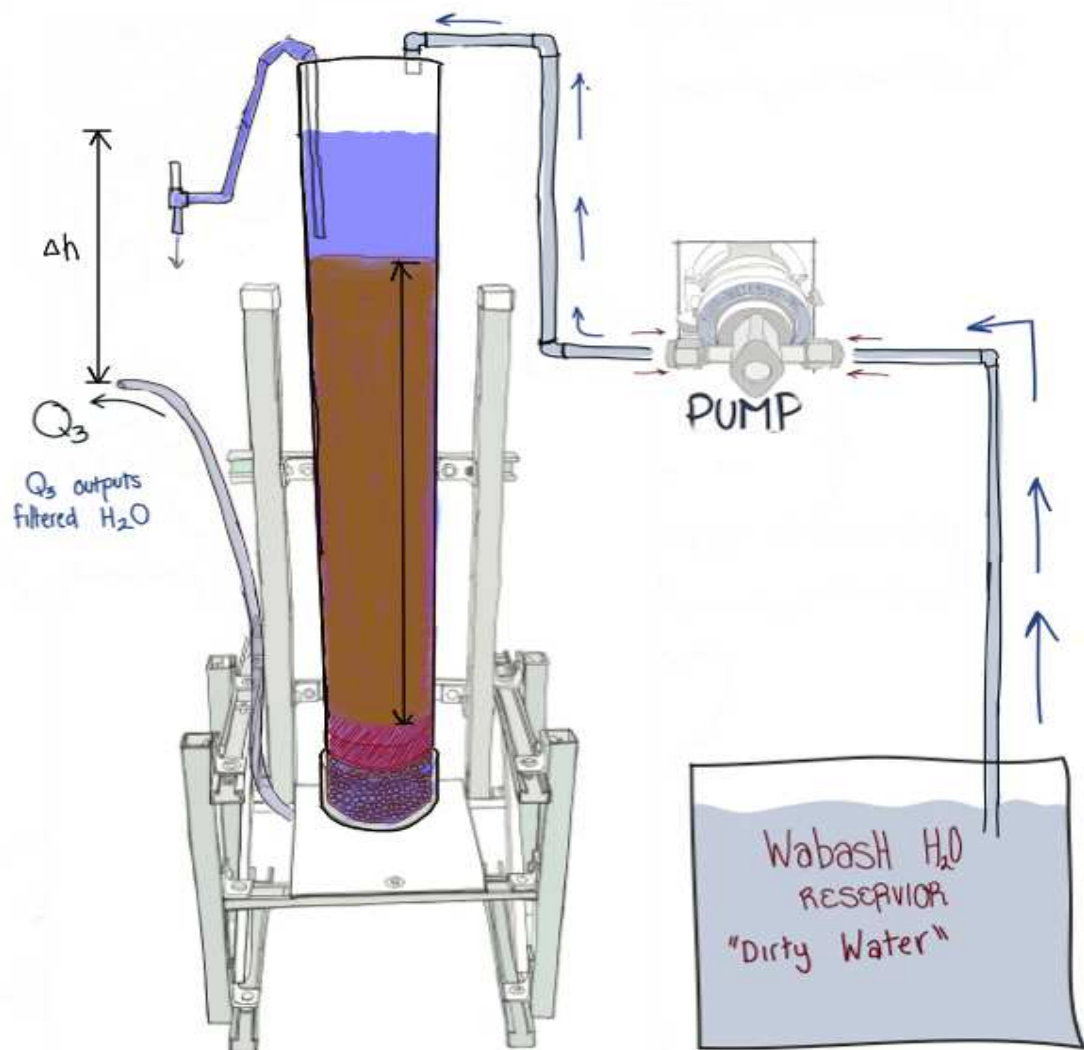


Figure 16. Pilot-Scale prototype filter diagram



Figure 17. Pilot-scale prototype filter picture

Sand Porosity Measurement

In order to calculate the desired flow rate to achieve an 8-hour retention time, the porosity of the sand had to be determined. This was achieved through a laboratory test using a 200 ml sample of the dry, sifted sand used in the pilot-scale filter. Water was added to the sand in discrete intervals until the sand had been completely saturated. The volume of water added was recorded and the porosity was calculated using eq 4,

$$\eta = \frac{V_w}{V_s} \quad (4)$$

where η is the porosity, V_w is the volume of water added, and V_s is the volume of sand. After completing two trials, an average porosity value of 0.36 was calculated.

Design Flow Calculation

Utilizing the experimentally determined porosity value (see above), the desired design flow rate of the pilot filter could be calculated. A hydraulic retention time of 8 hours was chosen to evaluate filter performance at the minimum desired value. Using the known sand depth of 65 cm, the velocity of the water through the sand layer (pore velocity) can be calculated (eq 5),

$$v_p = \frac{h_s}{\phi} \quad (5)$$

Where h_s is the sand height, ϕ is the retention time, and v_p is the pore velocity, 8.124 cm / hr. Using this value, and Darcy's Law, the water velocity above the sand layer (Darcy velocity) can be determined (Eq 6).

$$v_{darcy} = \eta * v_p \quad (6)$$

This yields a Darcy velocity (v_{darcy}) of 2.92 cm / hr. The desired outflow rate of the filter can then be calculated to be 8.89 cm³ / min, or 12.8 L / day (Eq 4).

$$Q_d = v_{darcy} * A_f \quad (7)$$

Q_d is the desired flow rate and A_f is the area of the filter (182.41 cm²). The goal of filter operation is to maintain this design flow rate by adjusting the hydraulic head between the water level and outflow pipe.

Design Parameters

Table 9. Filter Design Parameters

Sand column height:	65 cm
Sand column diameter:	6 in
Porosity of sand column:	0.36
Design Retention time:	8 hs
Overall flow rate:	12.8 L/day

Large Scale Design Cost

Table 10 lists all the materials used to build the prototype filter and describes the associated manufacturer and costs. Asterisks indicate that those materials were available in the lab and therefore there is no cost associated.

Table 10. Bill of Materials to Build Prototype

Item	Manufacturer	Quantity	Unit Cost	Total Cost
4-ft length 6-in ID Clear PVC Pipe	McMaster Carr	1	190.95	190.95
Threaded Female Through-Wall Fitting Connections for 1/2-in PVC pipe size	McMaster Carr	3	14.23	42.69
White PVC Pipe Unthreaded Socket End Cap (Female) for 6-in pipe size	McMaster Carr	1	11.94	11.94
Barbed Hose Fitting 90° Elbows (Male) for 3/8-in ID hose and 1/2-in pipe size (pkg. qty. 2)	McMaster Carr	1	7.17	7.17
Ultra-Chemical-Resistant Tygon PVC Tubing Clear, 1/4" ID, 3/8" OD, 1/16" Wall Thickness (sold per foot)	McMaster Carr	10	3.38	33.8
Economy Plastic Funnel Polyethylene, 16 Ounce Cap, 5" Top OD	McMaster Carr	2	1.94	3.88
FMI Pump Model QD RH1 CKC Serial No. 52630	Fluid Metering Inc.	1	**	**
1/4" ID Compression Tubing		10 ft	**	**
Tubing Adapters for 1/4" ID	Fluid Metering Inc.	2	17	34
Compression Nuts for 1/4" Tubing	Fluid Metering Inc.	2	6	12
3/8" Thin Walled Tubing		10 ft	**	**
Gravel, Sand			**	**
5 gallon carboy (Wabash River collection)		5	**	**
Hardware for outflow 'shelf'	Lowe's Hardware			30
Bungee Cords		3	**	**
10 L Reservoirs		2	**	**
3-in-1 Water Quality Test Strips	Hach	3	16.49	49.47
Total				415.9

Pilot-Scale operation and performance (Experimental data)

A continuous flow of 50/50 Wabash River (WH2O) and distilled water was pumped through the sand filter with a retention time of 8 hours for three months. Daily control of design parameters as well as water quality measurements allowed us to monitor the prototype performance and evaluate the success of the filter. Table 11 describes the performance test set up and timeline.

Table 11. Performance Test Set Up and Timeline

Date	
02/03/12	Turbidity measured: 22.8 NTUs
	1 liter of WH2O was added the day of collection and allowed to cycle through the filter for two days to kick-start the biological activity.
02/06/12	Influent and effluent tanks are set up to begin the experiment.
	Control variable: Influent water, 50% WH2O, and 50% distilled water.
	Independent variable: Effluent water is collected in a five-gallon plastic tank.
02/08/12 to 03/08/12	Daily, control of hydraulic head and effluent volume is done, and turbidity measurements are taken from the effluent. 3 times a week easy-gel, total alkalinity, total hardness, and pH are performed on influent and effluent water.
03/08/12 To 03/19/12	Filter operated in recirculation mode due to Spring break holiday
03/23/12	Control variable: Influent water 100% WH2O
04/20/12	Ends operation

Test Results

In order to control the prototype filter parameters, flow rate and water head measurements were recorded throughout filter operation. Water quality test were performed to assess the performance of the pilot-scale filter. These tests included turbidity, dissolved oxygen, *E. coli* and total coliform concentrations, alkalinity, total hardness, and pH. A detailed description of all the steps followed when doing testing is included in Appendix X. Complete tables with data recorded in every test are included in Appendix X.

Flow rate

While not a measure of water quality, flow rate is an important parameter. We measure the volume of water passed through the filter during a given day (between data gathering sessions) and divide by the elapsed time. From the flow rate, the retention time of the filter can be estimated; that is the amount of time any “packet” of water is moving through the sand of the filter. Higher retention times should provide higher effluent water quality but this benefit must be weighed against the detriment of lower filter capacity. Figure 18 displays the cumulative outflow (in liters) collected from the filter. The period between March 8th and March 22nd the filter operated in a closed loop due to spring break holidays.

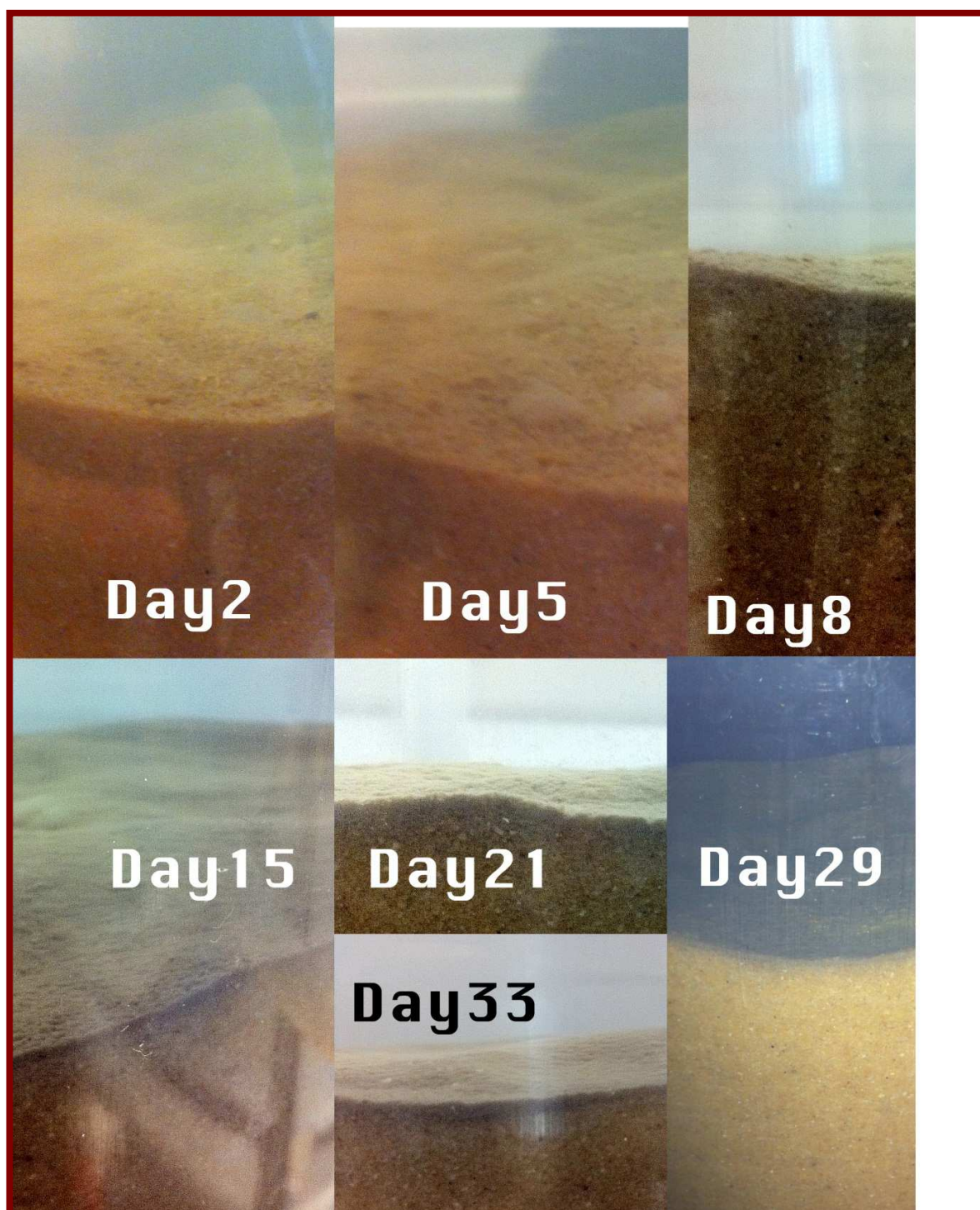


Figure 18

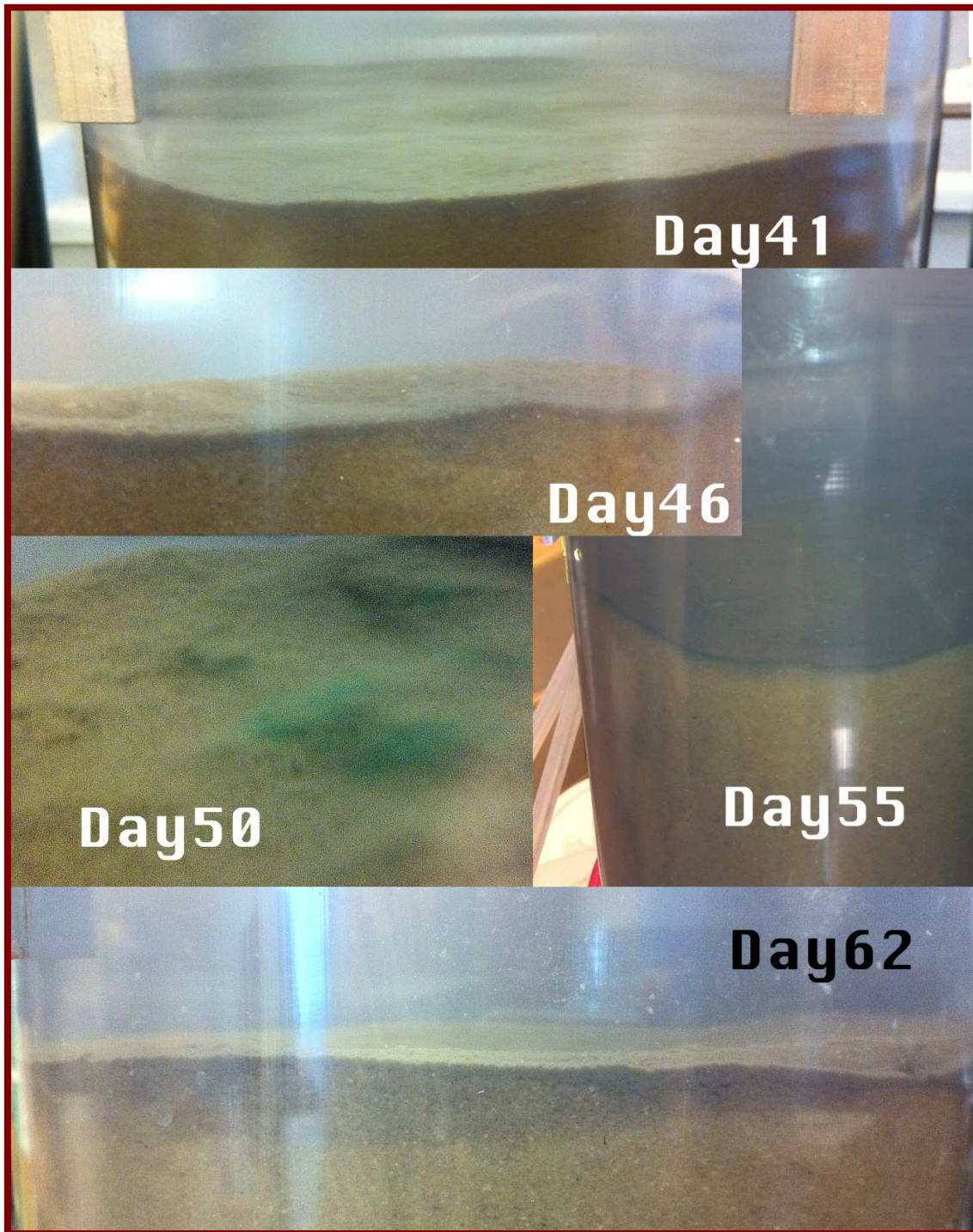


Figure 19

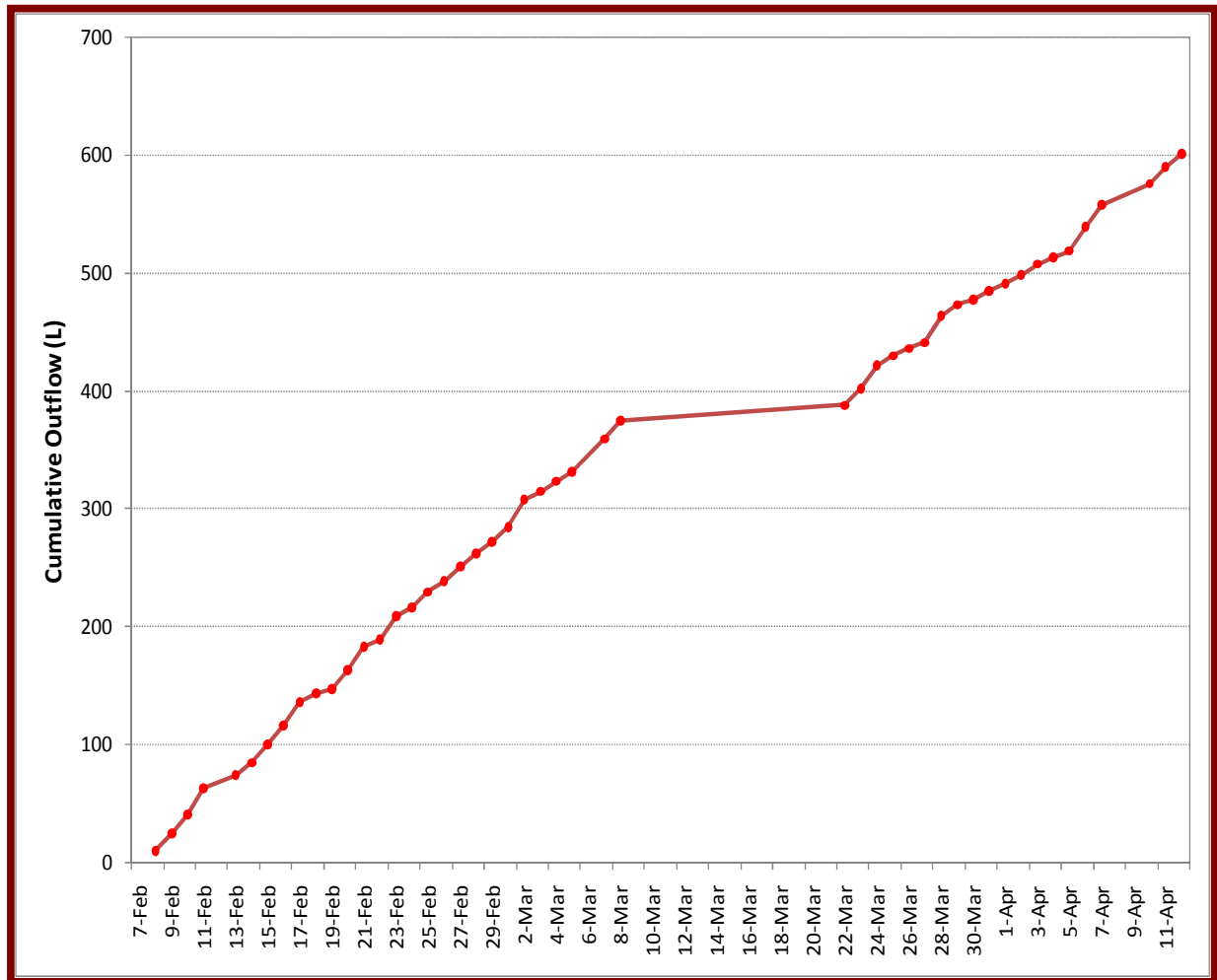


Figure 20. Cumulative Flow Rate

Hydraulic Water Head

The hydraulic head consists of the height of water over the level of outflow. This parameter is important because it regulates the outflow rate. The larger the head, greater is the pressure over the sand column and therefore the greater volume of water that will be filtered. That is why it is expected to have a stable head level in order to assure the retention time of the filter and resulting performance. However, over the course of the experiment, the hydraulic head is subject to increase because of clogging, as a result of the biological layer developing on the surface of the sand. The development of this layer, the Schmutzdecke, can be seen in Figures 18 and Figure 19. Figure 21 is a picture of the hydraulic head and measurement system installed in the prototype filter. Figure 22 shows the hydraulic head values measured daily. It is observed that the hydraulic head increased over time.



Figure 21. Picture of head

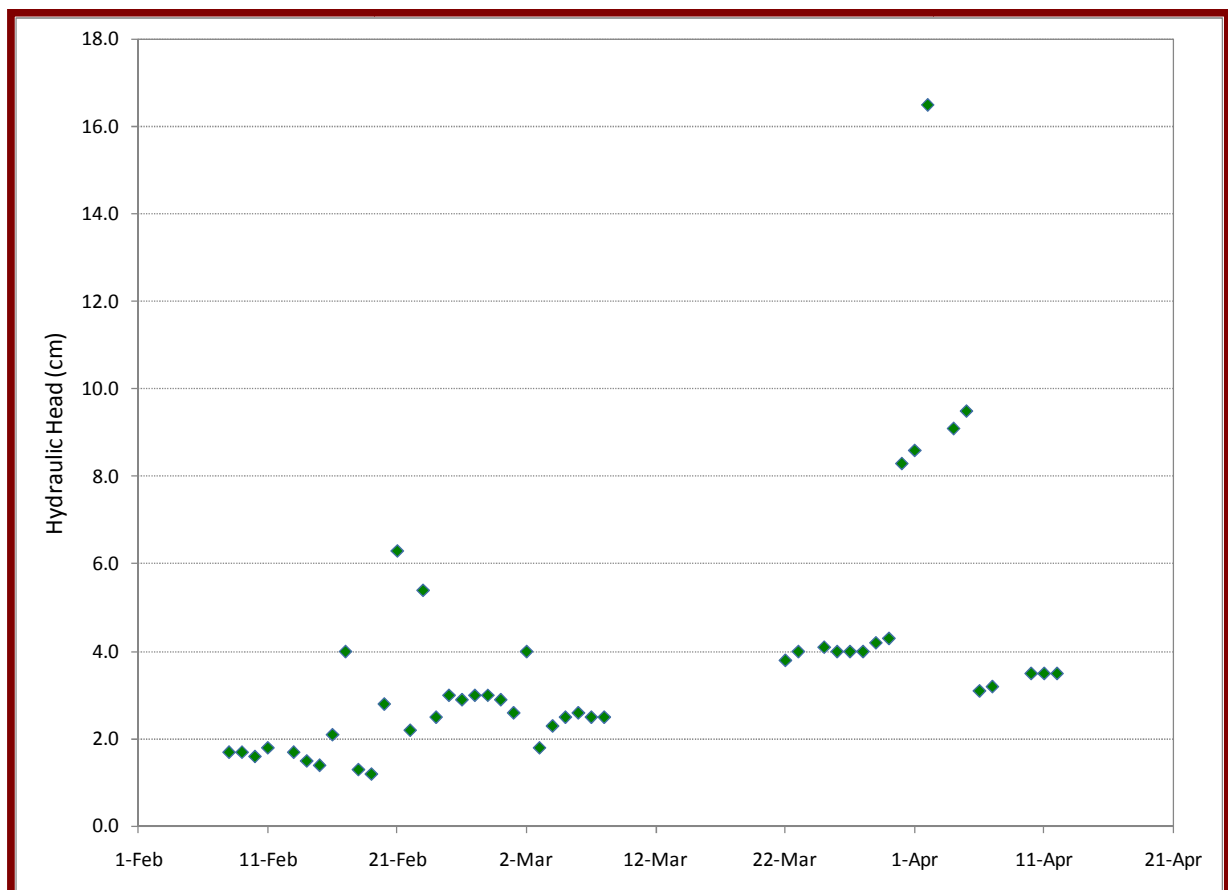


Figure 22. Hydraulic head

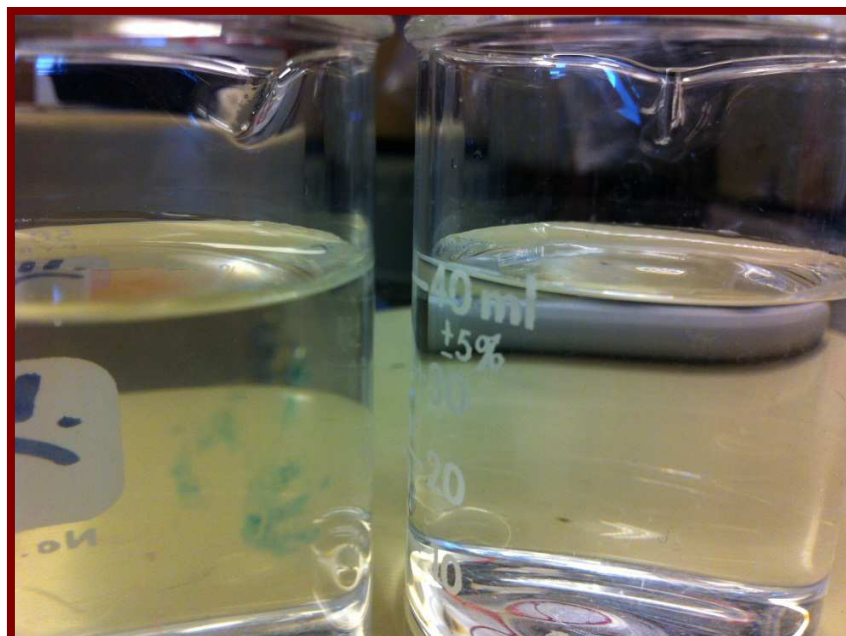
Turbidity

Turbidity is a measure of relative clarity of the water and an indirect measure of suspended particles in a water sample. This is not only an aesthetic characteristic of drinking water; controlling turbidity is a safeguard against pathogens (EPA, 1999). Turbid waters, in addition to appearing discolored and unappetizing, can inhibit disinfection by shielding microbes from disinfection processes. Therefore, turbidity must be reduced to ensure adequate disinfection. The US Environmental Protection Agency (EPA) allows a maximum turbidity level of 1 NTU for drinking water. Turbidity is quantified using a turbidimeter which projects a beam of light through a water sample and measures the amount of light deflected. It is reported in Nephelometric Turbidity Units (NTU).

Turbidity was measured in the source water and effluent obtained after the filtration process, daily. A HF Scientific Inc© DRT-15CE portable turbidimeter was used. Results are presented in Figure 24. It is observed that there is a clear reduction in turbidity levels and the filter meets EPA turbidity standards. A visible increase in water clarity can also be seen in Figure 23.



Figure 23. Pictures of turbidity before (left) and after (right) filtration (above and below)



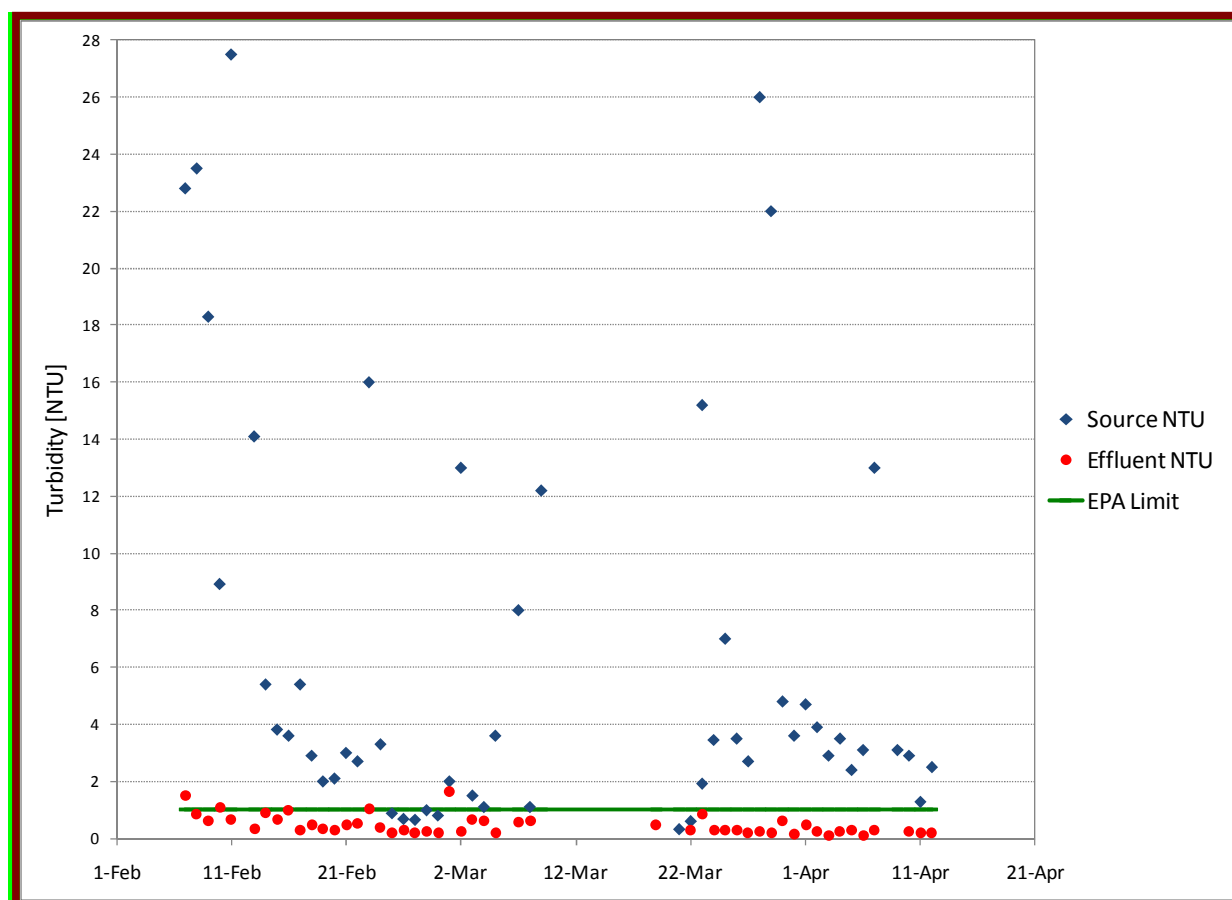


Figure 24. Turbidity measured in source water and filtered water

Dissolved Oxygen

Dissolved Oxygen (DO) measures the concentration of free molecular oxygen in a water sample. There are several ways to measure this; the method we used involves bringing a water sample into contact with a vial of testing fluid which turns a shade of blue in the presence of oxygen. The color intensity is compared to several standards to give an estimated oxygen concentration. Adequate oxygen levels are important in both the influent and effluent water. It is essential to keep the microbes in the filter in an aerobic environment. If oxygen levels are depleted, anaerobic metabolism will produce unwanted byproducts such as sulfides, known for their unpleasant odor and taste.

E. coli and total coliforms

Reduction in Coliform bacteria, including *E. coli*, is considered an indicator of filter performance. An *E. coli* and total coliforms test is an indirect measure of pathogens in a water sample. *E. coli* can be considered an “indicator organism” of the presence of other pathogenic microorganisms and coliform bacteria, and is often present in addition to potential human pathogens but are much easier to detect. The presence of coliform bacteria was tested using Coliscan EasyGel© technology. Five milliliters of water was added to a plastic vial containing the gel agent, agitated and poured into a treated Petri dish for incubation at 30°C for 24 hours. After incubation, *E. coli* colonies appear purple and general coliforms appear pink (Figure 25). The purpose of these tests is to assess water safety and the filter’s ability to remove harmful bacteria from the water. Figure 26 presents the results in coliform bacteria reduction. It is

observed that the filter is effective in removing some pathogens however it still cannot be relied on for complete disinfection.



Figure 25. Picture of E-coli and coliforms test, Wabash water (left), treated water (right)

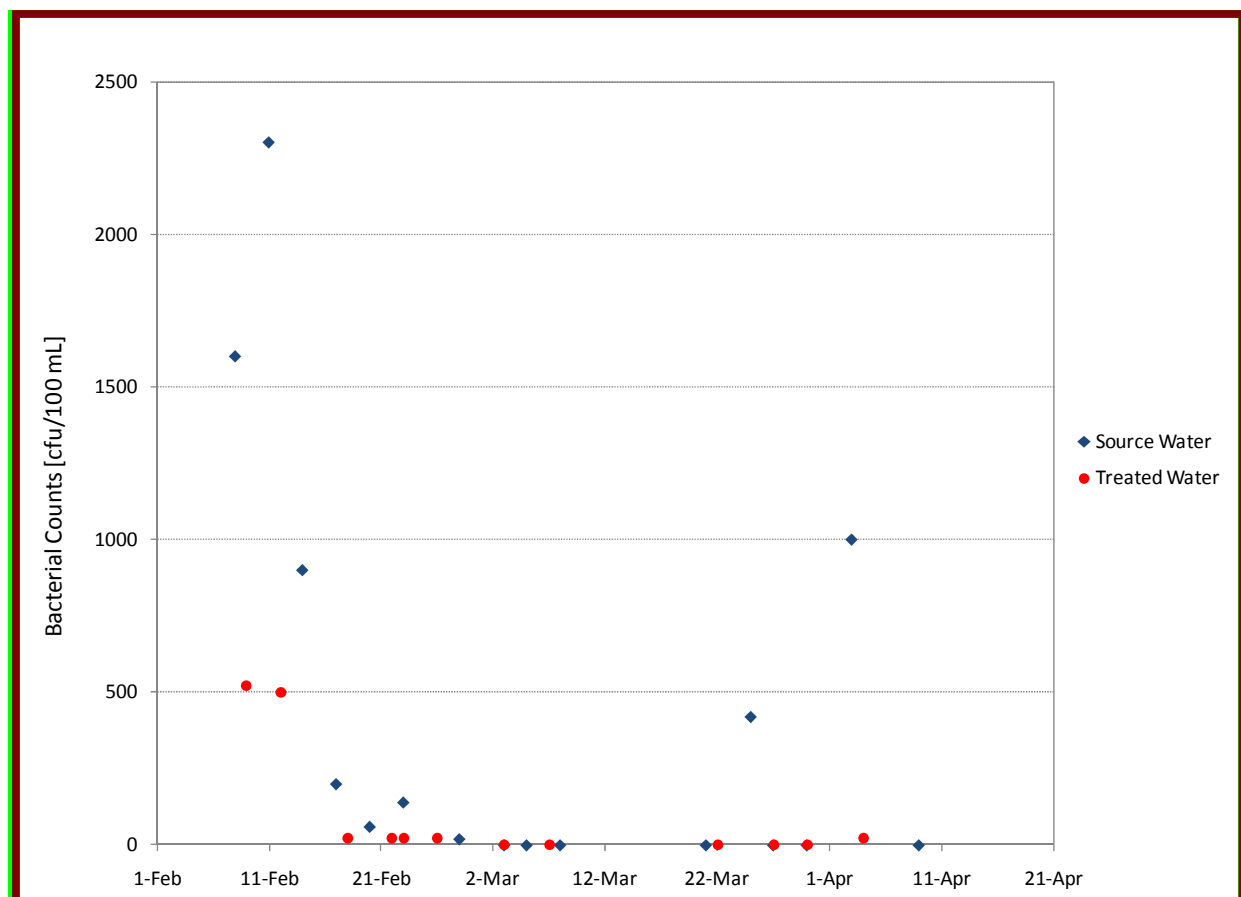


Figure 26. Coliform bacteria colonies present in the source and filtered water

Total Alkalinity, Total Hardness, and pH

Total alkalinity, total hardness, and pH were measured using Aqua Check HACH© water quality Test Strips which provide an approximate measurement of these parameters. Figure 27 shows pictures of the test strips container and scale of reference. Alkalinity and hardness are measures of dissolved minerals and relate to buffering potential, or the ability to resist large pH changes with the addition of a strong acid or base. Lower pH values for the effluent may indicate the production of a large amount of organic acids which can be another indicator for anaerobic metabolism in the filter.

Results of total alkalinity measurements indicate that both the water from the Wabash and the treated water have total alkalinity levels around 180 – 240 ppm. In the case of total hardness, the source water had levels that vary from 250 to 425 ppm and the treated water a total hardness of 250 ppm, what would indicate a reduction in total hardness due to the filter process. Results of pH measurements indicate that both source and treated waters present a pH that varies between 7.8 and 8.4.



Figure 27. Picture of test strips

Filter Design

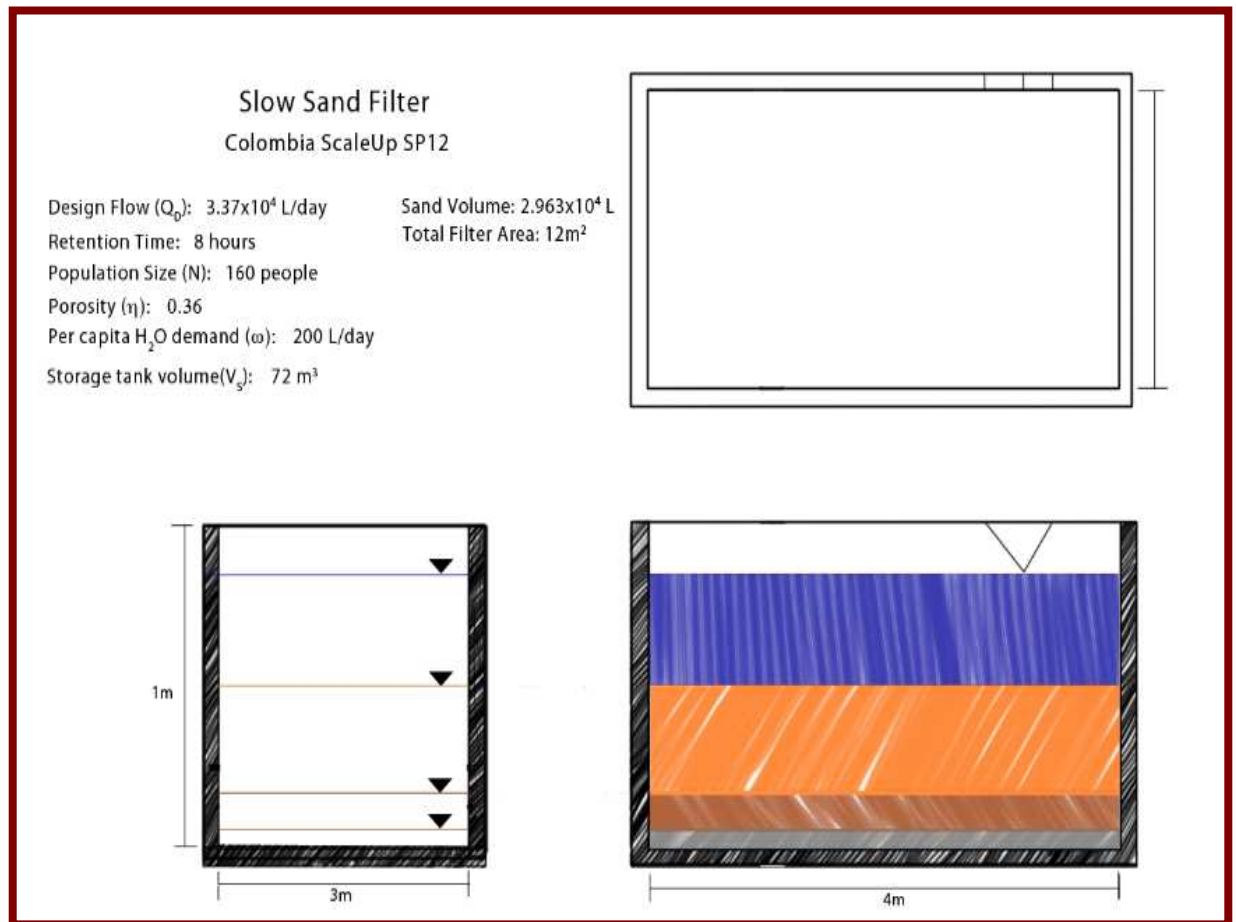


Figure 28. Scale-Up

The design presented by the GDT last spring is an important first step but several improvements can be made. First, the size of the filter (2 filters totaling 48 m^2) is too large to be feasible with the land area limitations around these communities. Additionally, several important design considerations were neglected. First, no underdrain, or water collection system was designed to transport treated water out of the bottom of the filter. Second, no allowance was made for draining and cleaning the filter when necessary. Finally, there is no description for an on-site operator to ensure the continued function of the filter system. This design seeks to remedy these issues with the previous design, beginning with a reduction in filter size, while still supplying the required amount of water to the community. This can be accomplished through changing several design parameters as described below.

In order to design a usable filter system, the total output required must first be determined. This data is unavailable for the communities in question. Estimates of domestic daily per capita water use vary from 194.5 L / person-day (Seckler 1998) to 59 L / person-day (SSPD 2007) and 322 L / person-day (CIA Factbook 2000). The previous design used a value of 211 L / person-day based on a report of per capita demand in the nearby city of Medellin (Tucci 2009). Finally, reports from residents in Graciano indicate their current water storage tank, which holds 11 m³, drains in approximately 8 hours. Simple calculation (assuming 120 current residents), yields a per capita water use rate of 275 L / person-day. This value, however, is unreliable as a design parameter. Based on the data collected above, a design per capita demand rate was determined to be 200 L / person-day. Taking future population growth into account, the filter system was designed to supply a population of 160 (~40 families with 4 members per family). The total demand flow for the filter system can then be calculated to be 32,000 L / day (eq 8):

$$Q_n = N * w_u \quad (8)$$

where Q_n is the demand flow for the filter system, N is the total population, and w_u is the daily per capita water usage. In order to reduce the required size of the filter, the retention time was chosen to be 8 hours (as opposed to 12 hours with the previous design). Based on the performance of the pilot-filter, a retention time of 8 hours is sufficient and yields water meeting our quality specifications. The required water volume capacity for the filter was determined to be 1,067 L (eq 9):

$$V_w = Q_n * \phi \quad (9)$$

where V_w is the required water volume capacity for the filter media and ϕ is the retention time. This volume is simply the volume of the pore space in the sand layer of the filter, not the total volume of the filter. Using this value, and the known porosity of the sand, the total sand layer volume can be calculated. The porosity used in this design was the experimentally determined porosity from the pilot-scale filter (0.36). Since the porosity of the sand used in Colombia is unknown, some design modification may be necessary if the actual sand porosity is determined to vary significantly from the assumed value. The total sand volume required in this design is 2,936 L, calculated from (eq 10):

$$V_s = \frac{V_w}{\eta} \quad (10)$$

where V_s is the required sand volume and η is the porosity. The total filter area required can then be calculated using this value and the design filter depth, which in this case is 1.3 m. This is higher than the depth used in the previous design (1.0 m) but remains within the recommended range (1.0 to 1.4 m) of sand layer depths (Huisman and Wood 1974). This increase has the double effect of reducing the required filter area and increasing the operation time of the filter before the sand needs to be replaced (discussed later). Additionally, because of the reduced retention time, the water has a higher flow rate through the filter. Increasing the filter depth ensures that organic matter and pathogens are not forced

Input Parameters	
Number of People, N	160
Daily Per Capita Water Usage, w_u (L/day)	200
Design Parameters	
Retention Time, Φ (hours)	8
Assumed Fine Sand Grain Size (mm)	0.3
Fine Sand Porosity, n (%)	36.0
Hydraulic Conductivity, K (m/day)	10
Calculated Parameters	
Demand Flow, Q_n (m ³ /day)	32.0
Design Flow Capacity, Q_d (m ³ /day)	33.7
Area Footprint of Each Filter, A (m ²)	12
Number of Filters	2
Storage Tank (m ³)	72

completely through the sand layer. Equation 11 was used to calculate the total required filter area, 22.792 m²:

$$A_t = \frac{V_s}{d} \quad (11)$$

where A_t is the total required filter area and d is the design depth of the filter. The required footprint of this filter is less than half that of the previous design which enables it to be installed more easily on the sloping terrain. A total of two filters will be installed and operated in parallel. This allows for continuous water treatment while an individual filter may be undergoing maintenance or cleaning. Two filters measuring 3 m by 4m yields a total design area of 24 m, slightly larger than the minimum required area. Using this total design area, the design flow rate of the system was determined to be 3,370 L / day (eq 12).

$$Q_d = A_d * d * \frac{\eta}{\phi} \quad (12)$$

Where Q_d is the design flow rate and A_d is the total design filter area. The design flow sufficiently meets the demand flow of 3,200 L /day. The area of each filter is relatively small, which increases the probability of short circuiting, or preferential water flow down the sides of the filter, bypassing the sand layer. In order to minimize the probability of short-circuiting, a number of baffles will be included in the design.

The total required depth of the filter is dependent not only on the sand depth but also final water depth, support layer depth, and freeboard. Assuming 0.25 m freeboard depth, 0.25 m for each of the three support layers, 1.3 m initially for the sand layer, and 1.0 m for the water level, a total filter depth of 3.3 m is achieved.

Control design:

It is also necessary to include flow controls and overflow systems in the SSF design. Water flow will enter each filter through a pipe from a sedimentation basin (discussed later). On this pipe will be a regulating valve to control flow into the filter. A second valve will be located on the outflow pipe from each filter. This valve should be adjusted to allow the flow rate out of the filter to equal the design outflow rate (2.34 L / min). The water head above the filter will remain at 1 m above the sand layer. In order to prevent backflow of water into the inflow pipe, an overflow weir is included at a level just below the inflow pipe. This overflow is designed to be used only under unwanted conditions and the filter should be cleaned before the water level reaches this point. The overflow weir is set at 1 m above the sand layer and the inflow pipe is located at 1.1 m above the sand layer.

The water exits the underdrain system in a pipe that goes directly into a secondary control basin with an adjustable weir, which will maintain a water level of at least 10 cm above the sand layer. As the sand layer depth is reduced due to maintenance, the weir can be moved with it to maintain the same 10 cm water level. This water level is essential to ensure the health of the biological community in the sand.

Media selection:

In order to provide adequate filtration, the sand media must be of adequate size. Sand with too small of grain size has lower hydraulic conductivity resulting in unreasonably low flow rate. Too large of grain size reduces the ability of the sand to remove particles and contact area between the water and biological layer. Therefore, an adequate grain size for filtration media should be between 0.15 – 0.35 mm (Huisman and Wood 1974). Based on grain sizes used in the lab, an effective grain size of 0.3 mm will be used in

this design. The coarse sand or gravel layers which support the sand filtration layer must be of adequate grain size to prevent migration of the sand through them. Generally, the effective diameters should be 4 times the size of the supported layer. Thus, the effective grain size of the second layer should be 1.2 mm. Similarly, the third layer should have an effective diameter of 4.8 mm. The final gravel layer will have an effective diameter of 19.2 mm. Each of the size measurements are given as a range because it is impossible to achieve completely uniform sizing. The above listings are average values and the ranges were determined using a standard deviation of 33%. This yields size ranges of 0.2-0.4 mm, 0.8-1.6 mm, 3.2-6.4 mm, and 12.8-25.6 mm respectively.

Piping design:

It is possible to determine the required pipe diameter to carry the necessary flow rate between the sedimentation basins and filters as well as between the filters and the storage basin (see below for discussion of these other components). Water will flow through the system using gravity and the natural slope of the area. This precludes the need for a pump system which adds cost and maintenance requirements. Basic pipe flow between two points can be described using Bernoulli's equation (eq 13):

$$\frac{p_1}{\gamma} + z_1 + \frac{\alpha v_1^2}{2g} + h_p = \frac{p_2}{\gamma} + z_2 + \frac{\alpha v_2^2}{2g} + K \frac{v^2}{2g} + f \frac{L}{d} \frac{v^2}{2g} \quad (13)$$

Where p_1 and p_2 are the water pressures at the inflow and outflow respectively, z_1 and z_2 are the vertical heights at these two points, v_1 and v_2 are the water velocities at these points, α is a correction factor, g is gravity, h_p is the pump head, K is a coefficient based on pipe fittings, f is a friction factor, L is pipe length, d is pipe diameter, and v is the velocity of the water in the pipe. Most of these terms can be neglected in this analysis. Since both ends of the pipe are open, the water pressure is atmospheric and these terms can be removed. Also, since the flow rate entering and exiting the pipe is the same, the velocity terms at each point are equal. The pump head and head loss due to fittings is assumed to be zero. Finally, the height of the filter is assumed to be the reference height, thus z_2 is zero. Neglecting these terms, and rearranging, allows one to solve for the term f/d^5 (Eq 14), the two unknowns.

$$\frac{f}{d^5} = 1.23 * \frac{z_1 g}{L Q^2} \quad (14)$$

The horizontal distance between the basin and filter was assumed to be 10 m. The slope of the hill was assumed to be 20 degrees. The piping material is polyvinylchloride (PVC). Using Moody's diagram and assuming a value for d , the correct diameter was found to be 1.2 cm through iteration. To account for higher than normal flows and adding a general safety factor, a design diameter of 4.8 cm was chosen (4 times the minimum size). Due to available pipe sizes, a 2" (5.08 cm) pipe diameter was selected.

The total pipe length needed to reach between each sedimentation basin and filter is ~10.7 m. The distance between each filter and the storage tank is the same. This necessitates a total of 42.8 m of piping. This structure should also be covered to prevent algae growth and contamination from windblown debris.

Underdrain design:

The water collection system, or underdrain system, collects water after it has traveled through all the media layers and transports it out of the filter. Several collection designs are acceptable including porous concrete, stacked bricks, and perforated piping. Due to cost and simplicity considerations, perforated polyvinylchloride (PVC) piping was chosen for this design. The layout of the pipe system consists of several "fingers" running perpendicular to the central axis of the filter. These fingers are attached to a

larger receiving pipe running the length of the filter on the external side. The outflow pipe connects through the filter wall to this collection pipe and allows the water to flow to the storage reservoir. The receiving pipe is to abut the side wall of the filter while each finger pipe will have 20 cm of clearance from both the sides of the filter and the adjacent finger pipe. Since the filter is 4 m long, 19 fingers are required in this setup. The ends of the fingers will be 5 cm from the far wall of the filter, just as they are 5 cm from the opposite wall due to the diameter of the receiving pipe (see below). Because the filters are 3 m wide, each finger pipe needs to be 2.9 m long. The receiving pipe is to be 3.9 m long, leaving 5 cm between each wall and the pipe ends.

The pipe size is determined by required flow capacity and the perforated hole size is dependent on the effective diameter of the media above it. Because it was determined that a pipe diameter of 2.5 cm is adequate for the design flow of the filter, the diameter of the “finger” pipes is chosen to be 2.54 cm (1”). These pipes will then feed into the receiving pipe which will have a diameter of 5.08 cm (2”). The holes to be drilled into the pipes will be 6 mm, thus fulfilling the requirement of being less than half the effective diameter of the media layer directly above (12.8-25.6 mm). Holes will be drilled on top and on both sides of the pipe to allow for adequate water flow into the pipes. They will be spaced 10 cm apart at a total of 29 discrete sites (pipe length is 2.9 m).

Combining pipe lengths needed for both the underdrain design and flow between filter system components yields a total of 50.6 m of 2” diameter pipe and 110.2 m 1” diameter pipe.

Maintenance:

Maintenance will be carried out as needed on the filters. Filter operation should be initially staggered so each filter requires cleaning at different periods. Using this strategy, one filter will always be in operation. Filter cleaning is needed when the water head above the filter does not provide the required flow rate. Specifically, when the control valve is completely open and the flow rate is still insufficient, filter cleaning is required. During cleaning, the water inflow to the filter will be shut off and the filter will be drained until the water level is just at the sand level. It is essential that the sand remain hydrated to preserve the integrity of the microbial community. A drain and valve will be located on the side of the filter at the level of the lowest possible sand level (0.7 m). A height-adjustable box will be constructed around this drain to hold the sand layer away from it. As sand is removed during cleaning, the wall on the box can be lowered with the sand level to allow for water draining when necessary.

Cleaning involves removing the top 1 – 2 cm of sand and disposing of it. This reduces the sand layer depth and after reaching a minimum level of 0.7 m, the entire sand level must be removed and replaced. While it is difficult to estimate the period between maintenance, a typical value is 2 months. Assuming 2 cm of sand is removed each time, 0.12 meters will be removed over the course of a year. Given an initial sand depth of 1.3 m, the system can be operated and cleaned for 5 years before sand replacement is necessary. This is double the time of the previous design and provides a significantly reduced burden on the filter operators. Access into the filter becomes more difficult as the sand layer is lowered but a temporary ladder should be sufficient to allow workers to move in and out of the filter during maintenance periods.

Storage Tank Design

Demand for water fluctuates throughout the day with significant water use during daylight hours and negligible demand at night. Since the sand filters operate continuously, with equal outflow at all hours, a storage tank is necessary to allow for variability between water demand and water supplied by the filters. Designing for the filter to store two days production from the filters yields a required storage volume of 67.4 m³. Assuming a water depth of 3 m in the filter, the required area must be 22.46 m². A storage tank with dimensions of 4 m by 6 m by 3 m deep gives a storage capacity of 72 m³. It is necessary to include

0.25 m of freeboard for this basin. Additionally, like the filters, this structure should be covered to prevent contamination by windblown debris and algae growth.

Sedimentation Tank Design

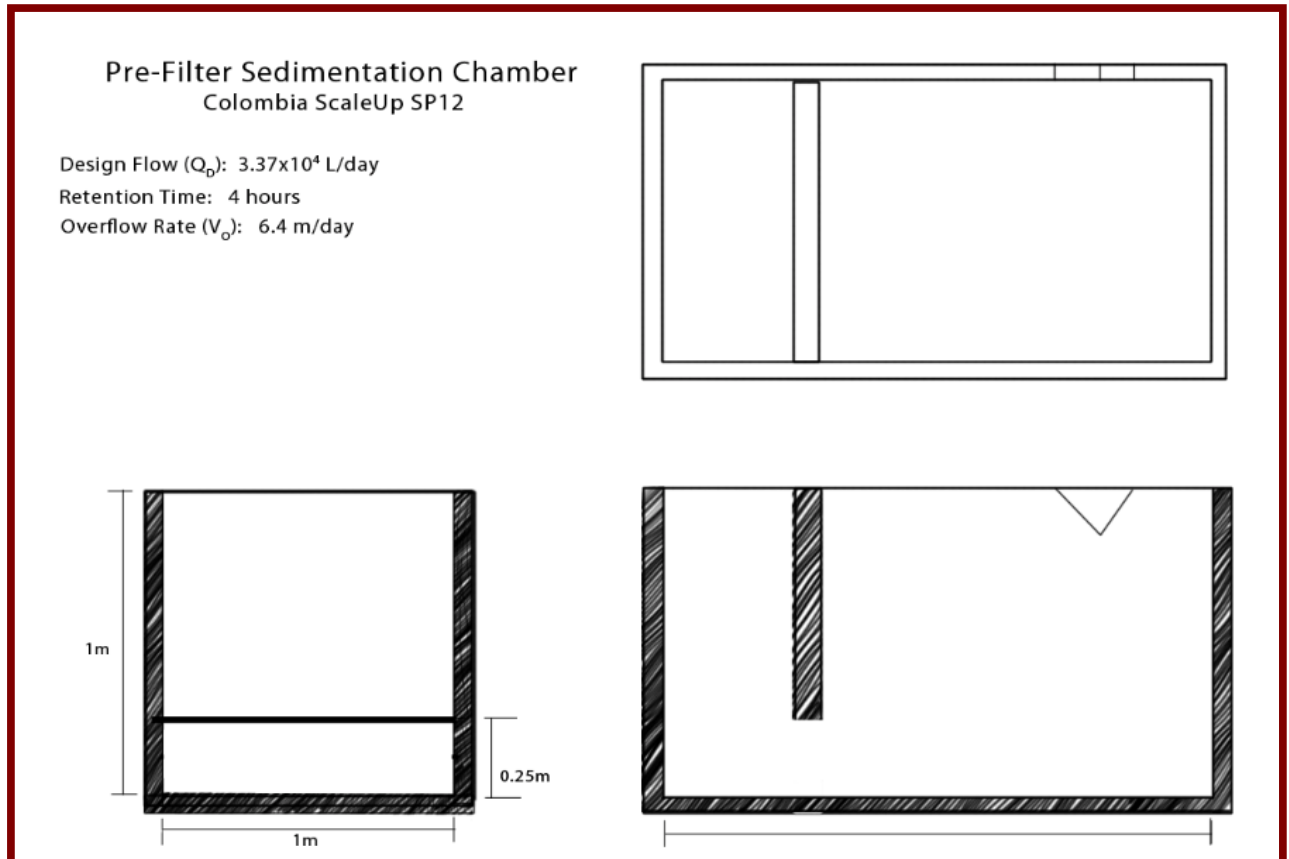


Figure 29.

In order to function properly, a slow sand filter should not receive input water with turbidity greater than 20 NTU and on average it should be less than 10 NTU (WSDOH 2003). We have observed in the lab turbidity values for Wabash River water that are easily above 20 NTU. While we have no data on average turbidity found in the Colombian mountain streams that supply these communities, it is safe to assume that the fast-moving water and rich soils of the area account for reasonably high turbidity levels. In order to ensure proper functioning of our filter, it is necessary to design a pre-treatment system. The previous design had such a system consisting of a gravel roughing filter in which water flows upward over a gravel bed to remove suspended solids. In order to reduce the cost of the filter system, we have elected for a simple sedimentation basin which will allow the suspended solids to settle out by gravity. This saves money because there is no need for expensive gravel.

In order to design an appropriate sedimentation basin, several design assumptions were made. First, the smallest particle diameter to be removed was selected to be $11 \mu\text{m}$. This was based on the fact that average silt particle sizes range from $4 - 62 \mu\text{m}$ (Ongley 1996). The value of $11 \mu\text{m}$ is on the lower end of the scale while allowing for a feasible basin size requirement. The density of soil particles was

assumed to be 2000 kg/m³ (Bunn and Montgomery 2004). Finally, a retention time of 4 hours was chosen to minimize the size of the basin while allowing for adequate particle removal. With these values, a particle settling velocity of 7.402 x 10⁻³ cm / s was calculated (eq 15).

$$V_s = \frac{g * (\rho_s - \rho_w) * d^2}{18 * \mu} \quad (15)$$

Where V_s is the particle settling velocity, g is gravitational acceleration (9.8 m / s²), ρ_s is particle density, ρ_w is water density (1000 kg / m³), d is the particle diameter, μ is the dynamic viscosity of water (8.90 x 10⁻⁴ Pa-s), and 18 is a proportionality constant. The settling velocity is also the design overflow rate of the sedimentation basin (6.395 m³ / (m²-day)). Using this value, the total required basin area can be determined to be 5.269 m² (eq 16).

$$A_p = \frac{Q_d}{V_o} \quad (16)$$

Where A_p is the required basin area, Q_d is the design flow rate of the filter system (33.7 m³ / day), and V_o is the overflow rate. The total required basin volume can then be determined to be 5.617 m³ (eq 17).

$$V_p = \phi * Q_d \quad (17)$$

Where V_p is the required basin volume and ϕ is the retention time (4 hours). The required basin depth can next be determined to be 1.066 m (Eq 18).

$$H_p = V_o * \phi \quad (18)$$

Where H_p is the basin depth. Using these calculations, a basin design was chosen incorporating two units each 1 meter wide, 3 meters long, and 1 meter deep. This gives a total design area of 6 m² and a total design volume of 6 m³. The width to length ratio is 1:3 which is typical of a sedimentation basin (Reynolds and Richards 1996). Adding a freeboard depth of 0.25 m, the total depth of each basin is 1.25 m. This design yields a design settling velocity of 6.5 x 10⁻³ cm / s (Eq 16). Because this is below the desired value of 7.402 x 10⁻³ cm / s, the basin design should be adequate in settling the particle sizes desired.

$$V_{sd} = \frac{Q_d}{A_d} \quad (19)$$

Where V_{sd} is the design flow rate. Further design considerations for the sedimentation basins include a baffle 0.5 m from the inflow point to force water down and encourage particle settling. This will extend down to 0.25 m above the bottom of the basin. An overflow weir will be situated on both basins to divert excess flow back to the source stream. Additionally, a drain valve will be located on the bottom of each basin. During maintenance, sediment can be flushed from the basin with excess water after shutting off the outflow to the filter. This high turbidity water can either be used for irrigation or be similarly land applied. The waste flow should not be returned to the stream because it will impair water quality for downstream users.

Cost Analysis

The total cost of the filter system was determined using US dollars. While some local costs are known, other assumptions had to be made. To simplify estimations, all concrete basins, including the sedimentation basins, filters, and storage tank, were assumed to be rectangular prisms with concrete walls

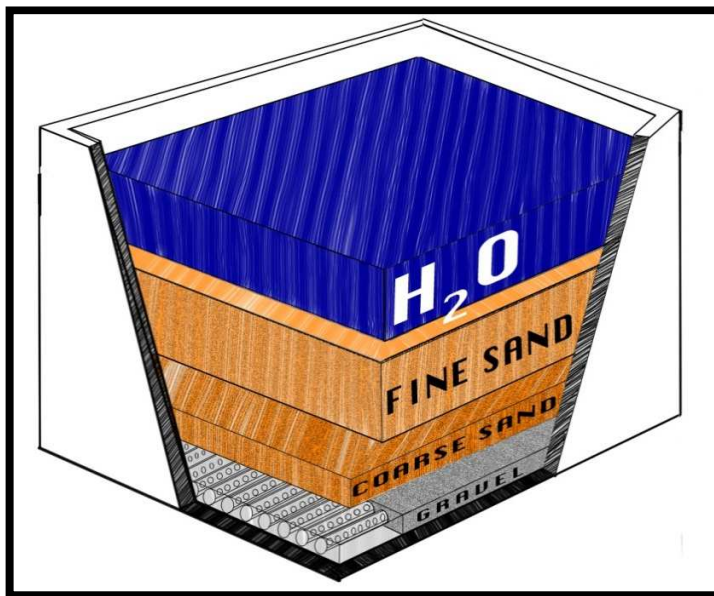


Figure 30.

using the densities used above (concrete [1360 kg/m^3]). Using these estimates, total shipping costs amount to \$8,100.51, or 41% of the total cost. Although just an estimate, shipping costs are likely so high due to the mountainous topography which makes it difficult for large trucks to navigate the roads in the area. The total cost of the entire filter system is \$19,537.04. Based on the design flow rate of the system ($33,700 \text{ L / day}$), the cost per liter per day is \$0.58. These values are significantly less than those of the previous design (\$43,927.11 total and \$1.19 / L-day). This indicates our goal of reducing overall cost of the filter system, while providing adequate water quality and quantity, has been reached.

As another option, large plastic tanks were examined for use as filters and storage tanks because they are more easily transported after installation and provide a more flexible option for later addition. Because the sedimentation basin must be of adequate length and depth, there are no suitable plastic tanks for this use. Using vertical heavy duty polyethylene tanks (US Plastic) would require three 120" diameter (7.3 m^2 area) by 152" tall (3.86 m) tanks for the filters for a total cost of \$16,083.72 and two 9500 gallon (35,958 L) capacity tanks for the storage basins for a total cost of \$16,644.04. These values can be compared to the cost of concrete structures (\$2,967 and \$2,558.75 respectively) to show the cost savings of using concrete.

0.25 m thick. In an effort to reduce cost, both sedimentation basins have a shared wall between them. The same is true for the filter basins. Assuming a cost of reinforced concrete of \$115 per cubic meter, the total cost of the sedimentation basins (including the baffle) is \$697.19. The storage tank has a total cost of \$2,558.75. Based on cost estimates for materials in Colombia provided by Kimberly-Clark ($\$0.04875/\text{kg}$ for fine sand [1590 kg/m^3], coarse sand [1540 kg/m^3], and gravel [1760 kg/m^3]) the filters have a total cost of \$6,865.44. Other components, including piping, valves and covers, have a combined cost of \$1,315.15. Shipping costs for the

concrete and filter materials were assumed to be \$0.0525/kg based on estimates given by Kimberly Clark and

Estimated Large-Scale Filter System Design Budget						
Sedimentation Basin	<i>Particle Size (mm)</i>	<i>Volume Required per Unit (m³)</i>	<i>Cost per m³</i>	<i>1 Unit</i>	<i>2 Units (shared wall)</i>	
Concrete	N/A	3.5	\$115.00	\$402.50	\$697.19	
Sedimentation Basin Subtotal						\$697.19
Slow Sand Filter	<i>Particle Size (mm)</i>	<i>Volume Required per Unit (m³)</i>	<i>Cost per m³</i>	<i>1 Unit</i>	<i>2 Units (shared wall)</i>	
Concrete	N/A	14.55	\$115.00	\$1,673.25	\$2,967.00	
Fine Sand	0.2-0.4	15.6	\$77.51	\$1,209.20	\$2,418.39	
Coarse Sand	0.8-1.6	3	\$75.08	\$225.23	\$450.45	
Fine Gravel	3.2-6.4	3	\$85.80	\$257.40	\$514.80	
Coarse Gravel	12.8-25.6	3	\$85.80	\$257.40	\$514.80	
Slow Sand Filter Subtotal						\$6,865.44
Storage Basin	<i>Particle Size (mm)</i>	<i>Volume Required per Unit (m³)</i>	<i>Cost per m³</i>	<i>1 Unit</i>		
Concrete	N/A	22.25	\$115.00	2558.75	N/A	
Subtotal						\$2,558.75
Piping	<i>Pipe Diameter (in)</i>	<i>Length Needed (ft)</i>	<i>Cost/ft</i>		<i>Total Cost</i>	
Gray PVC Pipe	2	165	\$1.75		\$288.75	
Gray PVC Pipe	1	111	\$0.87		\$96.57	
Piping Subtotal						\$385.32
Valves	<i>Pipe Diameter (in)</i>	<i>Number Needed</i>	<i>Unit Cost</i>			
Industrial Ball Valve	2	9	\$89.10		\$801.90	
Valves Subtotal						\$801.90
Covers		<i>Number Needed</i>	<i>Unit Cost</i>			
16' x 100' Reinforced Sheet piling		1	\$127.93		\$127.93	
Covers Subtotal						\$127.93
Material Shipping		<i>Weight (kg)</i>	<i>Cost per kg</i>		<i>Shipping Cost</i>	
Concrete		74327.4	0.0525		\$3,902.19	
Fine Sand		49608	0.0525		\$2,604.42	
Coarse Sand		9240	0.0525		\$485.10	
Fine Gravel		10560	0.0525		\$554.40	
Coarse Gravel		10560	0.0525		\$554.40	
Material Shipping Subtotal						\$8,100.51
Total Cost						\$19,537.04
Cost per L/day						\$0.58

0.2 μm Filter Team

A preliminary design of our disinfection filtration system was created. After a review of this design, it was determined that more than one filter was needed to effectively remove pathogens without clogging our filters. We also determined that in order for our pressure drop to work effectively we will need our water open to the atmosphere. The water being open to the atmosphere also allows for air to escape before entering the filter housings. A sketch of these designs can be seen below.

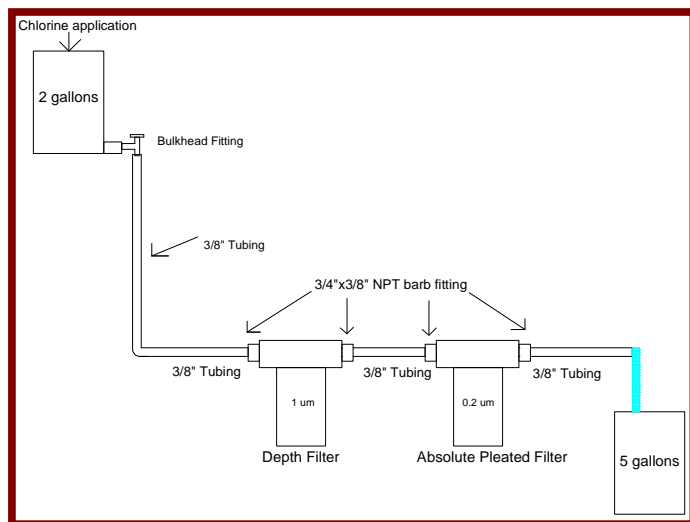


Figure 31. Newer Filter Design

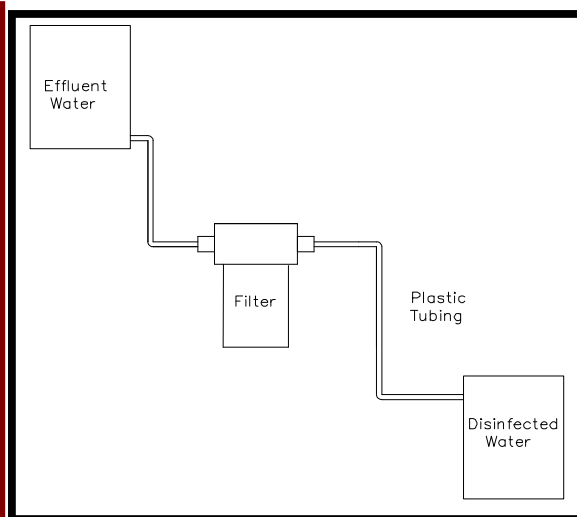


Figure 30. Preliminary Filter Design

Design 1: 0.2 micron System

The first design included a reservoir, 0.2 micron filter and an effluent reservoir. This design is the simplest design, however having only a 0.2 micron filter with chlorination would have resulted in more rapid clogging compared to a filter prior to the 0.2 micron filter. The clogging of the 0.2 micron filter would reduce the life expectancy thus resulting in design becoming more expensive.

Design 2: 1 micron and 0.2 micron System

This design begins with a reservoir of water that will then flow into a 1" PVC pipe. The PVC pipe is where the chlorine will be introduced in the process. After chlorination is a 1 micron filter and a 0.2 micron filter in series. The first filter is a depth filter with a higher rating (1 micron) that will allow for further filtration of the slow sand filter effluent. The second filter is a pleated filter and is the 0.2 micron filter. This will be the final step of the disinfection process. The pleated filter has a larger surface area, thus removing bacteria more efficiently.

Design 3: Pressurized System

The third design begins with a 20 L pressurized carboy. The carboy will have three bulk head fittings; one for the pressure gage, one for the pressure valve, and one for the tubing all located at the top of the carboy. Pressurizing the system will help push the water up through the tubing by giving the water enough pressure head. Chlorine will be introduced into the influent before it flows through the remainder of the system. After chlorination is a 1 micron filter and a 0.2 micron filter in series. The first filter is a depth filter with a higher rating (1 micron) that will allow for further filtration of the slow sand filter effluent. The second filter is a pleated filter and is the 0.2 micron filter. This will be the final step of the disinfection process. The pleated filter has a larger surface area, thus removing bacteria more efficiently.

Conceptual Design Phase

Our team has researched the different materials for filters, tubing, and hardware components. This was done by completing a literature review over filter disinfection options as well as secondary disinfection options. To determine the best filter option we took into consideration the sizes and ratings for pathogen removal in water. We planned to test these filters and evaluate their performance; however, due to hardware delivery and time constraints this was not achievable. Based on our findings from the literature review we decided that a 1 micron absolute depth filter followed by a 0.2 micron absolute pleated filter would be best at eliminating the pathogens from the water in Colombia. Prior to the filter housing methods, chlorine will be introduced into the system for secondary disinfection. The chlorine, a hypochlorite solution, is a cheap, simple and effective method at removing pathogens that may not easily be removed via filtration or the disinfection filters.

Detailed Design Phase

We determined which filters we needed to purchase for our filtration system. Once the filter was determined, we decided which parts we would need in order to build an entire disinfection unit. Many issues were encountered while assembling and ordering our filters and hardware. Many of the filter specifications sheets claimed that the filters measured 10" and would fit the filter housing the team had already purchased. However, when the filters were delivered and inserted into the filter housing, we found that at times the filter housing would not seal completely due to the filter not being exactly 10". An example can be seen in the photo below.



Figure 32. 0.2 Micron Filters

Both of the filters pictured above are specified as having a length of 10" and being able to fit in the 10" filter housing. The filter on the left has an actual measurement of 10" while the one on the right has an actual measurement of 9 ¾". While the filter on the right supposedly fits the filter housing, due to the incompressible material it is made of, it will not fit in the filter housing. It is important to contact distributors in order to verify actual filter length and to ensure it fits in the housing.

Filter Choices

Based upon our literature review performed on filters and findings related to filter prices we constructed a decision matrix factoring in several criteria and weighting each criterion on a scale of 1-10. A rating of ten would mean that the criterion is of most importance in the decision; while a rating of one would mean of least importance. Each of these criterions will be assigned a 1, 0, or -1. If the filter meets that criterion 100% of the time it will be assigned a 1; if it meets the criteria most of the time it will be assigned a 0; if it never meets the criteria it will be given a -1. The weight and ranking will then be multiplied and summed for each filter type. The filter with the highest score will be considered the best option for our design. Each of these filter types were reviewed within the literature review and only filters that could remove pathogens at least at the 1 micron level were considered for each type.

Table 12. Filter Decision Matrix

Criteria	Weight	Depth	Pleated	Ceramic
Pathogen Removal	10	0	1	1
Cost	8	1	0	0
Life Expectancy	9	0	0	1
Flow Rate (20 L/day)	7	1	1	0
Availability to Colombia	9	1	1	1
Pressurization Ability	5	1	1	-1
	Totals	29	31	23

Based upon the decision matrix above, pleated filters were the best decision for pathogen removal at 0.2 micron rating. These filters are often used for final filtration and disinfection. Although they are more expensive, their life expectancy can lengthen when maintained properly and preceded by a larger, cheaper filter. In an attempt to lengthen the life expectancy of the 0.2 micron pleated filter, we went with a 1 micron absolute depth filter to remove larger particles and reduce the amount of clogging in the smaller sized filter.

Items Purchased

- 1 micron filter
- 0.2 micron filter
- 20 L Carboy Polyethylene
- 2 Filter housings
- 25 ft of 3/8" tubing
- 2 quick disconnects
- 1 reducing unit
- 6 -3/4" Barbed fittings (NPT)
- 2-3/4" Bulk head fittings
- 1/2" Miniature bulk head fitting
- Pressure Gage
- 5 gallon bucket
- Pressure Valve

Table 13. Cost Summary

Item Description	Unit	Quantity	Unit Cost	Total Cost	Vendor
Filter Housings	1	2	\$27.80	\$55.60	Filter Source
1 micron filter	1	40	\$1.70	\$68.00	Filter Source (GE)
0.2 micron filter	1	1	\$112.52	\$112.52	Filters.com
5 gallon bucket	1	1	\$2.60	\$2.60	Menard's
20 L Carboy	1	1	29.77	29.77	McMaster-Carr
Quick Disconnect	1	2	\$4.12	\$8.24	McMaster-Carr
Reducing Unit	1	4	\$2.84	\$11.36	McMaster-Carr
Barbed Fitting	1	8	\$5.90	\$5.90	McMaster-Carr
Tubing	1	1	\$0.67/foot	\$16.75	McMaster-Carr
Bulk Head Fitting	1	2	\$13.11	\$26.22	McMaster-Carr
Mini Bulk Head Fitting	1	1	\$8.45	\$8.45	McMaster-Carr
Pressure Gage	1	1	\$9.20	\$9.20	McMaster-Carr
Pressure Valve	1	1	\$2.63	\$2.63	McMaster-Carr

Delivery Phase

The deliverable for the spring of 2012 will be a decision matrix of why which filters were chosen, the type of secondary disinfection chosen, and a prototype of the system to be tested. The final product goal will be a filtration system that meets the drinking water standards of Colombia.

Maintenance phase

The teachers of the Colombian schools will maintain the filters. They will receive proper documentation and instruction on how to do so.

Retirement or redesign

The prototype will be completed by the end of the spring 2012 semester. This will include the design of system 3, as previously mentioned above. If this prototype fails to remove pathogens as expected, a redesign of the system will need to occur. Our team entered the redesign phase of the design process earlier in the semester when our initial prototype failed to produce enough pressure to run water effectively through the system.

Results

Table 14. Flow Rate With Clean Water

Test	Volume (L)	Pressure Head (in)	Time (minutes)	Flow Rate (L/min)
1	1	54.8	7:00	0.143
2	1	54.8	6:57	0.144
3	1	54.8	7:32	0.133
4	1	53.9	9:23	0.107
5	1	53.05	10:15	0.098
6	1	52.18	12:21	0.081

Average Flow Rate (L/min): 0.118

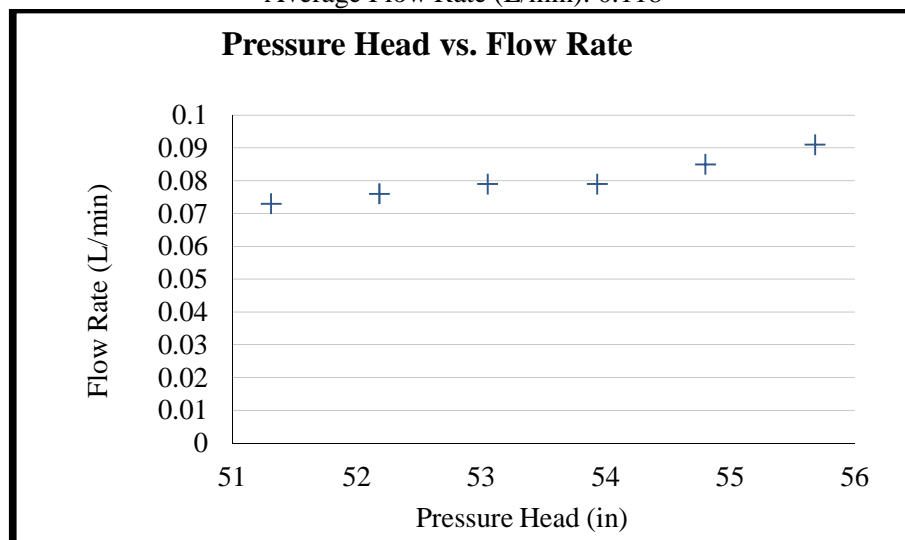


Figure 33. Graph of Pressure Head vs. Flow Rate of tap water

Table 15. Flow Rate With Dirty Water

Test	Volume (L)	Pressure Head (in)	Time (seconds)	Flow Rate (L/day)
1	1	55.68	10:57	0.091
2	1	54.8	11:46	0.085
3	1	53.93	12:38	0.079
4	1	53.05	12:35	0.079
5	1	52.18	13:08	0.076
6	1	51.31	13:37	0.073

Average Flow Rate (L/min): 0.0805

Table 16. Turbidity With Clean Water

Test	Pre-filtration	Post-filtration
1	0.96 NTU	0.16 NTU
2	1.45 NTU	0.09 NTU
3	0.77 NTU	0.08 NTU

Table 17. Turbidity With Dirty Water

Test	Pre-filtration	Post-filtration
1	0.71 NTU	0.14 NTU
2	0.68 NTU	0.10 NTU
3	0.65 NTU	0.07 NTU

UV Disinfection

Reactor Design Selection

Three design concepts were initially considered. After primary evaluation, two designs were compared for design selection. Both consisted of batch systems. One was designed to treat one 2 gallon bucket of water, while the other treated two 2 gallon buckets of water.

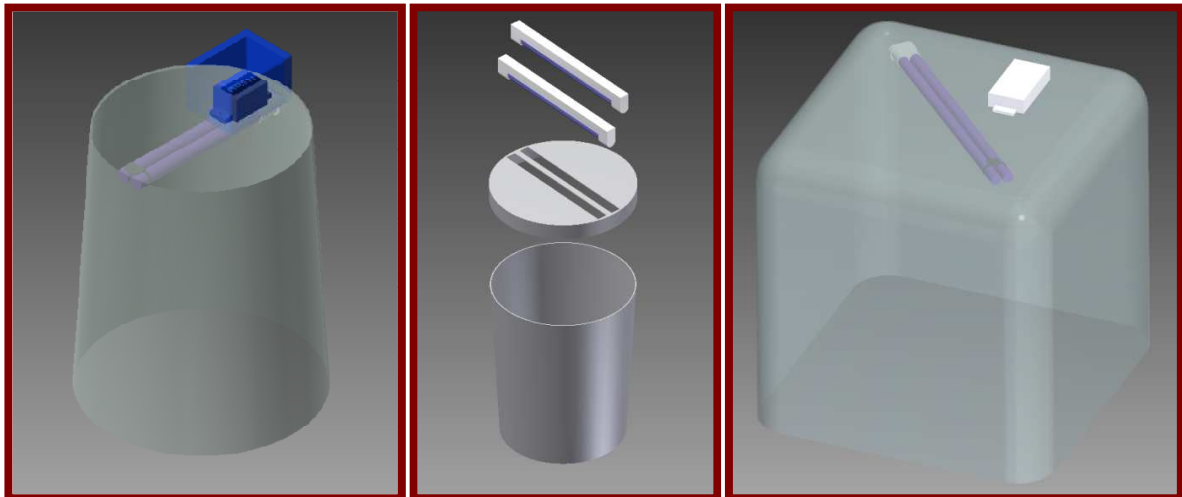


Figure 34.

To begin, the efficiency, cost, and overall design for each concept was reviewed and compared relative to the ability to meet the customer and engineering requirements. An overview of this comparison is shown in the weighted decision matrix below.

CUSTOMER REQUIREMENTS	WEIGHTS	CONCEPTS	
		Single Batch	Double Batch
Safe	10	1	1
Adequate Inactivation	10	1	1
Inexpensive	8	1	0
High total UV output	6	0	1
Durable	7	1	1
Long product life	7	1	1

Easy to produce	5	1	0
Efficient use of UV light	6	1	-1
Total +	7	5	
Total -	0	2	
Overall Total	7	3	
Weighted Total	53	38	

Concept Comparison - Weighted Decision Matrix

The number one priority of the weighted decision matrix was the safety of the design. Because of the Ultraviolet light the design has the potential to be very dangerous by adding harmful UV radiation to those who look at the light. Incorporating a design, which increased the safety factor was therefore a major priority. Comparing the designs, both methods provide adequate safety. Incorporating a safety switch to stop the bulb when either is lifted would also increase the safety. Both designs have therefore scored a one on the weighted decision matrix.

The second, but just as important requirement was providing adequate inactivation. Along with the safety of the utility the overall result of the disinfection is important as well. This customer requirement makes sure that the product will function properly. The use of Ultraviolet light in both methods ensures adequate inactivation in the biological matter left from the slow sand filters. Both methods have thus been given a score of one in this category.

The third requirement is cost. There are a few cost heavy items on the market for the product now. The desire of the design is to create a cheaper alternative method to provide ultraviolet disinfection. The inexpensive has been weighed eight out of ten because of this. Comparing the cost of the given designs both have their advantages and disadvantages. The advantage to the double batch method provides a larger area to mount larger less costly bulbs. The disadvantage is the cost of the housing greatly increases. The advantage of the single batch method is the extremely low cost of the bucket. The cost of the bulbs unfortunately rises due to the smaller area and shorter bulb lengths available. Doing a cost comparison of the advantages and disadvantages the cost of the housing greatly outweighed the cost of the bulb. The single batch method has been given a one while the double batch method has been given zero due to the higher costs.

The fourth requirement is having a high Ultraviolet Output. Having a high Ultraviolet Output both decreases the time needed for disinfection, but also increases the dosage applied to the water, as well as raising efficiency. The project plan will hopefully incorporate a renewable power supply in the future so using an efficient bulb is quite important. This has been weighted by a six out of ten. As mentioned the higher area of the double batch method provides an excellent surface to mount larger bulbs. This in turn dramatically increases the amount of UV light output. Surprisingly a very efficient bulb was found for the smaller length however so the increase in ultraviolet light turns out to be more of a cost benefit rather than a UV output benefit. Due to this the double batch method has been weighted as a one while the single

batch method has been given a zero.

The fifth requirement is durability. As mentioned before this product will be around children. Children create an added need for extra stability and durability. A major component of the durability is the effects of ultraviolet exposure to the devices and housing. Both designs use plastics and ultraviolet bulbs. The plastics in both designs have the ability to be covered with UV resistant paint, as well as being covered with Aluminum Foil to increase UV reflections to lower absorption. Since both methods succeed in this task, they have both been weighted one.

The sixth customer requires is the length of the product's life. The major aspect of the product's duration was the length of the bulbs' life. The longer the product functions, the better the design and less maintenance costs in the long run. It was discovered that typically the bulb length does not significantly dictate the bulb life duration. Since this is the major difference between both methods a distinguishing advantage cannot be chosen. The ultraviolet lights that were looked at all have around 8,000 hours. Both designs have been weighted one for this category.

The seventh weighted customer requirement is the ease of production. Since the design is currently centered around making these in Colombia a major aspect to the ease of production is using parts that are readily available there. Another ease of use factors in the amount of parts needed as well as the tools used in the construction process. The single batch method uses a bucket design. These buckets are known to be readily available in Colombia and have been used in the past. The double batch method design features a larger design that may not be available. If the team uses a wooden design for the double batch method, work to find the wood and produce these units would raise the time of creation. To simplify these results the single batch method has been weighted as one, while the double batch method has been weighted zero.

The final customer requirement is the efficient use of UV light. This requirement is measured by the amount of UV light output in comparison to the amount of water being inactivated. This isn't a measure of the efficiency of the bulbs, however an efficiency of the design. In the single batch method design a central lamp is located directly overhead the water. This provides a very efficient use of the light and has been weighted a one. The double batch method however has a much larger housing. This creates lots of empty space where ultraviolet light can escape and be absorbed elsewhere. This causes a very inefficient design, thus the product has been weighted as a negative one.

The weighted decision matrix provided an excellent comparison to the customer requirements. The single batch method received a total weight of 53 while the double batch method received a 39. This decision matrix suggests that the single batch method will provide a better design with the given customer requirements. Thus the single batch design has been selected.

Design Criteria

Component	Criteria
Housing	Inexpensive, Durable, Readily available, UV Resistant, Waterproof, Efficient use of space, Easy to assemble
Lamp	Inexpensive, Germicidal (254 nm), High UV wattage output, Proper length, Low input wattage, Long life (Hours)

Lamp Holder	Inexpensive, Compatible with lamp, Properly oriented for selected design
Lamp Clip	Inexpensive, Compatible with lamp, Provides support to bulb
Ballast	Inexpensive, Compatible with lamp, Compatible with lamp holder
Safety features	Prevents exposure to UV light, Considers customers (children)
Power indicator (plastic rod)	Inexpensive, Easy to use, Blocks UV light, Indicates on/off reading
Housing coating	Further blocks UV light, Maximizes potency of UV light on water
<i>Miscellaneous Components</i>	Various Criteria

Component Selection

Below is a comprehensive list on the products that the team chose to compare and the eventual selected design.

Clear <i>Unknown or Not Available</i>	Red <i>Bad</i>	Yellow <i>Average</i>	Green <i>Good</i>
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Housing

Options <i>Criterion</i>	5 Gallon Bucket	Large storage Container	Plywood box
<i>Inexpensive</i>	\$2.60	\$8.97	\$5.48 per 144 square feet and Cost of hardware
<i>Durable</i>	Yes	Yes	Yes
<i>Readily available</i>	Yes	No	Unknown
<i>UV Resistant</i>	No	No	Unknown
<i>Waterproof</i>	Yes	Yes	Unknown
<i>Efficient use of space</i>	Yes	No	No
<i>Easy to assemble</i>	Yes	Yes	No

Based on the results of the review of various housing options, it was determined that a 5-gallon bucket met the customer requirements and engineering specifications most completely.

Lamp

Options	Criterion	PLT LG04T5	Philips 32512-6 - PL-S9W/TUV	PLT PL-L18W/TUV 2G11
Inexpensive		\$3.21	\$14.49	\$10.87
Germicidal (254 nm)		Yes	Yes	Yes
High UV wattage output		0.8 W	2.4 W	5.5 W
Proper length		6 in	5.71 in	8.86 in
Low input wattage		4.5 W	9	18 W
Long life (hours)		6,000 hrs	8,000 hrs	8,000 hrs

The primary factor that narrowed down lamp options was size. After selecting the single batch concept, it was known that the lamp must fit into a 5-gallon bucket. Several options, which met these qualifiers, were then compared. Overall, the PLT PL-L18W/TUV 2G11 bulb best suits this specific function. The low price, long life, and high UV output are especially advantageous. This lamp will provide sufficient output with only one lamp, therefore reducing the need for additional ballasts.

Lamp Holder

Options	Criterion	Leviton 660 Watt Slide On Socket	PLT 660 Watt Screw Mounted Socket	75 Watt Screw Mounted Socket
Inexpensive		\$3.86	\$2.46	\$2.11
Compatible with lamp		Yes	Yes	Yes
Properly oriented for current design		Yes	Yes	Yes

Due to the selected bulb, the team needed to find a lamp holder with a 4-pin 2G11 base. This limited the number to very few models. The only difference between the models was the maximum voltage input and price. Since the team's input values are small in comparison, the team simply chose the least expensive model.

Lamp Clip

Options	Criterion	4 Pin 2G11 CFL Lamp Clip	Long Twin Tube Support Clip
Inexpensive		\$1.57	\$0.84
Compatible with lamp		Yes	Yes
Provides support to bulb		Yes	Yes

The lamp clip selected is inexpensive and well suited for the design. The clip will further support.

Ballast

Options	Criterion	Electrician Supplies	Kirby Risk Ballast	1000 Bulbs Ballast
	<i>Inexpensive</i>	\$49.27	\$18.38	\$18.27 ~ \$15.30 (10+)
	<i>Compatible with lamp</i>	Yes	Yes	Yes
	<i>Compatible with lamp holder</i>	Yes	Yes	Yes

Due to the bulb selected by the team, the Advanced LC25TPI was the only model available to use. The team found three competitors offering the same product. The team compared Electrician Supplies (dot com), Kirby Risk, and 1000 Bulbs. Not only was 1000 Bulbs the cheapest, but the team was already ordering more parts from 1000 Bulbs. This made the ease of ordering much easier and less expensive in shipping costs. Therefore the decision to purchase from 1000 Bulbs met the customer and engineering specifications most completely.

Safety Features

Options	Criterion	Power Indicator	UV paint	Emergency Switch
	<i>Prevents exposure to UV light</i>	Yes	Yes	Yes
	<i>Considers consumer (children)</i>	Yes	Yes	Yes

Power Indicator (Plastic Rod)

Options	Criterion	Acrylic Rod (1/4")	PETG ² Big Plate (1.5")	PETG ² Rod (1/4")
	<i>Inexpensive (6 ft.)</i>	\$1.99	\$13.88	\$3.54
	<i>Easy to use</i>	Yes	No	Yes
	<i>Blocks UV light</i>	Unknown	Yes	Yes
	<i>Indicates on/off reading</i>	Yes	Yes	Yes

The team looked into both Acrylic and PETG² as materials to be used as an indicator. First the team recognized that the thicker plate would both cost more, and would be harder to implement with relatively no benefits over the smaller width rod. Literature was available online for some transmittance, and cutoff properties of PETG² however no information was available on Acrylic Rods. The ultra violet light can be potentially dangerous so maintaining these safety measures are extremely important to the team. The team chose PETG² over Acrylic because of these reasons.

Housing Coating

Options	Criterion	Aluminum	Krylon UV Resistant Spray-paint
<i>Inexpensive</i>		\$1.96	\$6.50
<i>Maximizes potency of UV light on water</i>		Yes	No
Protects housing from UV Light		No	Yes

Miscellaneous Components

The following miscellaneous components were readily found in multiple locations on the Internet. The team therefore used only the cost as a criterion.

- Screws (90272A148)
- Nuts (9048A007)
- Washers (90126A512)
- Wire Nuts
- Aluminum Foil
- Extension Cord
- Black Spray Paint
- Generic Light Switch

Completed Bill of Materials

Attached in the appendix is a Bill of Materials. This breaks down the cost of each individual part bought and used in both a single cost solution, as well as a Prorated cost. The prorated cost is simply the unit cost with respect to the purchased part quantity. For instance the design only incorporates two wire nuts; however they must be purchased in bulk by the hundreds. The prorated cost takes the cost of the one hundred wire nuts and divides it by the quantity then multiplies it by the demanded number of the design. Doing this almost halves the cost of the design so it is an important thing to mention.

Something that has not been included on the Bill of Materials was the 25 grams of Potassium Trioxalatoferate (III) Trihydride purchased from Alfa Aesar. This has been left out by choice, as it is only for field-testing and will not be purchased by the end user. Alfa Aesar was the least expensive distributor at \$51.50 for 25 grams.

Tools and Utility for Construction

Below is a list of tools used in the construction of the prototype. This list will help in a construction manual for the user. Please note that these may change in the event of making the product design in a more efficient manner.

- Phillips Screwdriver
- Pliers
- Power Drill/Screwdriver
- Drill bits (2 of correct size)
- Jigsaw

- Marker
- Hand-saw
- Sandpaper (fine)
- Ruler
- Scrap-paper (to paint on)

Actinometry Experiment

Preliminary modeling was completed to determine intensity, dosage, and irradiation time for the UV disinfection unit. The following equation (a form of the Beer-Lambert law) calculates these conditions and can be found in the EPA UV Guidelines.

$$I(r) = \frac{P_L}{2\pi r} e^{-\alpha_e r}$$

Where:

$I(r)$ = intensity of transmitted light at a distance r from the line source

P_L = UV power emitted per unit arc length of line source

r = radial distance from the line source

α_e = Napierian (base e) absorption coefficient for water

The experiment was conducted beginning with a control test, using the prototype and potassium ferrioxalate in an open Petri dish. For the first test, six 50 mL volumetric flasks were utilized to measure several potassium ferrioxalate mixtures measured at 30-second intervals from 0-150 seconds. After calculating the results from the first test, a second test was conducted with longer, 3-minute intervals from 0-30 minutes to show stronger reactions. This test resulted in a wider range of intensity. The chemical details of this experiment are included in the appendix.

The results of the actinometry experiment show the intensity of the selected UV light to be 4.584820707 mL/(cm²*min). Therefore, the irradiation time necessary to complete 4log(inactivation) of cryptosporidium, giardia, and viruses is 5 minutes.

VII. Conclusion and Future Directions

Point-of-Use Slow Sand Filters

While finalizing the Porex plate design for the point of use slow sand filter, the price per unit of the Porex plates was found miscalculated during the initial design analysis. When the team learned that the price of the plates was actually increased tenfold, action was taken to contact Porex. When presented with information about this project and prompted for a donation, 15 Porex plates were donated to the team. Because this was a donation that will not be expected when constructing the SSFs in the future, it will be necessary that the next step in continuing the redesign is to figure out how to construct our own plastic plate out of high-density polyethylene (HDPE) beads or pellets. The forming process for this will have to be learned, mainly through trial and error. After finding where to order HDPE beads, the process can start with looking up the melting temperature of HDPE. One suggestion for how to form the plates is to clamp some beads into a round cake pan and bake in the oven. While looking into this aspect of the HDPE plate design and continuing the redesign process of the SSF, the initial variables will still need to be considered and reevaluated. These variables include overall cost, ease of construction, and effectiveness of the filter. The final redesign with the Porex plates will be implemented in schools in Barbosa, Columbia, this coming June 2012. The parts for each bucket have been ordered, and in the

weeks before the on-site trip members of the traveling team will work to construct the base plates and other elements for each bucket. There are 30 units being constructed, and therefore 60 buckets to construct with 2 buckets stacked in each unit.

Continuous-flow Large Filters

Lack of reliable information is a major design issue with this project. We do not have adequate data on per capita consumption, stream flow rates, and existing infrastructure. Specifically for water consumption, it is unknown how much water is used for direct consumption, personal hygiene, clothing and dish washing, and irrigation, most likely of gardens. A clear breakdown of water demand by sector would allow for a more specific design and provide treated water only for required uses (i.e. neglect irrigation). The water source, small mountain streams, is the cause of a great deal of uncertainty. Based on reports from the area, stream flow is seasonally variable, with little to no flow in the dry season. This provides a major constraint on the design as it is useless if there is no water to be treated. Additionally, the “health” of the filter is dependent on a relatively constant input of water. The microbial community in the filter will decay without a source of food and water. The presence of existing infrastructure is the final major unknown factor. We have assumed that a piping system exists to transport water from our filters to the homes of those in the communities. If this is not the case, or the existing pipe system is inadequate, a newly designed water conveyance system is required. By visiting these communities and speaking with residents and governmental officials, we will be able to have a better understanding of the constraints we are facing and how to adapt the design for final implementation.

0.2 μm Filters

Based on the needs of Colombia and the results of the disinfection analysis it has been determined that pleated filters should be used for final filtration due to their increased surface area, which can remove more pathogens. Their price is a little higher than other filter types; the longer life expectancy outweighs the cost of the filter. Depth filters are effective in removing larger sized pathogens. They are more cost efficient, so they can be used when using a higher rating for pathogen removal. It is crucial to use absolute ratings when selecting a filter for final disinfection because it can remove 98% - 99.98% of the pathogens at the stated micron rating as opposed to the 80% - 90% removal of nominally rated filters. It is important to use a small enough rating to remove all of the pathogens present in the water being treated. Because no filter has the capability to remove all pathogens and viruses, it is necessary to combine filtration disinfection with a secondary form of disinfection, like chlorination, to avoid clogging and the presence of microbial activity and viruses in the effluent. The lifetime of a filter can be determined by the size and amount of pathogens in the water, therefore it is important to use multiple forms of disinfection (i.e. chlorination combined with different filtration sizes).

For secondary disinfection purposes, chlorination is an effective step in the disinfection process. Chlorination combined with filtration can effectively remove *Giardia* cyst and other pathogens that may be present in the water in Colombia. The selected filter for the first filter to follow chlorination is a 1 micron absolute depth. This filter was chosen because it is cheap and capable of removing 98% - 99.98% of pathogens and *Cryptosporidium* oocysts at the 1 micron level. After the 1 micron filter, there will be a final filter of 0.2 micron absolute pleated filter. The 0.2 micron pleated filter was chosen to remove the pathogens that were able to flow through the 1 micron filtration process. The 0.2 micron pleated filter will further eliminate any remaining pathogens at the selected size. It was chosen at an absolute rating in order to ensure the most efficient removal of pathogens possible. The pleated filter was selected due to its increased life expectancy and surface area for maximum pathogen removal.

UV Disinfection

The actinometry experiment will provide approximate irradiation times and more accurate intensity data. After sufficient field-testing, the model for delivered dose will be recalculated. This may result in necessary alterations to the design and its components. Further actinometry testing will be conducted to evaluate design revisions. Once the design meets specifications, an assessment will be completed using Easy-Gel, followed by redesign.

Upon successful completion of the working prototype more safety features will also be installed. The first is incorporating an emergency switch located at the bottom of the housing. If lifted while the light is on, the switch will open and the light will inactivate. This will be a major asset to the safety especially when considering the children that may have access to the device. Another addition to the prototype will be a timer. Since irradiation times are currently unknown, a timer is very difficult to choose. Once this information is known a timer can be readily selected.

With the irradiation times provided, a better understanding of the absolute power consumed can be acquired. A design goal for the future is to use this information to create an alternative method for powering the device. Possible future concepts include solar powered, counter-weight powered, and DC hand powered generators. These concepts cannot be determined until provided with the irradiation times

VIII. References

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Appendix A: Scale-Up Team

1. Blog
2. Test procedures
3. Data Tables
4. Pipe flow calculations
5. Filter Design
6. Storage tank design
7. Sedimentation basin design

Appendix i

BLOG

<http://colombiascaleup.wordpress.com/>

Appendix ii

TESTING PROCEDURE

The daily testing procedure steps included:

1. Record date, time, and name of recorder.
2. Record volume of water in effluent bucket.
3. Calculate and record the flow rate (using the time since last recording and volume recorded earlier).
4. Record water height between effluent and overflow tubing (use tape measure on side of filter).
5. Measure turbidity of the source and treated water.
6. Take Easy Gel sample and/or count colonies as needed. (Note: This will be done every three days for both the source and treated water. The source water will be tested on one day, and the next day the treated water will be tested. Refer to data sheet. The white spaces correspond to days for which the sample was taken. For example, the blank on Day 2 for source water means whoever is collecting data on Day 2 will make the Easy Gel while the person collecting data on Day 3 will record the colony counts for that plate [in the Day 2 blank]. Also, the person collecting data on Day 3 will make an Easy Gel for the **treated** water. This plate will be counted by the person collecting data on Day 4 and recorded in the Day 3 blank.) Five milliliter samples are taken from the treated water and two milliliter samples are taken from the source water./ from both
7. Measure dissolved oxygen of both the source and treated water as needed.
8. Every Monday, Wednesday, and Friday, alkalinity, pH, and hardness are measured using easy testing strips.
9. Make sure the source reservoir has an adequate amount of 50/50 Wabash R. water/ treated water mixture.

Appendix iii - DATA TABLES

Date	Time	Initials	Obs	Δ time (h)	volume (L)	flow rate (L/hr) reported	Flow rate (L/hr) verification	Source NTU	Effluent NTU	Head (cm)	Cumulative Volume (L)
7-Feb	2:15 PM	RL						22.8	1.5		
8-Feb	1:20 PM	RL		23.00	10	0.45	0.43	23.5	0.85	1.7	10
9-Feb	4:00 PM	EC		26.50	15	0.56	0.57	18.3	0.61	1.7	25
10-Feb	1:30 PM	RL		20.50	16	0.74	0.78	8.92	1.1	1.6	41
11-Feb	1:30 PM	RL		24.00	22	0.92	0.92	27.5	0.64	1.8	63
12-Feb	1:30 PM	RL	adjustment	24.00				35.5	1.2	1.4	63
13-Feb	12:40 PM	FAS		23.00	11.5	30ml/3:18 mm:ss	0.50	14.1	0.35	1.7	74.5
14-Feb	1:20 PM	JW		25.00	10.5	0.42	0.42	5.4	0.9	1.5	85
15-Feb	12:30 PM	FAS		23.00	15.5	50ml/4:31	0.67	3.82	0.67	1.4	100.5
16-Feb	1:20 PM	JW		25.00	15.5	0.62	0.62	3.6	1	2.1	116
17-Feb	1:30 PM	JW		24.00	20	0.83	0.83	5.4	0.28	4.0	136
18-Feb	1:00 PM	RL		23.50	7.2	0.31	0.31	2.9	0.45	1.3	143.2
19-Feb	4:30 PM	RL		27.50	4	0.15	0.15	2	0.34	1.2	147.2
20-Feb	12:30 PM	FAS		20.00	16	0.88	0.80	2.1	0.3	2.8	163.2
21-Feb	11:20 AM	FAS/ JW	FLOAD	23.00	20	0.42	0.87	3	0.49	6.3	183.2
22-Feb	1:30 PM	JW		24.00	6	0.25	0.25	2.7	0.52	2.2	189.2
23-Feb	3:50 PM	FAS	FLOAD	26.00	20	0.76	0.77	16	1.03	5.4	209.2
24-Feb	2:15 PM	RL		22.50	7.3	0.37	0.32	3.3	0.4	2.5	216.5
25-Feb	3:40 PM	JW		25.50	13	0.52	0.51	0.88	0.2	3.0	229.5
26-Feb	12:10 PM	JW		20.50	9	0.42	0.44	0.68	0.28	2.9	238.5
27-Feb	1:30 PM	FAS		25.50	12.4	0.49	0.49	0.65	0.17	3.0	250.9
28-Feb	1:30 PM	JW		24.00	11	0.45	0.46	0.99	0.26	3.0	261.9
29-Feb	12:30 PM	FAS		23.00	10	0.44	0.43	0.8	0.18	2.9	271.9

1-Mar	12:45 PM	RL		24.00	12.3	0.51	0.51	2	1.65	2.6	284.2
2-Mar	1:40 PM	JW		25.00	23.5	0.98	0.94	13	0.26	4.0	307.7
3-Mar	2:15 PM	RL		24.50	7	0.29	0.29	1.5	0.65	1.8	314.7
4-Mar	10:45 AM	RL		20.50	8.7	0.42	0.42	1.1	0.6	2.3	323.4
5-Mar	4:40 PM	FAS		30.00	8	0.41	0.27	3.6	0.2	2.5	331.4
6-Mar	2:30 PM	FAS		22.00	13	0.59	0.59			2.6	344.4
7-Mar	1:00 PM	EC		22.50	15	0.66	0.67	8.00	0.57	2.5	359.4
8-Mar	5:25 PM	JW	We fill with wabash water	28.50	15	0.52	0.53	1.1	0.6	2.5	374.4
			Spring Break					12.2			374.4
19-Mar		JW							0.49	3.7	374.4
20-Mar		JW	Run dry							3.5	374.4
21-Mar	1:30 PM	FAS	Restart			100ml/12min		0.32	N/A	3.5	374.4
22-Mar	11:00 AM	JW		21.50	13.5	0.62	0.63	0.6	0.28	3.8	387.9
23-Mar	12:30 PM	FAS		25.50	14	1.04	0.55	1.92	0.85	4.0	401.9
23-Mar		FAS / jw	Refill of Wabash water 100%			n/a		15.2	N/A		401.9
24-Mar	1:45 PM	RL			20	0.8		3.45	0.3	3.8	421.9
25-Mar	5:30 PM	JW		27.50	8	0.29	0.29	7	0.29	4.1	429.9
26-Mar	1:30 PM	RL		20.00	6.2	0.31	0.31	3.5	0.3	4.0	436.1
27-Mar	12:00 PM	RL		22.50	5	0.22	0.22	2.7	0.2	4.0	441.1
28-Mar	2:00 PM	EC		26.00	23	0.88	0.88	26	0.22	4.0	464.1
29-Mar	12:00 PM	JW		22.00	9	0.4	0.41	22	0.21	4.2	473.1
30-Mar	1:30 PM	RL		24.50	4	0.16	0.16	4.8	0.6	4.3	477.1
31-Mar	2:30 PM	EC		25.00	7.5	0.3	0.30	3.6	0.13	8.3	484.6
1-Apr	12:30 PM	JW		22.00	6	0.27	0.27	4.7	0.49	8.6	490.6
2-Apr	1:30 PM	RL		25.00	8	0.32	0.32	3.9	0.26	16.5	498.6
3-Apr	2:00 PM	RL		24.50	9		0.37	2.9	0.09		507.6

4-Apr	1:30 PM	RL		23.50	6	0.26	0.26	3.5	0.25	9.1	513.6
5-Apr	1:20 PM	JW		24.00	5	0.2	0.21	2.4	0.3	9.5	518.6
6-Apr	2:00 PM	EC	Top Layer removed	24.50	21	0.85	0.86	3.1	0.1	3.1	539.6
7-Apr	2:00 PM	JW		24.00	18	0.75	0.75	13	0.27	3.2	557.6
8-Apr			Recirculating								557.6
9-Apr	12:00 PM	RL						3.1		3.0	557.6
10-Apr	1:30 AM	FAS		24.50	18	0.7	0.73	2.9	0.22	3.5	575.6
11-Apr	1:30 AM	JW		24.00	14	0.58	0.58	1.28	0.19	3.5	589.6
12-Apr	3:30 PM	JW		26.00	11	0.42	0.42	2.5	0.2	3.5	600.6

Appendix iv

PIPE FLOW CALCULATIONS

Constants

Flow Rate	16.85	m^3/day	Slope	20	degrees
	0.000195023	m^3/s		0.34906585	radians
Pipe Length	10.64177772	m	Horizontal distance	10	m
Height	3.639702343	m			
epsilon	1.50E-06	m			
gravity	9.81	m/s^2			
dynamic viscosity	1.00E-06				

	Bernoulli Equation	Assume d =	epsilon/d =	Reynolds =	f=
f/d^5	108505931.1	0.03 m	5.00E-05	8.24E+03	7.76E-03
		0.009352	1.60E-04	2.64E+04	2.60E-02
		0.01191	1.26E-04	2.08E+04	0.026
		0.01191			

DESIGN DIAMETER

0.047639146	m
4.763914576	cm

Appendix v

Filter Design

Assumptions

Population size	Retention time	Porosity	Sand depth	Per capita demand
$N := 160$	$\phi := 8\text{hr}$	$\eta := 0.36$	$d := 1.3\text{m}$	$wu := 200 \frac{\text{L}}{\text{day}}$

Calculate total demand flow

$$Q_n := wu \cdot N \quad Q_n = 3.2 \times 10^4 \cdot \frac{\text{L}}{\text{day}}$$

Calculate water volume of filter

$$V_w := Q_n \cdot \phi \quad V_w = 1.067 \times 10^4 \text{ L}$$

Calculate sand filter volume

$$V_s := \frac{V_w}{\eta} \quad V_s = 2.963 \times 10^4 \text{ L}$$

Calculate total area of filter

$$A_t := \frac{V_s}{d} \quad A_t = 22.792 \text{ m}^2$$

Filter dimensions

$$\text{side} := \sqrt{\frac{A_t}{2}} \quad \text{side} = 3.376 \text{ m}$$

$$\text{width} := 3 \text{ m} \quad \text{length} := 4 \text{ m}$$

round to get 2 filters at 3m x 4m

Calculate design filter area

$$A_d := \text{width} \cdot \text{length} \cdot 2 \quad A_d = 24 \text{ m}^2$$

Calculate design flow rate

$$Q_d := A_d \cdot d \cdot \frac{\eta}{\phi} \quad Q_d = 3.37 \times 10^4 \cdot \frac{\text{L}}{\text{day}}$$

Appendix vi

Storage tank design

Assumptions

Capacity

$$St := 2\text{day}$$

Depth

$$\text{depthst} := 3\text{m}$$

Calculated required volume

$$V_{st} := Qd \cdot St \quad V_{st} = 6.739 \times 10^4 \text{ L}$$

Calculate required area

$$\text{areast} := \frac{V_{st}}{\text{depthst}} \quad \text{areast} = 22.464 \text{m}^2$$

Assume dimensions are 4m x 6m

$$\text{lengthst} := 4\text{m}$$

$$\text{widthst} := 6\text{m}$$

Calculate storage volume

$$\text{StorageV} := \text{lengthst} \cdot \text{widthst} \cdot \text{depthst} \quad \text{StorageV} = 72 \cdot \text{m}^3$$

Appendix vii

Sedimentation basin design

Assumptions

Design Flow	Particle Diameter	Particle Density	Water Density
$Q_d := 3.37 \times 10^4 \frac{\text{L}}{\text{day}}$	$d := 11 \cdot 10^{-6} \text{ m}$	$\rho_s := 2000 \frac{\text{kg}}{\text{m}^3}$	$\rho_w := 1000 \frac{\text{kg}}{\text{m}^3}$
Dynamic Viscosity of Water	Acceleration of Gravity	Retention Time	
$\mu := 8.90 \cdot 10^{-4} \text{ Pa} \cdot \text{s}$	$g := 9.8 \frac{\text{m}}{\text{s}^2}$	$\phi := 4 \text{ hr}$	

Calculate Particle Settling Velocity

$$V_s := \frac{g \cdot (\rho_s - \rho_w) \cdot d^2}{18 \mu} \quad V_s = 7.402 \times 10^{-3} \frac{\text{cm}}{\text{s}}$$

Solve for the Overflow Rate

$$V_o := V_s \quad V_o = 6.395 \frac{\text{m}}{\text{day}}$$

Solve for the total basin area

$$A_p := \frac{Q_d}{V_o} \quad A_p = 5.269 \text{ m}^2$$

Solve for the total basin volume

$$V_p := \phi \cdot Q_d \quad V_p = 5.617 \text{ m}^3$$

Solve for the basin depth

$$H_p := V_o \cdot \phi \quad H_p = 1.066 \text{ m}$$

Final basin dimensions (2 basins)

$$\text{widthd} := 1 \text{ m} \quad \text{lengthd} := 3 \text{ m} \quad \text{depthd} := 1 \text{ m}$$

Total design area and volume

$$\begin{aligned} A_d &:= 2 \cdot \text{widthd} \cdot \text{lengthd} & A_d &= 6 \text{ m}^2 \\ V_d &:= A_d \cdot \text{depthd} & V_d &= 6 \text{ m}^3 \end{aligned}$$

Calculate design settling velocity

$$V_{sd} := \frac{Q_d}{A_d} \quad V_{sd} = 6.501 \times 10^{-3} \frac{\text{cm}}{\text{s}}$$

Appendix B: UV Disinfection Team

Ultraviolet Disinfection Semester Project Plan Project Tasks and Milestones Spring 2012

Team Name:	Ultraviolet Disinfection Team
------------	-------------------------------

	January					January					January					January - February					February				
	9	10	11	12	13	16	17	18	19	20	23	24	25	26	27	30	31	1	2	3	6	7	8	9	10
Project Tasks and Milestones	M	T	W	R	F	M	T	W	R	F	M	T	W	R	F	M	T	W	R	F	M	T	W	R	F
Problem Definition																									
UV Overview Research																									
EPA UV Guidelines Research																									
UV Case Study Research																									
Intensity, Dosage, Log-kill Research																									
Effective Modeling																									

	February					February					February-March					March					March				
	13	14	15	16	17	20	21	22	23	24	27	28	29	1	2	5	6	7	8	9	19	20	21	22	23
Project Tasks and Milestones	M	T	W	R	F	M	T	W	R	F	M	T	W	R	F	M	T	W	R	F	M	T	W	R	F
Design Options																									
Housing Research																									
Bulb Research																									
Ballast Research																									
Lampholder Research																									
Remaining Component Research																									
Design Comparison																									
Final Report Outline																									
Blurb for Blog																									
UV Bulb Analysis																									
CAD																									
Order Parts																									

	March					April					April					April					April				
	26	27	28	29	30	2	3	4	5	6	9	10	11	12	13	16	17	18	19	20	23	24	25	26	27
	M	T	W	R	F	M	T	W	R	F	M	T	W	R	F	M	T	W	R	F	M	T	W	R	F
Project Tasks and Milestones																									
Electrical Work in Lab																									
Building Prototype																									
Final Report Work																									
Problem Definition & Task																									
Design Objectives																									
Design Criteria																									
Design Comparison																									
Decision Matrix																									
Bill of Materials																									
Conduct Actinometry Experiment																									
Record Actinometry Results																									

General Research Write-Up																									
Case Study Write-Up																									
Calculation Write-Up																									
Refine Design																									

Items	Type	Item Description	Qty Used	Cost	Qty/Cost	Prorated Cost*	Company Purchased From
Advanced LC25TPI Ballast	E	Ballast	1	\$18.27	1	\$15.30	1000bulbs.com
PLT PL-L18W/TUV 2G11 Bulb	E	Bulb	1	\$10.87	1	\$10.87	1000bulbs.com
75 Watt Screw Mounted Socket Lampholder	E	Bulb Holder	1	\$2.11	1	\$2.11	1000bulbs.com
Blue Wire Nuts	E	Wire Nuts	2	\$5.35	100	\$0.11	1000bulbs.com
Step Switch Extension Cord	E	Cord	1	\$3.79	1	\$3.79	Menards (local)
5 Gallon Bucket	S	Bucket	1	\$2.60	1	\$2.60	Menards (local)
Long Twin Tube Support Clip	S	Support Clip	1	\$0.84	1	\$0.84	1000bulbs.com
Reynolds Aluminum Foil (Qty in sq ft)	U	Aluminum Foil	3	\$1.96	30	\$0.20	Reynoldskitchens.com
Krylon UV Resistant Spray Paint (Qty in sq ft)	U	UV Paint	0.8	\$7.35	8	\$0.74	Unitednow.com
Krylon Black Spray Paint (Qty in sq ft)	I	Black Paint	0.8	\$6.50	8	\$0.65	Unitednow.com
PETG Rod (Quantity in inches)	I	Plastic Indicator	3	\$3.54	72	\$0.15	Mcmastercarr.com
90126A512 Multipurpose Washer .03"-.07" Thick	H	Washers	9	\$1.42	100	\$0.13	Mcmastercarr.com
90480A007 Hex Nut 6-32 Thread	H	Nuts	5	\$1.16	100	\$0.06	Mcmastercarr.com
90272A148 Phillips Screw #6 x 1/2	H	Screws	5	\$2.17	100	\$0.11	Mcmastercarr.com
Total Cost Per Unit	<div> <div>\$67.93</div> <div>\$37.66</div> </div>						

*The prorated cost assumes cheaper 10+ ballast pricing

**Aluminum, Paints, and Caulk prorated values

assume that 10 units can be created with cost

E Electronics
S Structure
U Ultra Violet Inhibitors
H Hardware
I Indicator Utility

Measure light intensity by ferrioxalate actinometry. xls

Date: April 2012

Experimenter: Stephanie Wink, Robert McKenna, Meghan Newman

Materials

$\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$

1,10-phenanthroline monohydrate

H_2SO_4

FeCl_3

$\text{K}_2\text{C}_2\text{O}_4 \cdot \text{H}_2\text{O}$

CH_3COONa

DI water

Hair dryer

Thermometer

Rayonet merry-go-round photochemical reactor: RPR-100, Southern New England Ultraviolet, Branford, CT.

UV lamp: 300-400 nm, centered at 350 nm, 24 W, RPR-3500 Å, Southern New England Ultraviolet, Branford, CT.

Procedure

$\text{K}_3\text{Fe}(\text{C}_2\text{O}_4)_3 \cdot 3\text{H}_2\text{O}$ had to be prepared in the lab, as no commercial product is available. To do this, 15 mL 1.5 M $\text{K}_2\text{C}_2\text{O}_4$ was mixed with 5 mL of 1.5 M FeCl_3 in a beaker. 1.5 M $\text{K}_2\text{C}_2\text{O}_4$ was made by placing 13.958 g $\text{K}_2\text{C}_2\text{O}_4 \cdot \text{H}_2\text{O}$ in a 50 mL volumetric flask and made up to mark by adding water. 1.5 M FeCl_3 was prepared by the same way except 12.542 g FeCl_3 was added. The mixed solution was recrystallized 3 times under magnetic stirring in a stream of warm air by a hair dryer. The solution temperature was kept at around 45° C by adjusting wind speed and the distance of the hair dryer to the beaker and monitored by a thermometer. Between each recrystallization, the same volume of 20 mL water as the initial one was added to the beaker. It is noted that the mixing and recrystallization procedures were done in a dark room. The resulting $\text{K}_3\text{Fe}(\text{C}_2\text{O}_4)_3 \cdot 3\text{H}_2\text{O}$ crystal appeared green in color and was stored in an amber vial and can last for a long time according to the literature.

To prepare **30 mM** ferrioxalate solution for photolysis, **50 mL 60 mM** $\text{K}_3\text{Fe}(\text{C}_2\text{O}_4)_3$ in 0.1 N H_2SO_4 and **5 mL 1 N** H_2SO_4 were mixed in a 100 mL volumetric flask and diluted to 100 mL. For photolysis, glass tubes containing 5-17 mL (V_1) solution along with dark control samples were exposed to 8 UV lamps in a Rayonet merry-go-round photochemical reactor. Dark control samples were prepared as irradiated samples except they were covered by aluminum foil. To produce sufficient ferrous iron, 6 min of irradiation was generally enough. For analysis, **1.0 0.1 mL** (V_2) solution was quickly (i.e., to prevent solid precipitate evolution) taken from each sample and mixed with buffer solution that had a volume equal to half the solution taken (i.e., **0.05 0.5 mL**), and **2 mL 0.1 wt% 1,10-phenanthroline in 50 mL (V_3) volumetric flasks** and made up to mark by adding water. At least 30 min had to past to let the complex of ferrous iron and 1,10-phenanthroline fully develop. The complex concentration was determined on a UV-visible spectrophotometer at 510 nm (UV-visible spectrophotometry method 1) using the standard curve. To make the standard curve, the following solutions were needed.

(I) A buffer solution was made by mixing 600 mL 1 N CH₃COONa (47.715 g) and 360 mL 1 N H₂SO₄ in a 1 L volumetric flask and diluted to 1 L by water. 1 N H₂SO₄ was made by diluting 27.62 mL pure (95-98 %) sulfuric acid to 1 L by water.

(II) 0.1 wt % 1,10-phenanthroline was prepared by diluting 109.987 mg 1,10-phenanthroline monohydrate to 0.1 L by water and stored in the dark..

(III) 0.4 mM ferrous iron in 0.1 N H₂SO₄ was made freshly by diluting 0.1 M FeSO₂ in 0.1 N H₂SO₄. For this, 0.8 mL 0.1 M FeSO₂ in 0.1 N H₂SO₄ was mixed with 20 mL 1 N H₂SO₄ and diluted to 200 mL by water. 0.1 M FeSO₄ in 0.1 N H₂SO₄ was prepared by mixing 2.7801 g FeSO₄·7H₂O and 10 mL 1 N H₂SO₄ in a 100 mL volumetric flask and diluting to 100 mL.

Procedure (cont'd)

0, 1.25, 2.5, 3.75, 5, 6.25 mL 0.4 mM FeSO₄ were added to a series of 25 mL volumetric flasks and mixed with 1.25 mL 1 N H₂SO₄ and 6.25 mL buffer solution. The resulting concentrations of ferrous iron ranged from 0 to 0.1 mM. To the volumetric flasks, 2.5 mL 0.1 wt % 1,10-phenanthroline monohydrate was added and sat for a least 30 min to let the complex of ferrous iron and 1,10-phenanthroline fully develop. Standard solutions were analyzed on a UV-vis spectrophotometer at 510 nm (UV-vis spectrophotometry method 1) and the standard curve was

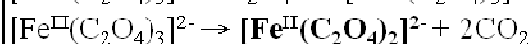
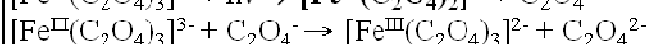
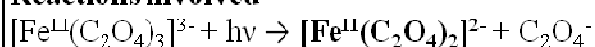
UV-visible spectrophotometry method 1

Spectrophotometer: Varian Cary 300 Bio

Scan range: 200-800 nm

Scan speed: 240 nm/min

Reactions involved



Calculation

The light intensity can be calculated by the following equations.

$$I = \Delta n / (10^{-3} \cdot \Phi \cdot V_1 \cdot t) \quad \text{unit: Einstein/L/s}$$

where Δn = ferrous iron photo-generated (mole).

Φ = quantum yield. 1.22 was used, as the majority of UV light centered at 350 nm for the lamps used.

V_1 = irradiated volume (mL).

t = irradiation time (s).

Δn can be calculated by the equation below.

$$\Delta n = 10^{-3} \cdot V_1 \cdot V_3 \cdot C_t / V_2$$

where V_1 = irradiated volume (mL).

V_2 = volume taken from the irradiated samples (mL).

V_3 = volume after dilution for concentration determination (mL).

C_t = concentration of ferrous iron after dilution (M).

C_t can be calculated from the absorbance at 510 nm as follows.

$$C_t = \text{abs.} / (\epsilon \cdot l)$$

where abs. = absorbance at 510 nm.

ϵ = molar absorptivity (l/M/cm). The value is the slope of the standard curve.

l = 1 cm, the light path of the quartz cell.

Sample numbering

sample name	explain
Blank	0 mM Fe ²⁺
STD 1	0.02 mM Fe ²⁺
STD 2	0.04 mM Fe ²⁺
STD 3	0.06 mM Fe ²⁺
STD 4	0.08 mM Fe ²⁺
STD 5	0.10 mM Fe ²⁺

blank water sample

blank

0 all samples refer to time in minutes

3

6

9

12

15

15

18

21

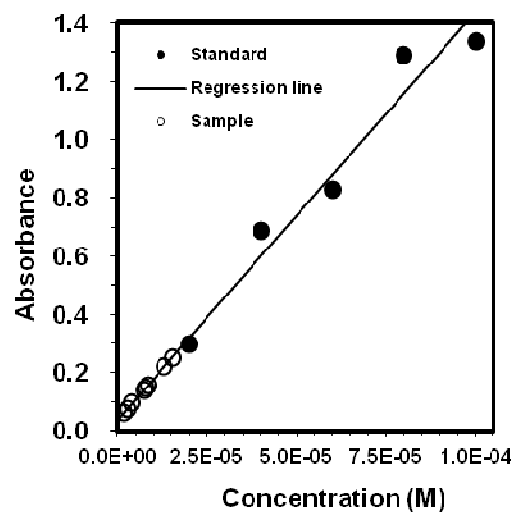
24

27

30

Standard curve

sample name	Conc (M)	Abs	Abs (calc)	X*Y	X ²	Y ²
Blank	0	-0.0036531	3.83E-02	0	0	1.33451E-05
STD1	2.00E-05	0.298654795	3.19E-01	5.9731E-06	4.00E-10	0.089194686
STD2	4.00E-05	0.685874224	5.99E-01	2.7435E-05	1.60E-09	0.470423451
STD3	6.00E-05	0.828828096	8.79E-01	4.97297E-05	3.60E-09	0.686956013
STD4	8.00E-05	1.28733182	1.16E+00	0.000102987	6.40E-09	1.657223215
STD5	1.00E-04	1.33621192	1.44E+00	1.34E-04	1.00E-08	1.785462295
		2 parameter regression		1 parameter regression		
		slope =	14011.8715	Sum (X*Y) = 3.20E-04		
		intercept =	0.038281051	Sum (X ²) = 2.20E-08		
		correl =	0.98599083	Sum (Y ²) = 4.69E+00		
				slope= 1.45E+04 =molar absorptivity (1/M/cm)		
				r= 0.995497849		



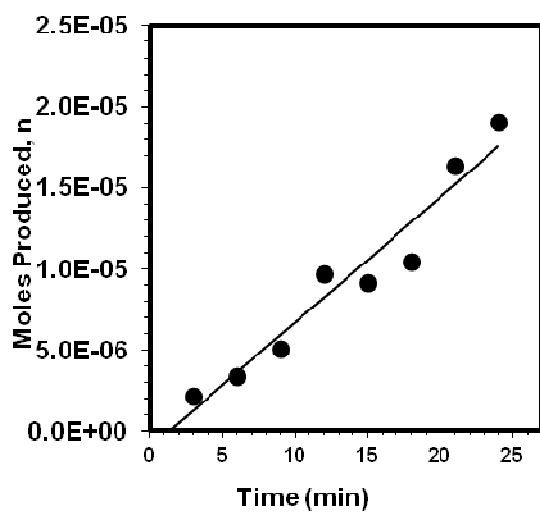
Volume of Sample in petri dish (mL) = 25
Volume of Sample removed at each time point (mL) = 1
Volume of Phenanthroline solution (mL) = 50

Sample

sample name			Meas. conc.	Concentration in Irradiated Sample	n of Fe2+ photo- produced	n Calculated
	Time (min)	Absorbance	(M)	(M)	(mole)	(mole)
blank		-0.019947147	-4.16E-06	-2.08E-04		
blank		-0.023306318	-4.40E-06	-2.20E-04		
0		-0.021138491	-4.24E-06	-2.12E-04		
3		-0.01010417	-3.45E-06	-1.73E-04		
6		0.006807554	-2.25E-06	-1.12E-04		
9	0	0.031228334	-5.03E-07	-2.52E-05	-6.29E-07	-1.04938E-06
12	3	0.062021639	1.69E-06	8.47E-05	2.12E-06	1.27148E-06
15	6	0.075438723	2.65E-06	1.33E-04	3.31E-06	3.59234E-06
15	9	0.094023243	3.98E-06	1.99E-04	4.97E-06	5.9132E-06
18	12	0.146112293	7.70E-06	3.85E-04	9.62E-06	8.23406E-06
21	15	0.139702901	7.24E-06	3.62E-04	9.05E-06	1.05549E-05
24	18	0.154494047	8.29E-06	4.15E-04	1.04E-05	1.28758E-05
27	21	0.22069326	1.30E-05	6.51E-04	1.63E-05	1.51966E-05
30	24	0.251512021	1.52E-05	7.61E-04	1.90E-05	1.75175E-05

References

Hatchard C.G.; Parker C.A. A new sensitive chemical actinometer. 2. Potassium ferrioxalate as a standard chemical actinometer. *Proc. R. Soc. London, Ser. A.* **1956**, 235, 518-536.



slope = 7.7362E-07

Intercept = -1.0494E-06

r = 0.976473461

Quantum Yield at 254 nm = 1.25

$\Delta n/\Delta t$ (mol/min) = 7.7362E-07

Light intensity:

(Einstein/s) = 1.03149E-08

(Einstein/L/s) = 4.12597E-07

Now that the Einsteins/s or Einsteins/(L s) entering the Petri dish are known, you only need to know the surface area of the Petri dish to calculate the light flux accross the plane of the air-water interface at the experimental distance away from the lamp. The internal diameter of a Petri dish is 9 mm. Calculations are

Petri Dish radius (cm) = 4.5

Petri Dish Surface area (cm²) = 63.61725124

Distance from the lamp (cm) = TBD

Light Flux at distance from the lamp:

(Einstein/cm²/s) = 1.6214E-10

(Einstein/cm²/min) = 9.72843E-09

Constants:

h (J s) = 6.626E-34 Planck Constant

c (m/s) = 300000000 Speed of Light

j = 6.02E+23 Photons per einstein

λ (nm) = 254 Emission wavelenth of lamp

nm/m = 1.00E+09 Unit Convection

So: E (joule/einstein) = 4.71E+05

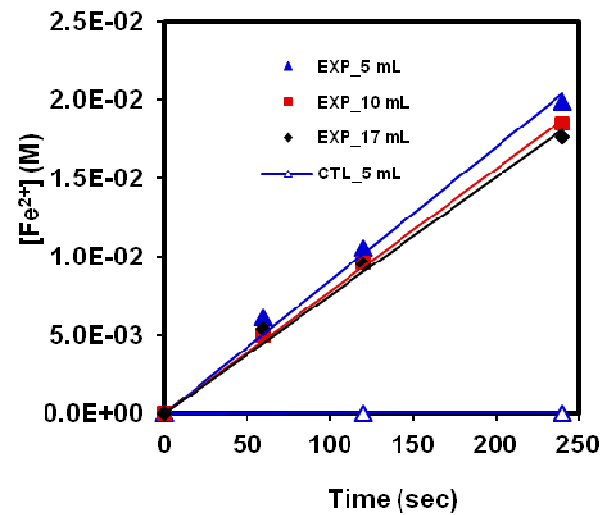
Energy flux (Joules/(cm² min) = 4.58E-03

Energy flux (mJ/(cm² min) = **4.584820707**

Required Irradiation Time (min) = 5
for 4log(inactivation)

Fe²⁺ conc. (M)

Irradiation time (sec)	EXP_5 mL	EXP_10 mL	EXP_17 mL	CTL_5 mL
0	0	0	0	0
60	6.16E-03	5.00E-03	5.40E-03	-
120	1.06E-02	9.64E-03	9.50E-03	3.19075E-05
240	1.99E-02	1.85E-02	1.76E-02	3.69251E-05



Exposed volume	[Fe ²⁺] production rate	Fe ²⁺ production rate	Light intensity			Exposed Area	R ²
(mL)	(M/sec)	(mole/sec)	(Einstein/s)	(Einstein/L/s)	(Einstein/cm ² /s)	(cm ²)	
5	8.48E-05	4.24E-07	3.47E-07	6.95E-05	1.65E-08	21.11	0.9926
10	7.80E-05	7.80E-07	6.39E-07	6.39E-05	1.74E-08	36.69	0.9988
17	7.53E-05	1.28E-06	1.05E-06	6.17E-05	1.81E-08	57.81	0.9927

Appendix C: Filter Disinfection Team Order Requests

DEPT: EPICS		ARMSTRONG SERVICE CENTER PURCHASE REQUEST								
Date:		Card #:								
Vendor Information		Purpose/Specific Benefit to the Project:				Deliver To:				
VENDOR NAME BuildersSquare		Materials for GDT- Colombia				Name: EPICS/Cathy Noerenberg				
Contact Person builderssquare.com						Building: Neil Armstrong Hall of Engr				
ADDRESS						Room: 1200				
CITY						Phone: 765-496-1068				
STATE ZIP						Email: epics@purdue.edu				
VENDOR PHONE#										
VENDOR FAX #										
Account(s) Information		Leagcy Account#		Project Period		Account Balance		Date		Special Shipping Instructions
Fund	Cost Center	Internal Order	G/L Account	\$ Amount or %	Begin Date	Expiration				
Student Name	Katie Gretencord	Email	kgretenc@purdue.edu	Team	WRM Team					
CATALOG #	ITEM DESCRIPTION					UNIT	QUAN	UNIT COST	TOTAL COST	
FXUTC	GE Smartwater replacement Water Filter					UNIT	1	\$13.49	\$13.49	
									\$0.00	
									\$0.00	
									\$0.00	
									\$0.00	
									\$0.00	
									\$0.00	
									\$0.00	
REQUISITION TOTAL									\$13.49	
Does the project require animal & care approval? Yes _____ No _____ If yes, please provide PACUC #:										
Advisor/ Signature _____ Date _____ Comptroller: Signature _____ Date _____ Chemical Order: Signature _____ Date _____ EPICS Admin : Signature _____ Date _____ NEW!					Business Office Use Only:			Card # Reconciled: Received:		
					Conf#					
					Trans ID#					
								Ref. Doc#		
Is there a discount? Yes _____ No _____ (Fill out the Form 41B) If educational discount, track internally. Has an equipment screening been completed? Yes _____ No _____ (Required for >=\$25,000 on Sponsored Accts, Desired for all other accounts)? Has the Request for Waiver of Competitive Bidding document been completed? Yes _____ No _____ (Required for all single source acquisitions >=\$10,000). Is there proper documentation from the PI approving the purchase (signature, email, other _____)?										
Will you be driving? If so please check the box and sign on the line provided. Driver Certification: By checking this box and signing this form, I am certifying that I am in compliance with all requirements established by the 'Use of Vehicles for University Business'										

DEPT: EPICS		ARMSTRONG SERVICE CENTER PURCHASE REQUEST							
Date:		Card #:							
Vendor Information					Deliver To:				
VENDOR NAME filtersource.com				Purpose/Specific Benefit to the Project:				Name: EPICS/Cathy Noerenberg	
Contact Person				Project Title: Water Resource Management: Disinfection Team				Building: Neil Armstrong Hall of Engr	
ADDRESS 726 State Fair Blvd.								Room: 1200	
CITY Syracuse				Benefit to project:				Phone: 765-496-1068	
STATENY ZIP 13209								Email: epics@purdue.edu	
VENDOR PHONE# 3154882222				Is this purchase related to grant funds: No					
VENDOR FAX # 3154883565									
Account(s) Information			Leagcy Account#		Project Period		Account Balance		Special Shipping Instructions
Fund	Cost Center	Internal Order	G/L Account	\$ Amount or %	Begin Date	Expiration	Date		
Student Name	Kathryn Gretencord	Email	kgretenc@purdue.edu	Team	WRM				
CATALOG #	ITEM DESCRIPTION				UNIT	QUAN	UNIT COST	TOTAL COST	
4600510	FM-5-975 - 5 Micron, 10" Pleated Polyester Media Cartridge Filter					1	\$5.00	\$5.00	
								\$0.00	
								\$0.00	
								\$0.00	
								\$0.00	
								\$0.00	
								\$0.00	
								\$0.00	
REQUISITION TOTAL								\$5.00	
Does the project require animal & care approval? Yes _____ No _____ If yes, please provide PACUC #: _____									
Advisor/ Signature _____ Date _____ Comptroller: Signature _____ Date _____ Chemical Order: Signature _____ Date _____ EPICS Admin : Signature _____ Date _____				Business Office Use Only:				Card # _____ Reconciled: _____ Received: _____	
				Conf# _____ Trans ID# _____ Ref. Doc# _____					
Is there a discount? Yes _____ No _____ (Fill out the Form 41B) If educational discount, track internally. Has an equipment screening been completed? Yes _____ No _____ (Required for >=\$25,000 on Sponsored Accts, Desired for all other accounts)? Has the Request for Waiver of Competitive Bidding document been completed? Yes _____ No _____ (Required for all single source acquisitions >=\$10,000). Is there proper documentation from the PI approving the purchase (signature, email, other _____)?									
Will you be driving? If so please check the box and sign on the line provided. Driver Certification: By checking this box and signing this form, I am certifying that I am in compliance with all requirements established by the 'Use of Vehicles for University Business'									

DEPT: EPICS				ARMSTRONG SERVICE CENTER PURCHASE REQUEST											
Date:		Card #.													
Vendor Information				Purpose/Specific Benefit to the Project:				Deliver To:							
VENDOR NAME Filters				Materials for GDT- Colombia				Name: EPICS/Cathy Noerenberg							
Contact Person filters.com								Building: Neil Armstrong Hall of Engr							
ADDRESS								Room: 1200							
CITY								Phone: 765-496-1068							
STATE ZIP								Email: epics@purdue.edu							
VENDOR PHONE#															
VENDOR FAX #															
Account(s) Information				Leagcy Account#				Project Period		Account Balance		Date		Special Shipping Instructions	
Fund	Cost Center	Internal Order	G/L Account	\$ Amount or %	Begin Date	Expiration									
Student Name	Katie Gretencord	Email	kgretenc@purd	Team	WRM Team										
CATALOG #		ITEM DESCRIPTION							UNIT	QUAN	UNIT COST	TOTAL COST			
MNY921AAB		0.2 mic Abs. Hydrophil. NY66 Mem., 10 in., Open End Gas.							UNIT	1	\$112.52	\$112.52			
												\$0.00			
												\$0.00			
												\$0.00			
												\$0.00			
												\$0.00			
												\$0.00			
												\$0.00			
REQUISITION TOTAL												\$112.52			
Does the project require animal & care approval? Yes _____ No _____ If yes, please provide PACUC #:															
Advisor/								Business Office Use Only:				Card #			
Signature				Date				Conf#							
Comptroller:								Trans ID#				Reconciled:			
Signature				Date				Ref. Doc#				Received:			
Chemical Order:															
Signature				Date											
EPICS Admin :															
Signature				Date											
NEW!															
Will you be driving? If so please check the box and sign on the line provided. Driver Certification: By checking this box and signing this form, I am certifying that I am in compliance with all requirements established by the 'Use of Vehicles for University Business'															

DEPT: EPICS				ARMSTRONG SERVICE CENTER PURCHASE REQUEST								
Date:		Card #.										
Vendor Information				Purpose/Specific Benefit to the Project:				Deliver To:				
VENDOR NAME mcmastercarr.com				Project Title: Water Resource Management: Disinfection Team				Name: EPICS/Cathy Noerenberg				
Contact Person								Building: Neil Armstrong Hall of Engr				
ADDRESS 600 N. County Line Rd.				Benefit to project:				Room: 1200				
CITY Elmhurst								Phone: 765-496-1068				
STATE IL ZIP 60126				Is this purchase related to grant funds: No				Email: epics@purdue.edu				
VENDOR PHONE# 6308330300												
VENDOR FAX # 6308337100												
Account(s) Information				Leagcy Account#				Project Period		Account Balance		Special Shipping Instructions
Fund	Cost Center	Internal Order	G/L Account	\$ Amount or %	Begin Date	Expiration			Date			
Student Name Kathryn Gretencord				Email kgretenc@purdue.edu	Team WRM							
CATALOG #	ITEM DESCRIPTION			UNIT	QUAN	UNIT COST	TOTAL COST					
5372K154	I.D. 3/8" plastic nylon barbed tube fittings				1	\$5.90	\$5.90					
5231K361	3-A Sanitary Clear PVC tubing I.D. 3/8"			ft.	25	\$0.67	\$16.75					
36895K112	Unthreaded female x threaded female connections PVC 3/4"				1	\$13.19	\$13.19					
								\$0.00				
								\$0.00				
								\$0.00				
								\$0.00				
								\$0.00				
REQUISITION TOTAL								\$35.84				
Does the project require animal & care approval? Yes _____ No _____ If yes, please provide PACUC #:												
Advisor/ Signature _____ Date _____ Comptroller: Signature _____ Date _____ Chemical Order: Signature _____ Date _____ EPICS Admin : Signature _____ Date _____ NEW!				Business Office Use Only:				Card #				
				Conf#				Reconciled:				
				Trans ID#				Received:				
				Ref. Doc#								
Is there a discount? Yes _____ No _____ (Fill out the Form 41B) If educational discount, track internally. Has an equipment screening been completed? Yes _____ No _____ (Required for >=\$25,000 on Sponsored Accts, Desired for all other accounts)? Has the Request for Waiver of Competitive Bidding document been completed? Yes _____ No _____ (Required for all single source acquisitions >=\$10,000). Is there proper documentation from the PI approving the purchase (signature, email, other _____)?												
Will you be driving? If so please check the box and sign on the line provided. Driver Certification: By checking this box and signing this form, I am certifying that I am in compliance with all requirements established by the 'Use of Vehicles for University Business'												

PURCHASE REQUEST										SC #									
										PO #									
Vendor Information										Deliver To:									
Vendor:		McMaster-Carr			Purpose/Specific Benefit to the Project: Materials for GDT- Colombia					Name:									
Contact:		mcmastercarr.com								Building:									
Address:										Room:									
City:										Phone:									
State:		ZIP:								Email:									
Phone:										:									
Fax:																			
Account Information										Legacy Account #					Special Shipping Instructions				
Fund		Cost Center		Internal Order		G/L Account		\$ Amount or %		Project Period Begin Date Expiration		Account Balance		Date					
CATALOG #		ITEM DESCRIPTION								UNIT		QUAN		UNIT COST		TOTAL COST			
43005T3		Rectangle High Density Polyethylene 20 L								UNIT		1		\$ 29.77		\$ 29.77			
3736K2		Polyethylene 3/4" pipe size through wall fittings threaded, female x threaded female								UNIT		2		\$ 13.11		\$ 26.22			
8674T42		Miniature through wall fittings								UNIT		1		\$ 8.45		\$ 8.45			
4089K61		ABS thermoplastic case general service pressure gauge								UNIT		1		\$ 9.20		\$ 9.20			
4269T32		2 gallon pail white								UNIT		6		\$ 4.13		\$ 24.78			
REQUISITION TOTAL														\$ 98.42					
Does the project require animal & care approval? Yes _____ No _____ If yes, please provide PACUC #:																			
Dept. Head/ Advisor/PI:				Signature				Date				Business Office Use Only: Conf# Trans ID# Ref. Doc#				Card #			
																Reconciled:			
Comptroller:				Signature				Date								Received:			
Chemical Order:				Signature				Date											
Order Placed By:				Signature				Date											
<small>Is there a discount? Yes _____ No _____ (Fill out the Form 41B) If educational discount, track internally. Has an equipment screening been completed? Yes _____ No _____ (Required for >=\$25,000 on Sponsored Accts, Desired for all other accounts)? Has the Request for Waiver of Competitive Bidding document been completed? Yes _____ No _____ (Required for all single source acquisitions >=\$10,000). Is there proper documentation from the PI approving the purchase (signature, email, other _____)?</small>																			

PURCHASE REQUEST										SC #		
										PO #		
Vendor Information					Purpose/Specific Benefit to the Project:					Deliver To:		
Vendor:	McMaster-Carr				Materials for GDT- Colombia					Name:		
Contact:	mcmastercarr.com									Building:		
Address:										Room:		
City:										Phone:		
State:		ZIP:								Email:		
Phone:										:		
Fax:										Special Shipping Instructions		
Account Information					Legacy Account #							
					Project Period		Account Balance					
Fund	Cost Center	Internal Order	G/L Account	\$ Amount or %	Begin Date	Expiration	Date					
CATALOG #									ITEM DESCRIPTION			
									UNIT	QUAN	UNIT COST	
									TOTAL COST			
53055k142									5/8" Reducing unit			
5923k74									3/8" barbed quick disconnect with shut off valve			
5923k72									3/8" barbed quick disconnect without shut off valve			
5923k44									3/8" barbed quick disconnect with shut off valve			
5923k42									3/8" barbed quick disconnect without shut off valve			
											\$ -	
											\$ -	
											\$ -	
REQUISITION TOTAL										\$ 30.63		
Does the project require animal & care approval? Yes _____ No _____ If yes, please provide PACUC #: _____												
Dept. Head/ Advisor/PI:					Business Office Use Only: Conf#					Card #		
Signature					Date					Reconciled:		
Comptroller:					Trans ID#					Received:		
Chemical Order:					Ref. Doc#							
Signature					Date							
Order Placed By:												
Signature					Date							
Is there a discount? Yes _____ No _____ (Fill out the Form 41B) If educational discount, track internally. Has an equipment screening been completed? Yes _____ No _____ (Required for >=\$25,000 on Sponsored Accts, Desired for all other accounts)? Has the Request for Waiver of Competitive Bidding document been completed? Yes _____ No _____ (Required for all single source acquisitions >=\$10,000). Is there proper documentation from the PI approving the purchase (signature, email, other _____)?												

DEPT: EPICS		ARMSTRONG SERVICE CENTER			
Date: _____		PURCHASE REQUEST			
<div style="border: 1px solid black; width: 30px; height: 20px; display: inline-block;"></div> Vendor Information				Deliver To:	
VENDOR NAME Filters		Purpose/Specific Benefit to the Project:		Name: EPICS/Cathy Noerenberg	
Contact Person filters.com		Materials for GDT- Colombia		Building: Neil Armstrong Hall of Engr	
ADDRESS				Room: 1200	
CITY				Phone: 765-496-1068	
STATE ZIP				Email: epics@purdue.edu	
VENDOR PHONE#					
VENDOR FAX #					

Account(s) Information		Leagcy Account#		Project Period		Account Balance	Date	Special Shipping Instructions
Fund	Cost Center	Internal Order	G/L Account	\$ Amount or %	Begin Date	Expiration		
Student Name	Jenny Zenobio	Email	jzenobio@purdue.edu	Team	WRM Team			

CATALOG #	ITEM DESCRIPTION	UNIT	QUAN	UNIT COST	TOTAL COST
PX01-10	1 Micron, 10" Spun-Bonded Polypropylene Cartridge Filter	UNIT	2	\$1.70	\$3.40
					\$0.00
					\$0.00
					\$0.00
					\$0.00
					\$0.00
					\$0.00
REQUISITION TOTAL					\$3.40

Does the project require animal & care approval? Yes _____ No _____ If yes, please provide PACUC #: _____

Advisor/ Comptroller: Chemical Order: EPICS Admin : <div style="background-color: #90ee90; padding: 2px;">NEW!</div>		Business Office Use Only: Conf# Trans ID# Ref. Doc# Is there a discount? Yes _____ No _____ (Fill out the Form 41B) If educational discount, track internally. Has an equipment screening been completed? Yes _____ No _____ (Required for >=\$25,000 on Sponsored Accts, Desired for all other accounts)? Has the Request for Waiver of Competitive Bidding document been completed? Yes _____ No _____ (Required for all single source acquisitions >=\$10,000). Is there proper documentation from the PI approving the purchase (signature, email, other _____)?	Card # Reconciled: Received:
	Signature _____ Date _____		
	Signature _____ Date _____		
	Signature _____ Date _____		

Will you be driving? If so please check the box and sign on the line provided. Driver Certification: By checking this box and signing this form, I am certifying that I am in compliance with all requirements established by the 'Use of Vehicles for University Business' policy.

Appendix D: UV Disinfection Team Order Requests

PURCHASE REQUEST					SC #							
					PO #							
Vendor Information Vendor: Alfa Aesar Contact: www.alfa.com/en/GP100W_pgm?dsstk=031124 Address: City: State: ZIP: Phone: Fax:					Purpose/Specific Benefit to the Project: Materials for GDT- Colombia- Actinometry experiment				Deliver To: Name: Building: Room: Phone: Email: Professor:			
Account Information Fund Cost Center Internal Order G/L Account \$ Amount or %					Legacy Account #		Project Period Begin Date Expiration		Account Balance Date		Special Shipping Instructions	
CATALOG #		ITEM DESCRIPTION					UNIT	QUAN	UNIT COST	TOTAL COST		
Model: MFCD00150450 CAS: 5936-11-8 UN# UN3288 EINECS: 238-954-7		25g of 31124 Potassium Trioxalatoferate(III) Trihydride					un.	1	\$51.50	\$ 51.50		
REQUISITION TOTAL									\$ 51.50			
Does the project require animal & care approval? Yes _____ No _____ If yes, please provide PACUC #: _____												
Dept. head/ Advisor/PI:		Signature				Date				Business Office Use Only: Conf# Trans ID# Ref. Doc# Is there a discount? Yes _____ No _____ (Fill out the Form 41B) If educational discount, track internally. Has an equipment screening been completed? Yes _____ No _____ (Required for >=\$25,000 on Sponsored Accts, Desired for all other accounts)? Has the Request for Waiver of Competitive Bidding document been completed? Yes _____ No _____ (Required for all single source acquisitions >=\$10,000). Is there proper documentation from the PI approving the purchase (signature, email, other _____)?		
Comptroller:		Signature				Date						
Chemical Order:		Signature				Date						
Placed By:		Signature				Date						
										Card # Reconciled: Received:		

PURCHASE REQUEST					SC # _____																																																													
					PO # _____																																																													
Vendor Information					Deliver To:																																																													
Vendor: 1000bulbs			Purpose/Specific Benefit to the Project: Materials for GDT- Colombia		Name: _____																																																													
Contact: http://www.1000bulbs.com					Building: _____																																																													
Address: _____					Room: _____																																																													
City: _____					Phone: _____																																																													
State: _____ ZIP: _____					Email: _____																																																													
Phone: _____					Professor: _____																																																													
Fax: _____					Special Shipping Instructions																																																													
Account Information			Legacy Account # _____																																																															
Fund	Cost Center	Internal Order	G/L Account	\$ Amount or %			Project Period Begin Date Expiration	Account Balance Date																																																										
<table border="1" style="width:100%; border-collapse: collapse;"> <tr> <th style="text-align: left;">CATALOG #</th> <th style="text-align: left;">ITEM DESCRIPTION</th> <th style="text-align: center;">UNIT</th> <th style="text-align: center;">QUAN</th> <th style="text-align: center;">UNIT COST</th> <th style="text-align: center;">TOTAL COST</th> </tr> <tr> <td>Model: PL-L18W/TUV SKU: AU-LPLL18UV</td> <td>2G11 4 Pin Base - PLT PL-L18W/TUV - Germicidal Fluorescent</td> <td style="text-align: center;">un.</td> <td style="text-align: center;">1</td> <td style="text-align: right;">\$10.71</td> <td style="text-align: right;">\$ 10.71</td> </tr> <tr> <td>Model: LC-25-TP-I SKU: BA-LC25TPI</td> <td>Advance LC-25-TP-I - Lamp - F25T12 - 120 Volt - Preheat Start - 0.9 Ballast Factor</td> <td style="text-align: center;">un.</td> <td style="text-align: center;">1</td> <td style="text-align: right;">\$17.59</td> <td style="text-align: right;">\$ 17.59</td> </tr> <tr> <td>Model: 286-SC SKU: SOCK-EG286SC</td> <td>75 Watt - CFL Socket -PLT 286-SC 4 Pin 2G11 Base - Screw Mounted Lampholder</td> <td style="text-align: center;">un.</td> <td style="text-align: center;">1</td> <td style="text-align: right;">\$2.06</td> <td style="text-align: right;">\$ 2.06</td> </tr> <tr> <td>Model: EG787-2 SKU: SOCK-EG7872</td> <td>Support Clup for Long Twin Tube Lamps - PLT EG787-2</td> <td style="text-align: center;">un.</td> <td style="text-align: center;">1</td> <td style="text-align: right;">\$0.82</td> <td style="text-align: right;">\$ 0.82</td> </tr> <tr><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td></tr> <tr> <td colspan="5">REQUISITION TOTAL</td> <td style="text-align: right;">\$ 31.18</td> </tr> </table>							CATALOG #	ITEM DESCRIPTION	UNIT	QUAN	UNIT COST	TOTAL COST	Model: PL-L18W/TUV SKU: AU-LPLL18UV	2G11 4 Pin Base - PLT PL-L18W/TUV - Germicidal Fluorescent	un.	1	\$10.71	\$ 10.71	Model: LC-25-TP-I SKU: BA-LC25TPI	Advance LC-25-TP-I - Lamp - F25T12 - 120 Volt - Preheat Start - 0.9 Ballast Factor	un.	1	\$17.59	\$ 17.59	Model: 286-SC SKU: SOCK-EG286SC	75 Watt - CFL Socket -PLT 286-SC 4 Pin 2G11 Base - Screw Mounted Lampholder	un.	1	\$2.06	\$ 2.06	Model: EG787-2 SKU: SOCK-EG7872	Support Clup for Long Twin Tube Lamps - PLT EG787-2	un.	1	\$0.82	\$ 0.82																									REQUISITION TOTAL					\$ 31.18
CATALOG #	ITEM DESCRIPTION	UNIT	QUAN	UNIT COST	TOTAL COST																																																													
Model: PL-L18W/TUV SKU: AU-LPLL18UV	2G11 4 Pin Base - PLT PL-L18W/TUV - Germicidal Fluorescent	un.	1	\$10.71	\$ 10.71																																																													
Model: LC-25-TP-I SKU: BA-LC25TPI	Advance LC-25-TP-I - Lamp - F25T12 - 120 Volt - Preheat Start - 0.9 Ballast Factor	un.	1	\$17.59	\$ 17.59																																																													
Model: 286-SC SKU: SOCK-EG286SC	75 Watt - CFL Socket -PLT 286-SC 4 Pin 2G11 Base - Screw Mounted Lampholder	un.	1	\$2.06	\$ 2.06																																																													
Model: EG787-2 SKU: SOCK-EG7872	Support Clup for Long Twin Tube Lamps - PLT EG787-2	un.	1	\$0.82	\$ 0.82																																																													
REQUISITION TOTAL					\$ 31.18																																																													
Does the project require animal & care approval? Yes _____ No _____ If yes, please provide PACUC #: _____																																																																		
Dept. Head/ Advisor/PI:		Signature _____ Date _____			Business Office Use Only: Conf# _____ Trans ID# _____ Ref. Doc# _____		Card # _____																																																											
							Reconciled: _____																																																											
Comptroller:		Signature _____ Date _____			Ref. Doc# _____		Received: _____																																																											
Chemical Order:		Signature _____ Date _____			Is there a discount? Yes _____ No _____ (Fill out the Form 41B) If educational discount, track internally. Has an equipment screening been completed? Yes _____ No _____ (Required for >=\$25,000 on Sponsored Accts, Desired for all other accounts)? Has the Request for Waiver of Competitive Bidding document been completed? Yes _____ No _____ (Required for all single source acquisitions >=\$10,000). Is there proper documentation from the PI approving the purchase (signature, email, other _____)?																																																													
Order Placed By:		Signature _____ Date _____																																																																

PURCHASE REQUEST											
Vendor Information Vendor: McMaster-Carr Contact: mcmastercarr.com Address: City: State: ZIP: Phone: Fax:					Purpose/Specific Benefit to the Project: Materials for GDT- Colombia					SC #	
										PO #	
										Deliver To:	
										Name:	
										Building:	
Room:		Phone:		Email:		:		Special Shipping Instructions			
Fax:											
Account Information					Legacy Account #					Special Shipping Instructions	
Fund	Cost Center	Internal Order	G/L Account	\$ Amount or %	Project Period		Account Balance	Date			
					Begin Date	Expiration					
CATALOG #		ITEM DESCRIPTION				UNIT	QUAN	UNIT COST	TOTAL COST		
43005T3		Rectangle High Density Polyethylene 20 L				UNIT	1	\$ 29.77	\$ 29.77		
3736K2		Polyethylene 3/4" pipe size through wall fittings threaded, female x threaded female				UNIT	2	\$ 13.11	\$ 26.22		
8674T42		Miniature through wall fittings				UNIT	1	\$ 8.45	\$ 8.45		
4089K61		ABS thermoplastic case general service pressure gauge				UNIT	1	\$ 9.20	\$ 9.20		
4269T32		2 gallon pail white				UNIT	6	\$ 4.13	\$ 24.78		
8325K17		Machinable and Bendable Clear PETG (1 Six Foot Rod)				1 Unit	6 (ft)	\$ 0.59	\$ 3.54		
REQUISITION TOTAL								\$ 101.96			
Does the project require animal & care approval? Yes _____ No _____ If yes, please provide PACUC #:											
Dept. Head/ Advisor/PI:					Business Office Use Only:			Card #			
Signature					Conf#			Reconciled:			
Date					Trans ID#						
Comptroller:					Ref. Doc#						
Signature					Date			Received:			
Chemical Order:											
Signature					Date						
Order Placed By:					Is there a discount? Yes _____ No _____ (Fill out the Form 41B) If educational discount, track internally.						
Signature					Has an equipment screening been completed? Yes _____ No _____ (Required for >=\$25,000 on Sponsored Accts, Desired for all other accounts)?						
Date					Has the Request for Waiver of Competitive Bidding document been completed? Yes _____ No _____ (Required for all single source acquisitions >=\$10,000).						
					Is there proper documentation from the PI approving the purchase (signature, email, other _____)?						

PURCHASE REQUEST										SC #			
										PO #			
Vendor Information					Purpose/Specific Benefit to the Project:					Deliver To:			
Vendor: United Art & Education					Materials for GDT- Colombia- Build Items					Name:			
Contact: http://www.unitednow.com/product/626/krylon-uv										Building:			
Address: P.O. Box 9219										Room:			
City: Fort Wayne										Phone:			
State: Indiana ZIP: 46899-9219										Email:			
Phone: 1-800-322-3247										Professor:			
Fax:										Special Shipping Instructions			
Account Information					Legacy Account # _____								
Fund	Cost Center	Internal Order	G/L Account	\$ Amount or %	Project Period		Account Balance	Date					
					Begin Date	Expiration							
CATALOG #													
ITEM DESCRIPTION										UNIT	QUAN	UNIT COST	TOTAL COST
KRY-1305 Krylon UV - Resistant Clear Acrylic Coating										un.	1	\$7.35	\$ 7.35
KRY-1602 Krylon Indoor/Outdoor Spray Paint Ultra-Flat Black										un.	1	\$6.50	\$ 6.50
REQUISITION TOTAL												\$	13.85
Does the project require animal & care approval? Yes _____ No _____ If yes, please provide PACUC #: _____													
Dept. Head:					Business Office Use Only:					Card #			
Advisor/PI:					Conf#								
					Signature _____ Date _____					Reconciled:			
Comptroller:					Trans ID#					Received:			
					Signature _____ Date _____								
Chemical Order:					Ref. Doc#								
					Signature _____ Date _____								
Placed By:					Is there a discount? Yes _____ No _____ (Fill out the Form 41B) If educational discount, track internally.								
					Signature _____ Date _____								
					Has an equipment screening been completed? Yes _____ No _____ (Required for >=\$25,000 on Sponsored Accts, Desired for all other accounts)?								
					Has the Request for Waiver of Competitive Bidding document been completed? Yes _____ No _____ (Required for all single source acquisitions >=\$10,000).								
					Is there proper documentation from the PI approving the purchase (signature, email, other _____)?								

Appendix E: Redesign Team Order Requests

PURCHASE REQUEST										SC #		
										PO #		
Vendor Information					Purpose/Specific Benefit to the Project:					Deliver To:		
Vendor: McMaster-Carr					Materials to be used in the construction of summer implementation of filters into 15 schools.					Name:		
Contact: http://www.mcmaster.com/										Building:		
Address: 200 New Canton Way										Room:		
City: Robbinsville										Phone:		
State: New Jersey ZIP: 08691-2343										Email:		
Phone: (609) 689-3415 / (609) 259-8900										Professor:		
Fax: (609) 259-3575 / (609) 689-3280					Special Shipping Instructions							
Account Information		Legacy Account #			Project Period		Account Balance		Date			
Fund	Cost Center	Internal Order	G/L Account	\$ Amount or %	Begin Date	Expiration						
CATALOG #							ITEM DESCRIPTION		UNIT	QUAN	UNIT COST	TOTAL COST
5113K34							Flexible Low-Temperature White EVA Tubing - 1/4" ID - 3/8" OD - 1/16" Wall		ft	200	\$ 0.30	\$ 60.00
69915K53							Nylon Liquid-Tight Cord Grip- 0.84" Thread OD - (0.24"-0.47") Cord Dia. Range		qty	70	\$ 2.74	\$ 191.80
9555K26							NSF-Certified Buna-N O-Ring- 13/16" ID - 1" OD - 3/32" W 25/pack		pack	6	\$ 4.82	\$ 28.92
71295K62							Solid Colored Nylon Cable Tie 4-1/8" Length, 7/8" Bundle Diameter 100/pack		pack	2	\$ 2.16	\$ 4.32
95611A030							Chemical-Resistant PVC Washer - 3/8" ID - 7/8" - OD 50/pack		pack	2	\$ 9.35	\$ 18.70
97860A320							Stainless Steel Small-Head Nails- 2.25"L 13 Gage 200/pack		pack	3	\$ 19.23	\$ 57.69
5016K744							White Polypropylene Compression Tube Fitting Tee- 3/8" Tube OD - 5/8"-20 NPT - 5/pack		pack	8	\$ 7.54	\$ 60.32
REQUISITION TOTAL											\$ 421.75	
Does the project require animal & care approval? Yes _____ No _____ If yes, please provide PACUC #: _____												
Dept. Head/ Advisor/PI:					Business Office Use Only:					Card #		
Signature _____					Conf# _____							
Date _____					Trans ID# _____					Reconciled:		
Comptroller:					Ref. Doc# _____					Received:		
Signature _____												
Date _____												
Chemical Order:												
Signature _____												
Date _____												
Order Placed By:												
Signature _____												
Date _____												
Is there a discount? Yes _____ No _____ (Fill out the Form 41B) If educational discount, track internally. Has an equipment screening been completed? Yes _____ No _____ (Required for >=\$25,000 on Sponsored Accts, Desired for all other accounts)? Has the Request for Waiver of Competitive Bidding document been completed? Yes _____ No _____ (Required for all single source acquisitions >=\$10,000). Is there proper documentation from the PI approving the purchase (signature, email, other _____)?												

					PURCHASE REQUEST		SC #						
							PO #						
Vendor Information					Deliver To:								
Vendor:		McMaster-Carr			Purpose/Specific Benefit to the Project: Tubing of two different sizes with all of the associated hardware components necessary for the complete construction of a bench scale slow sand filter. Three different tubing material selector packages for design purposes.		Name:						
Contact:		http://www.mcmaster.com/					Building:						
Address:		200 New Canton Way					Room:						
City:		Robbinsville					Phone:						
State:		New Jersey					Email:						
Phone:		(609) 689-3415 / (609) 259-8900					r:						
Fax:		(609) 259-3575 / (609) 689-3280			Special Shipping Instructions								
Account Information		Legacy Account #											
Fund	Cost Center	Internal Order	G/L Account	\$ Amount or %						Project Period Begin Date	Expiration	Account Balance	Date

CATALOG #	ITEM DESCRIPTION	UNIT	QUAN	UNIT COST	TOTAL COST
5113K33	Flexible Low-Temperature White EVA Tubing - 3/16" ID - 5/16" OD - 1/16" Wall	ft	25	\$ 0.24	\$ 6.00
5113K34	Flexible Low-Temperature White EVA Tubing - 1/4" ID - 3/8" OD - 1/16" Wall	ft	25	\$ 0.30	\$ 7.50
69915K51	Nylon Liquid-Tight Cord Grips (NEMA 6) - 0.68" Thread OD - 0.16"-0.31" Cord Dia.	each	10	\$ 2.82	\$ 28.20
69915K53	Nylon Liquid-Tight Cord Grips (NEMA 6) - 0.84" Thread OD - 0.24"-0.47" Cord Dia.	each	10	\$ 3.24	\$ 32.40
5121K751	White Polypropylene Single-Barbed Tube Fittings - 3/16" Tube ID - High Temperature - 10/pack	pack	1	\$ 4.79	\$ 4.79
5121K761	White Polypropylene Single-Barbed Tube Fittings - 1/4" Tube ID - High Temperature - 10/pack	pack	1	\$ 5.06	\$ 5.06
5117K15	Clear Polycarbonate Single-Barbed Tube Fittings - 3/16" Tube ID - 10/pack	pack	1	\$ 11.46	\$ 11.46
5117K16	Clear Polycarbonate Single-Barbed Tube Fittings - 1/4" Tube ID - 10/pack	pack	1	\$ 12.42	\$ 12.42
5016K777	White Polypropylene Compression Tube Fittings for Drinking Water - 5/16" Tube OD - 5/pack	pack	2	\$ 11.09	\$ 22.18
5016K744	White Polypropylene Compression Tube Fittings for Drinking Water - 3/8" Tube OD - 5/pack	pack	2	\$ 11.60	\$ 23.20
5016K377	White Polypropylene Tube Supports for Drinking Water - 5/16" Tube OD - 10/pack	pack	1	\$ 1.41	\$ 1.41
5016K344	White Polypropylene Tube Supports for Drinking Water - 3/8" Tube OD - 10/pack	pack	1	\$ 1.71	\$ 1.71
3077K1	Tubing Material Selector Pack - Plastic Pack I	pack	1	\$ 3.58	\$ 3.58
3077K2	Tubing Material Selector Pack - Plastic Pack II	pack	1	\$ 10.65	\$ 10.65
3077K3	Tubing Material Selector Pack - Rubber and Blended Rubber/Plastic	pack	1	\$ 7.30	\$ 7.30
REQUISITION TOTAL					\$ 177.86

Does the project require animal & care approval? Yes _____ No _____ If yes, please provide PACUC #: _____

Dept. Head/ Advisor/PI:		Business Office Use Only: Conf#	Card #
	Signature _____ Date _____		
Comptroller:		Trans ID#	Reconciled:
	Signature _____ Date _____	Ref. Doc#	Received:
Chemical Order:		Is there a discount? Yes _____ No _____ (Fill out the Form 41B) If a educational discount, track internally. Has an equipment screening been completed? Yes _____ No _____ (Required for >-\$25,000 on Sponsored Accts. Desired for all other accounts)? Has the Request for Waiver of Competitive Bidding document been completed? Yes _____ No _____ (Required for all single source acquisitions >-\$10,000). Is there proper documentation from the PI approving the purchase (signature, email, other _____)?	
Order Placed By:			
	Signature _____ Date _____		

PURCHASE REQUEST										SC #	
										PO #	
Vendor Information					Purpose/Specific Benefit to the Project:					Deliver To:	
Vendor: McMaster-Carr					Materials for GDT- Colombia: wire mesh needed to build sand sieves					Name:	
Contact: http://www.mcmaster.com/										Building:	
Address: 9630 Norwalk Blvd.										Room:	
City: Sante Fe Springs										Phone:	
State: CA ZIP: 90670-2932										Email:	
Phone: (562) 692-5911										Professor:	
Fax: (562) 695-2323										Special Shipping Instructions	
Account Information			Legacy Account # _____			Project Period		Account Balance	Date		
Fund	Cost Center	Internal Order	G/L Account	\$ Amount or %	Begin Date	Expiration					
CATALOG #	ITEM DESCRIPTION							UNIT	QUAN	UNIT COST	TOTAL COST
9230T79	HI-Volume Particle-Sifting Woven Wire Cloth 304 SS, 60 X 60 Mesh, .0045" Wire Diameter (36" wide, 72" long)							sq. ft.	18	\$ 3.95	\$ 71.10
9230T74	HI-Volume Particle-Sifting Woven Wire Cloth 304 SS, 24 X 24 Mesh, .0075" Wire Diameter (36" wide, 72" long)							sq. ft.	18	\$ 4.07	\$ 73.26
9217T42	Easy-to-Form Galvanized Steel Wire Cloth Welded, 4 X 4 Mesh, .025" Wire Diameter (36" Wide, 96" long)							sq ft.	24	\$ 0.84	\$ 20.16
REQUISITION TOTAL										\$ 164.52	
Does the project require animal & care approval? Yes _____ No _____ If yes, please provide PACUC #: _____											
Dept. Head/ Advisor/PI:					Business Office Use Only:					Card #	
Comptroller:					Conf#					Reconciled:	
Chemical Order:					Trans ID#					Received:	
Order Placed By:					Ref. Doc#						
Is there a discount? Yes _____ No _____ (Fill out the Form 41B) If educational discount, track internally. Has an equipment screening been completed? Yes _____ No _____ (Required for >=\$25,000 on Sponsored Accts. Desired for all other accounts)? Has the Request for Waiver of Competitive Bidding document been completed? Yes _____ No _____ (Required for all single source acquisitions >=\$10,000). Is there proper documentation from the PI approving the purchase (signature, email, other _____)?											

PURCHASE REQUEST										SC #	
										PO #	
Vendor Information					Purpose/Specific Benefit to the Project:					Deliver To:	
Vendor: McMaster-Carr					Materials for GDT- Colombia: Wire to suspend diffuser plate from top of bucket					Name:	
Contact: http://www.mcmaster.com/										Building:	
Address: 600 N. County Line Rd.										Room:	
City: Elmhurst										Phone:	
State: IL ZIP: 60126-2081										Email:	
Phone: (630) 833-0300										Professor:	
Fax: (630) 834-9427										Special Shipping Instructions	
Account Information			Legacy Account #			Project Period		Account Balance			
Fund	Cost Center	Internal Order	G/L Account	\$ Amount or %	Begin Date	Expiration		Date			
CATALOG #		ITEM DESCRIPTION					UNIT	QUAN	UNIT COST	TOTAL COST	
8860K12		Stainless Steel Wire (Type 304) Soft Temper, .020" Dia, 1/4-lb Spool, 230' Spool					un.	1	\$ 8.85	\$ 8.85	
8860K14		Stainless Steel Wire (Type 304) Soft Temper, .032" Dia, 1/4-lb Spool, 91' Spool					un.	1	\$ 6.10	\$ 6.10	
8860K75		Stainless Steel Wire (Type 304) Soft Temper, .045" Dia, 1/4-lb Spool, 46' Spool					un.	1	6.37	6.37	
REQUISITION TOTAL									\$ 21.32		
Does the project require animal & care approval? Yes _____ No _____ If yes, please provide PACUC #: _____											
Dept. Head/ Advisor/PI:					Business Office Use Only: Conf# Trans ID# Ref. Doc#				Card #		
									Reconciled:		
Comptroller:									Received:		
Chemical Order:											
Order Placed By:											
					Is there a discount? Yes _____ No _____ (Fill out the Form 41B) If educational discount, track internally. Has an equipment screening been completed? Yes _____ No _____ (Required for >=\$25,000 on Sponsored Accts, Desired for all other accounts)? Has the Request for Waiver of Competitive Bidding document been completed? Yes _____ No _____ (Required for all single source acquisitions >=\$10,000). Is there proper documentation from the PI approving the purchase (signature, email, other _____)?						