INVESTIGATIONS IN TO THE EFFECT OF INFLUENT TOTAL ORGANIC CARBON CONCENTRATIONS ON BIOSAND WATER FILTRATION EFFICIENCIES AND IMPLEMENTATION IMPLICATIONS IN HONDURAS

By

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Title of Study: INVESTIGATIONS IN TO THE EFFECT OF INFLUENT TOTAL ORGANIC CARBON CONCENTRATIONS ON BIOSAND WATER FILTRATION EFFICIENCIES AND IMPLEMENTATION IMPLICATIONS IN HONDURAS

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Abstract: This document is a compilation of three papers, made for publication, detailing the findings from research conducted in a laboratory and in Honduras regarding the implementation and monitoring of the household, point-of-use, water treatment technology known as intermittent slow sand filters (ISSF), also known as biosand filters (BSF). While laboratory results have shown biosand filters can provide a high degree of biological removal from contaminated water, field results can vary greatly. Three trials using six 1/30th scale volume filters and a full scale filter were conducted, varying total organic carbon (TOC) and biodegradable dissolved organic carbon (BDOC). Fecal coliform (FC) removals, nitrate concentrations, and sulfate concentrations were analyzed to better understand how aerobic and anaerobic conditions affect filtration efficiency. Higher organic loadings had a higher oxygen demand on the "schmutzdecke" layer of the sand filters. Filters with a standing head DO of 3mg/L or less had signs of the filters turning anaerobic, conditions unconducive to pathogen removal. Filters with TOC loadings higher than 20 mg/L and BDOC loadings higher than 10 mg/L can turn anaerobic, generating more anaerobic organisms than are removed. By working with communities around the Campana region of Honduras, wooden molds were developed for the construction BSFs. Entirely sourced from in-country materials and labor, a local production facility and foreman was established to provide the filters and clean water information to the surrounding communities. Rotary style sieves were developed to process the filtration medium, reducing the labor required per filter. Under the moniker of AguaSeis filters, the filters were sold for $25.00 USD with a material cost of $7.50 USD per filter. The concerted effort of having a sustained, local BSF production and adoption was carried out between March 2011 and January 2014. During that time, 46 filters were made in-country with 72% still in operation. An averaged removal rate of total coliforms, sampled from 27 filters, was found to be 91%.

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CHAPTER I

IMPETUS FOR BIOSAND RESEARCH

COMPOSITION OF THESIS

This research is presented in three separate chapters, originally written for publication outside of this collection, covering the literature review and findings relevant to each component addressed. Chapter II details the findings from laboratory experiments varying total organic carbon (TOC) loading through lab scale and full scale biosand filters (BSF)s. Chapter III contains the field findings from attempting to establish a BSF production facility in the Campana region of Honduras. Chapter IV contains the assessment of BSFs operating in Honduras over the course of a few years. Further publications related to this research can be found at www.aguaseis.org. The content of this first chapter is to explain preliminary details that would not normally be included in environmental engineering publications, but gives a necessary introduction in to why.

BACKGROUND INTO BIOSAND FILTERS

Poor quality drinking water is a global problem, gravely affecting the developing world and contributing to approximately 1.8 million deaths per year and 1.1 billion without access to “improved” drinking supplies (WHO, 2007) (Ashbolt, 2004). Consequences from having improperly designed water systems can adversely affect the health and economic productivity of a nation (Poverty-Environment Partnership, 2014). In countries without well maintained water systems, point-of-use water (POU) treatment technology can be an effective solution to meeting the water quality needs of communities, with the potential to prevent 94% of worldwide diarrheal cases (Sobsey, Stauber, Casanova, Brown, & Elliott Mark, 2008), (WHO, 2007). Most of these interventions require a consumable product that must be purchased, failing to provide clean water during periods of financial strife. Intermittent slow sand filters (ISSF), commonly referred to as biosand filters (BSF), are POU water filters that are installed in the household and can be used continuously without outside intervention (Sobsey, Stauber, Casanova, Brown, & Elliott Mark, 2008). By retaining the microorganisms of a contaminated water supply within a simple sand medium, BSF technology has been shown to have as much as 4 $\log_{10}$ removal of *E.coli*, and 95% removal of bacteriophages (Elliott, Sauber, Koksal, DiGiano, & Sobsey, 2008).

The original BSF filter was invented in 1990 by Dr. David Manz, out of Calgary, Canada. After an initial successful implementation of the technology, he later founded the non-profit organization known as the Center for Affordable Water and Sanitation Technology (CAWST). As a result of the efforts of CAWST and other NGOs such as Samaritan's Purse, there are now over 200,000 BSFs installed in over 70 countries (Manz, 2007). The design is based off of the traditional slow sand filters (SSF), used in some municipalities for cleaning drinking water. By retaining organisms within a sand matrix, and given sufficient time, pathogens will be adsorbed on to the surface of the sand medium and subsequently oxidized by other microorganisms (Metcalf & Eddy, 2003). The operation parameters that govern SSF efficiencies differs from the BSF in a few ways. First, SSFs operate continuously while BSFs are intermittent. This means SSF performance relies on hydraulic loading rates to determine retention time while BSFs use batch volume loading rates and rest periods for retention times (Huisman & Wood, 1974). Second, because SSFs are continuously fed, the sand column is modeled to be completely aerobic. This may not be true for BSFs, where the sand would have a gradient of aerobic to anaerobic activities as the oxygen is consumed down the column. Third, because the surface area to volume ratio for SSFs are larger than BSFs, the aerobic fraction of the BSF is that much more reduced. The closer a BSF operates to an SSF, the better the pathogen removal, as evidenced when BSFs are operating continuously (Young-Rojanschi & Madramootoo, 2013). The research detailed in this paper kept these differences in mind during the design phase.

THEORETICAL OXYGEN DEMAND

All of the literature regarding slow sand filters and their intermittent counterparts indicates the pathogen removal capabilities of these systems are reliant on a biologically active layer contained in the sand layers (Huisman & Wood, 1974). Despite this fact, most previous research has treated the filter as normal sand filters modeled for particulate removal as evidenced by the prevalent use of turbidity and effluent velocity as the primary means to determine filtration efficiency (CAWST, 2012). Biological removal has been determined in broad strokes by analyzing total coliform and *E. coli* removal. However, what has not been examined is how influent composition can affect filtration efficiencies of the biosand filter because of changes in the biological characteristics of the biologically active layers.

In developing countries, it is common for wastewater contamination to enter drinking water supplies, hence the prevalence of fecal-oral type diseases in these countries (Ashbolt, 2004). That would mean the BSF would be better analyzed as a wastewater treatment device, hinged on the organic composition of the influent. As such, the primary objective of the BSF should be to oxidize dissolved and particulate biodegradable components in to inert products (Metcalf & Eddy, 2003). If the influent is modeled as domestic wastewater, with the substrate generalized to $C_{10}H_{19}O_3N$, and the electron acceptor is oxygen, then the stoichiometry of the reaction can be calculated as seen in *Equation 1*. This also gives a cellular yield of 0.4479 gVSS/gCOD. This is a measure of grams of cells produced per gram of chemical oxygen demand. This means the aerobic growth of cells would be dependent on available oxygen. If the oxygen demand exceeds the oxygen transfer of the water, then it stands to reason higher bioactivity could cause cellular die off, reducing pathogenic removal capabilities.

$$0.02C_{10}H_{19}O_3N + 0.1036\ O_2 + 0.0117NH_4^+ + 0.0117HCO_3^-$$

$$\rightarrow 0.0317C_5H_7O_2N + 0.1325\ H_2O + 0.0532CO_2$$

Equation 1: Generalized Wastewater Oxidation Stoichiometry

The theoretical amount of oxygen needed is a real number required by the filters. By measuring the TOC of the influent, this gives an estimate of the amount of substrate available to the microorganisms within the BSF. At higher concentrations of TOC, the amount of available oxygen, in terms of the rate of oxygen entering the water from the atmosphere, will not be high enough to sustain aerobic activity. Previous research has not adequately explained how a filter will function under these conditions. Chapter II will attempt to experimentally determine how excess assimilable dissolved organic carbon will affect the filtration capabilities of the BSF technology.

The next chapter will delve in to laboratory studies to assess how higher organic loadings can affect filtration efficiency. The overall goal of this paper is to demonstrate the TOC laboratory research in Chapter II, show the efforts contributing to the establishment of a BSF production facility in Honduras conducted by the Oklahoma State University Engineers Without Borders student chapter in Chapter III, and the longitudinal assessment of those filters in Honduras in Chapter IV.

CHAPTER II

EFFECTS OF TOTAL ORGANIC CARBON LOADING ON BIOSAND FILTRATION EFFICIENCIES

HIGHLIGHTS

- Varying total organic carbon (TOC) concentrations were loaded in to biosand filters.
- 1/30th scale volume filters made of polycarbonate tubes were built for bench scale testing.
- Filters are stratified by biolayers depending on aerobic and anaerobic conditions.
- TOC loadings higher than 20 mg/L can cause filters to generate anaerobes.
- Dissolved oxygen tests of field filters can confirm excessive TOC loadings.

ABSTRACT

Intermittent slow sand filters, also known as biosand filters, are a point-of-use water filtration technology for household use. While laboratory results have shown biosand filters can provide a high degree of biological removal from contaminated water, field results can vary greatly. The effects of filter construction and operations have been thoroughly studied, but influent organic loading has not. Three trials using six 1/30th scale filters and a full scale filter were conducted, varying total organic carbon (TOC) and

biodegradable dissolved organic carbon (BDOC). Fecal coliform (FC) removals, nitrate concentrations, and sulfate concentrations were analyzed to better understand how aerobic and anaerobic conditions affect filtration efficiency. Higher organic loadings had a higher oxygen demand on the “schmutzdecke” layer of the sand filters. Filters with a supernatant dissolved oxygen (DO) measurement of 3mg/L or less had signs of the filters turning anaerobic, conditions unconducive to pathogen removal. Filters with TOC loadings higher than 20 mg/L and BDOC loadings higher than 10 mg/L can turn anaerobic, generating more anaerobic organisms than are removed.

INTRODUCTION

Poor quality drinking water is a global problem, gravely affecting the developing world and contributing to approximately 1.8 million deaths per year and 1.1 billion without access to “improved” drinking supplies (WHO, 2007) (Ashbolt, 2004). Consequences from having improperly designed water systems can adversely affect the health and economic productivity of a nation (Poverty-Environment Partnership, 2014). In countries without well maintained water systems, point-of-use water (POU) treatment technology can be an effective solution to meeting the water quality needs of communities, with the potential to prevent 94% of worldwide diarrheal cases (Sobsey, Stauber, Casanova, Brown, & Elliott Mark, 2008), (WHO, 2007). Most of these interventions require a consumable product that must be purchased, failing to provide clean water during periods of financial strife. Intermittent slow sand filters (ISSF), commonly referred to as biosand filters (BSF), are POU water filters that are installed in the household and can be used continuously without outside intervention (Sobsey, Stauber, Casanova, Brown, & Elliott Mark, 2008). By retaining the microorganisms of a contaminated water supply within a simple sand medium, BSF technology has been shown to have as much as 4 $\log_{10}$ removal of *E.coli*, and 95% removal of bacteriophages (Elliott, Sauber, Koksal, DiGiano, & Sobsey, 2008).

The most common BSF is constructed out of concrete, but plastic versions are available for purchase (Lea, 2008). The concrete configuration proposed by the Centre for Affordable Water and Sanitation Technology (CAWST), consists of a three foot tall concrete basin containing four inches of gravel at the bottom and fine sand, sized 16 to 20mm, to form the filtration media (Lea, 2008). Filters of this size can be effective at processing 15 to 20 gallons of water per day. The outlet is made of a PVC pipe two inches taller than the total height of the filtration media, using hydrostatic pressure to ensure the standing water level in the filter does not decrease below the sand layer (Lea, 2008). Previous research has contended optimal pathogenic removal can be achieved through the use of finer sand and longer retention times (Jenkins, Tiwari, & Darby, 2011). The combination of these two factors allow for the aerobically active biolayer, or “schmutzdecke” of the sand surface, to better develop, increasing the filtration capabilities of the filter (Elliott, Sauber, Koksal, DiGiano, & Sobsey, 2008; Jenkins, Tiwari, & Darby, 2011).

The BSF technology utilizes naturally occurring organisms in a water supply to form a biofilm in the interstitial spaces of the filtration media. Most of the filtration and subsequent biological removal of pathogens and viruses rely on the vital metabolic occurrences within these biofilms (Elliot, DiGiano, & Sobsey, 2011). The development of biofilms along surfaces can be assessed by measuring the presence of coliforms and other heterotrophic plate count (HPC) bacteria (LeChevallier, Welch, & Smith, 1996).

One study using this method found water purification plants can have regrowth of attached biofilms in pipe systems based on temperature, presence of disinfectants, and assimilable organic carbon (AOC) (LeChevallier, Welch, & Smith, 1996). The AOC of a sample represents only 0.1-9.0% of the total organic carbon (TOC) content, quantifying the fraction of TOC usable by specific mixtures of bacteria (Van der Kooij, 1990). AOC, biodegradable dissolved organic carbon (BDOC), and TOC are all usable indicators of determining the growth potential of a water source (Escobar & Randall, 2001), (Dubber & Gray, 2010).

Because BSFs can be built entirely in country, this technology can be very effective at meeting the long-term, sustained water needs of a communities in developing countries. Performance studies of filters in Haiti over an average of 2.5 years found 97% of filters tested had an effluent of 0-10 *E.Coli* cfu /100mL (Duke, Nordin, & Mazumder, 2006). Another study in rural Nicaragua found 154 out of 199 filters in continued use after 2 years, with a median *E. coli* colony forming units (CFU) removal of 74% (Fiore, Minnings, & Fiore, 2010). Assessment of BSF technology in the Dominican Republic found 90% of 328 households visited were still using filters after one year of operation, with an average of 84-88% bacterial reduction (Aiken, Sauber, Ortiz, & Sobsey, 2011). While the results of field filters are mostly positive, some filters have shown to produce more coliforms in the effluent than influent (Duke, Nordin, & Mazumder, 2006), (Fiore, Minnings, & Fiore, 2010), (Aiken, Sauber, Ortiz, & Sobsey, 2011), (Fewster, Mol, & Weisent-Brandsma, 2004), (Mwabi, Mamba, & Momba, 2013). One study from Cambodia found many filters to have more *E. coli* in the effluent than in the influent. They claimed this was because of inconsistent influent *E. coli* concentrations causing break through, residual organisms in water collection vessels, and outlet tubes that are recontaminating effluent (Water and Sanitation Program, 2010). While poor filtration performance can be attributed to user error or inconsistent construction, few studies have looked at how the influent organic composition can affect filter operation.

This paper will attempt to systematically determine how excessive organic loading rates could adversely impact the biolayers crucial to effective BSF operations. While one study did report a source water TOC of 5 to 8 mg/L, field conditions could vary greatly (Elliot, DiGiano, & Sobsey, 2011). Many waste water treatment plants (WWTP) utilize aerobic conditions to bio-oxidize undesirable constituents of waste water (Reynolds & Richards, 1996). In the regions of the world where BSFs are likely to be implemented, filters are often used to treat drinking water contaminated by human waste water (Ashbolt, 2004). Differences in TOC concentration, depending on severity of the contamination, would change dissolved oxygen concentrations, determining whether aerobic or anaerobic biological process are dominant (Sawyer, McCarty, & Parkin, 2003). Past research has shown continuous operation of filters, rather than intermittent, can improve filtration *Escherichia coli* and viral bacteriophage MS2 removal (Young-Rojanschi & Madramootoo, 2013). This could be because the aerobic biofilms are better developed from the increased DO of a continuous flow. The known advantages of longer retention times and finer sand could be benefitting filter operation by retaining more non-dissolved TOC in the upper aerobic fraction of the sand columns (Jenkins, Tiwari, & Darby, 2011). By analyzing how the influent organic quality of a BSF affects the schmutzdecke and bio-oxidation potential of the device, both in the aerobic and anaerobic fractions, usable data can be extracted to predict how well a BSF might operate in certain conditions. Varied TOC concentrations were loaded in to BSFs to determine how influent TOC affects filtration efficiency.

MATERIALS AND METHODS

Testing Platform

Two configurations of BSF were used for this study, a full scale filter and six $1/30^{th}$ scale filters. Full scale filters constructed in the field have a volume of around 12 liters, a high daily loading volume for laboratory research. To facilitate reproducibility of results, six $1/30^{th}$ scale filters were built for emulation, based on a full scale filter and work done by previous research (Young-Rojanschi & Madramootoo, 2013), (Elliot, DiGiano, & Sobsey, 2011). Each filter was constructed out of impact-resistant polycarbonate tubes, (item number 8585K64, mcmaster.com). Each tube has an outer diameter of two inches, inner diameter of 1 7/8 inches, and 3 feet of length. The filtration medium was made using sand processed the same as in the field, with an effective size (ES) between 0.15 to 0.20 mm and uniformity coefficient (UC) less than 2.5 (CAWST, 2012). The bottom two inches of filtration medium is made of washed gravel, underlying sieved and washed sand. Sampling ports were placed in the tubes with holes drilled in to rubber stoppers, as seen in *Figure 1*. Connected flexible tubing with clamps and plastic syringes allowed for cheap, easy sampling. The standing water above the sand could be visually assessed to maintain the water level. The influent was mixed on the lab bench and then percolated in to the filters, ensuring the biolayer can properly develop without agitation. The full scale filter was constructed from concrete with the configuration as seen in *Figure 2*. The loading and sampling procedures, for the full scale filters, were the same as the $1/30^{th}$ scale filters.

Figure 1: 1/30th Scale BSF Tubes

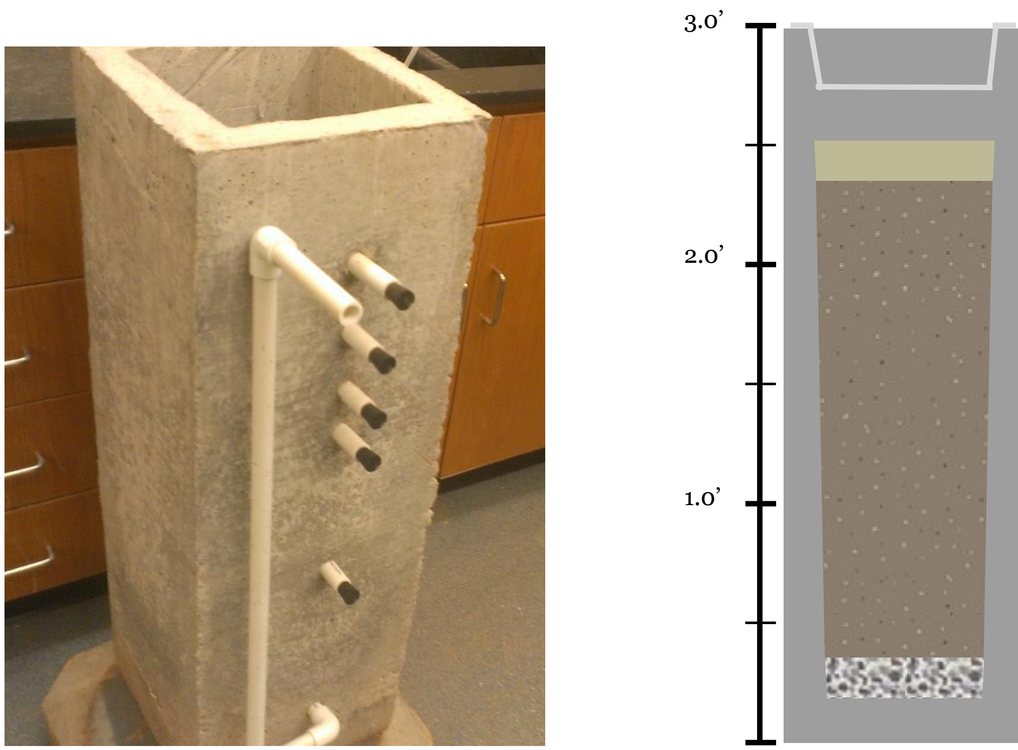

Figure 2: Full Scale Experimental BSF

Hydraulic Loading Formulation

Three trials were carried out to determine what how influent TOC affects filtration efficiency, labeled Trial A, Trial B, and Trial C. Each trial ensured the hydraulic loading rate of each filter was equivalent to or less than one pore volume over 24 hours ± 2, as recommended by previous research (Elliot, DiGiano, & Sobsey, 2011), (Young-Rojanschi & Madramootoo, 2013). The daily total volume did not exceed 9.0 liters, which is 90% of the total pore volume, in the full scale filter. The 1/30th scale filters were loaded with 0.35 liters, 95% of the total pore volume, of influent every day.

Each trial used a different mix of solutions as needed. Primary and final effluent from the Stillwater, OK waste water treatment plant (WWTP) was used to emulate drinking water contamination. Boomer Lake, Stillwater, Oklahoma provided background organisms found in natural water sources. Deionized water (DI) was used to dilute filter influents as required.

Analytical Methods

3M™ Petrifilm™ E. coli/Coliform Count Plates (Petrifilm™ EC plates) were used to quantify the coliform CFU concentration, in CFUs/mL, of influent and effluent water related to the test filters (3M, 2014). When compared with other coliform enumeration tests recommended by the American Public Health Association (APHA), Petrifilm™ EC plates allowed for easier parallel testing of biological contaminant indicators while maintaining a high specificity percentage, only 0.5 $\log_{10}$ lower than mHPC agar (Schraft & Watterworth, 2005). This methodology has also been used for fecal coliform (FC) enumeration in other papers (White, et al., 2013).

Ion chromatography was used to measure nitrate and sulfate concentrations (APHA, 1998), (APHA, 1998). The instrument used was a Thermo Scientific Dionex ICS-1100 with a Dionex IonPac™ AS14 anion column attached. DO was measured using a Hach dissolved oxygen field probe at 21 ± 2°C.

TOC tests were done using Hach Low Range Total Organic Carbon (TOC) Test 'N Tube™ Reagent Set 2760345, method 10129, with a range of 0.3 to 20.0 mg/L TOC. All loadings were analyzed once a week to maintain TOC concentrations within ±0.2mg/L. TOC loadings were chosen to be around the 5 to 11 mg/L TOC used in previous research (Elliot, DiGiano, & Sobsey, 2011), (Young-Rojanschi & Madramootoo, 2013), (Reith & Birkenhead, 1998).

Experimental Trials

Trial A

Trial A used six 1/30th scale filters. The loading is found in *Table 1*. This initial run was performed to determine whether or not a variable TOC loading would affect filtration efficiency. To run the experiment, primary effluent from the local waste water treatment plant was used as the TOC and coliform supply. Autoclaved primary effluent was used to change the TOC loading between tubes while maintaining a relatively consistent coliform load to each column. Water from Boomer Lake provided additional background organisms that would allow for proper biofilm development. One of the tubes was loaded with a "Forced 0" mix, containing WWTP primary effluent filtered through a 0.6 micron paper filter. The trapped particles were then re-suspended in DI water, measuring an average of 176 CFU/ml. This mix was used to drop the TOC while keeping the coliform loading similar to the rest of the tubes; the remaining tubes contained a percent volume of autoclaved WWTP primary effluent, with an average of 536 CFU/ml. These mixes ensured all tubes had equivalent biological loadings and variant TOC loadings. The ID labels are percent of the loading volume that contained autoclaved primary WWTP effluent.

Table 1: Trial A Influent Composition

ID	FILTERED 1', ML	AUTOCLAVED 1', ML	DI, ML	BOOMER, ML	1', ML	[TOC], MG/L
FORCED 0	35	0	70	245	0	24.6
0%	0	0	70	245	35	28.6
5%	0	3.5	66.5	245	35	28.0
10%	0	7	63	245	35	29.4
25%	0	17.5	52.5	245	35	33.2
50%	0	35	35	245	35	35.4

Trial B

Trial B used six 1/30th scale filters and one full scale, ran in parallel. The respective hydraulic and TOC loadings can be found in

Table 2. The purpose of this trial was to compare how the variant TOC affected the aerobic and anaerobic fractions in both lab and full scale. In order to achieve the lowest TOC loading, WWTP primary effluent was filtered and re-suspended to provide coliforms without adding BDOC. The rest of the filters were loaded with different volumes of WWTP primary effluent. Because of this, influent CFUs had to be recorded for each filter to determine individual filtration efficiencies with averages ranging from 406 to 3064 CFU/ml. The loading fractions were stored in a refrigerator at 3-5°C between

loadings, to limit biological degradation.

Table 2: Trial B Influent Composition

ID	DESIGN TOC (MG/L)	ACTUAL TOC (MG/L)	FILTERED PRIMARY EFFLUENT (ML)	1' (ML)	BOOMER (ML)	DI (ML)	CALCULATED DOC (MG/L)
1	5	5.37	50	0	100	200	3.46
2	10	10.51	0	20	100	230	6.78
3	15	15.66	0	40	100	210	10.1
4	20	20.80	0	60	100	190	13.4
5	25	25.94	0	80	100	170	16.7
6	30	31.09	0	100	100	150	20.0
FULL SCALE	6	6.09	0	400	1000	7600	3.92

Trial C

Trial C used six 1/30th scale filters. The loadings can be found in *Table 3*. This experiment attempted to use a TOC loading that was mostly in the dissolved fraction. Following the reagent standard for 5-day BOD tests, a glucose-glutamic acid 1.0 M solution was used to supply BDOC composing the majority of the TOC loadings (Clesceri, Greenberg, & Eaton, 1998). Boomer Lake water and WWTP final effluent provided background organisms and coliforms, consistently across all tubes. The average FC loading was 10.7 CFU/ml.

Table 3: Trial C Influent Composition

ID	TOC DESIRED, MG/L	TOC LOADING, MG/L	BOOMER LAKE, ML	FINAL EFFL, ML	GLUC/GLUTA, ML	DI, ML
1	5	5.5	50	50	0.5	249.5
2	10	10.1	50	50	2.5	247.5
3	15	14.8	50	50	4.5	245.5
4	20	20.5	50	50	7	243
5	25	25.2	50	50	9	241
6	30	29.8	50	50	11	239

RESULTS AND METHODS

Trial A

This initial run was performed to determine how a high, variable TOC loading would affect filtration efficiency. Each of the six filters were dosed once a day for 26 days with a FC loading with an average of 276 ± 20 CFU/mL. DO readings of the tubes were taken at each sampling port for the first week. At the four day mark, all of the sub-surface sampling ports had readings of 0.0 mg/L DO. This effectively means after the biolayer has matured, the aerobic fraction of the filter does not extend past the first two inches of sand at the selected TOC loadings. Subsequent DO readings were taken from the standing water, after the 24 hour rest period, the rest of the 26 days, as seen in *Figure 3*. The tube with the artificially low BDOC had the highest DO concentration, consistently between 7.0 and 6.0 mg/L, while the tube with the highest TOC of 35 mg/L had a DO that was precipitously dropping, approaching 1.0 mg/L. The filtration efficiency was gauged by measuring the influent coliform CFU and the effluent coliform CFU. This gave a fractional CFU concentration plotted against the age of each tube on a log chart with linear best fit lines, as seen in *Figure 4*. The three lowest TOC loadings had overall better removal approaching 2 log10 removal towards the end of the run. The three higher TOC loadings were more variant through the experiment, as evidenced by the less steep linear lines.

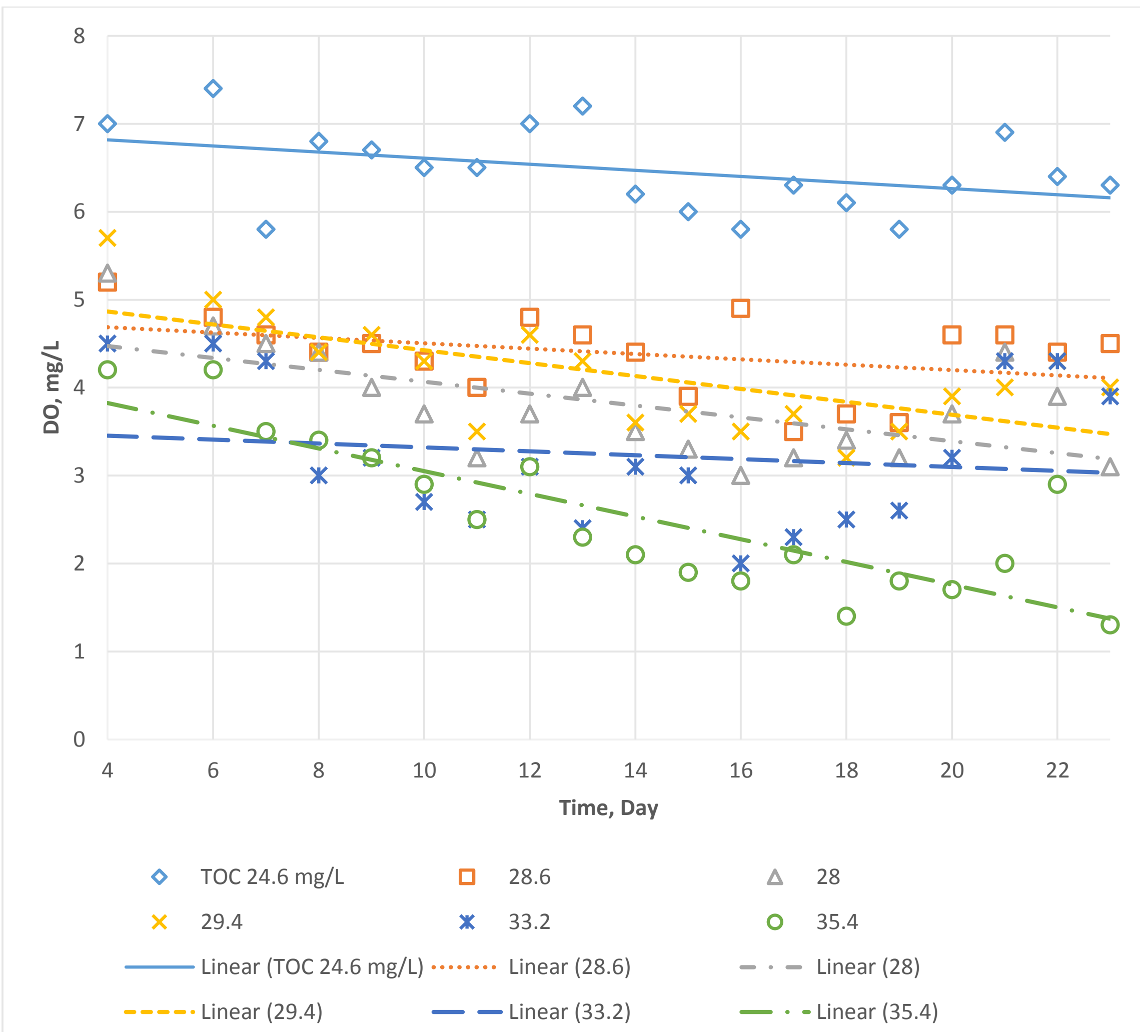

Figure 3: Trial A DO in standing water 24 hours after loading

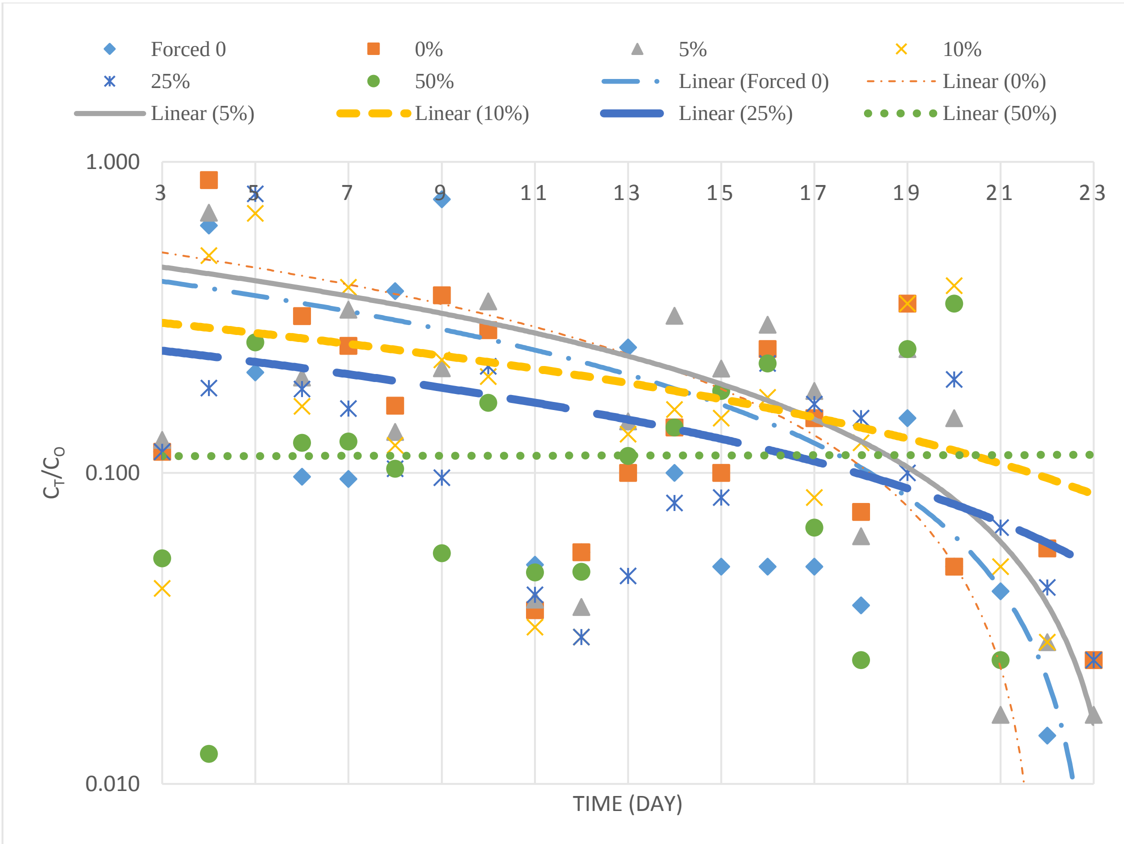

Figure 4: Trial A CFU Removal Results

Trial B

1/30th Scale Filters

The influent coliform CFU for each tube started relatively high and dropped over time, until the stock solutions could be replenished from the WWTP. Respective influent CFUs for Tubes 5, 10, 15, 20, 25, and 30 were 250, 350, 1400, 1400, 2400, and 2800 CFUs/mL on day 5, dropping to 120, 520, 710, 820, 1100, and 1600 CFUs/mL on day 10. The stock solutions of WWTP effluent were restocked on days 11 and 23, increasing the CFU loading back to day 5 levels. The removal efficiency for each filter experienced decreased removal percentages when the influent CFUs spiked after each restocking. The filters with lower TOC loadings maintained higher, more consistent removals than the filters with higher TOC loadings, especially during CFU spikes. The increased resiliency of the filters loaded with lower TOC concentrations is evidenced by the sinusoidal nature of the plot in *Figure 5*, with higher amplitudes for higher organic loadings.

On the 28th day of operation, the filters were considered to be operating at a reasonably steady state. In order to quantify how the schmutzdecke within each filter developed, from the variant TOC loadings, samples from the supernatant and the subsurface sample port were analyzed for anion changes. Schmutzdecke development was examined through nitrate levels, as seen in *Figure 6*, because nitrifiers operate in aerobic conditions (Metcalf and Eddy, 2003). While the presence and interaction of the biological communities are complex, previous research has shown nitrifying organisms are contained within the surface biolayer (Feng, et al., 2012). More nitrification would indicate healthier aerobic conditions, ideal for pathogenic removal from a water source. *Figure 6* indicates TOC loadings higher than 20 mg/L had more anaerobic activity than aerobic nitrification. Additionally, the presence of sulfide reducers would indicate anaerobic conditions within the schmutzdecke, undesirable for robust biofilm development (Metcalf and Eddy, 2003). *Figure 7* shows TOC loadings higher than 20 mg/L had the highest rates of sulfate reduction.

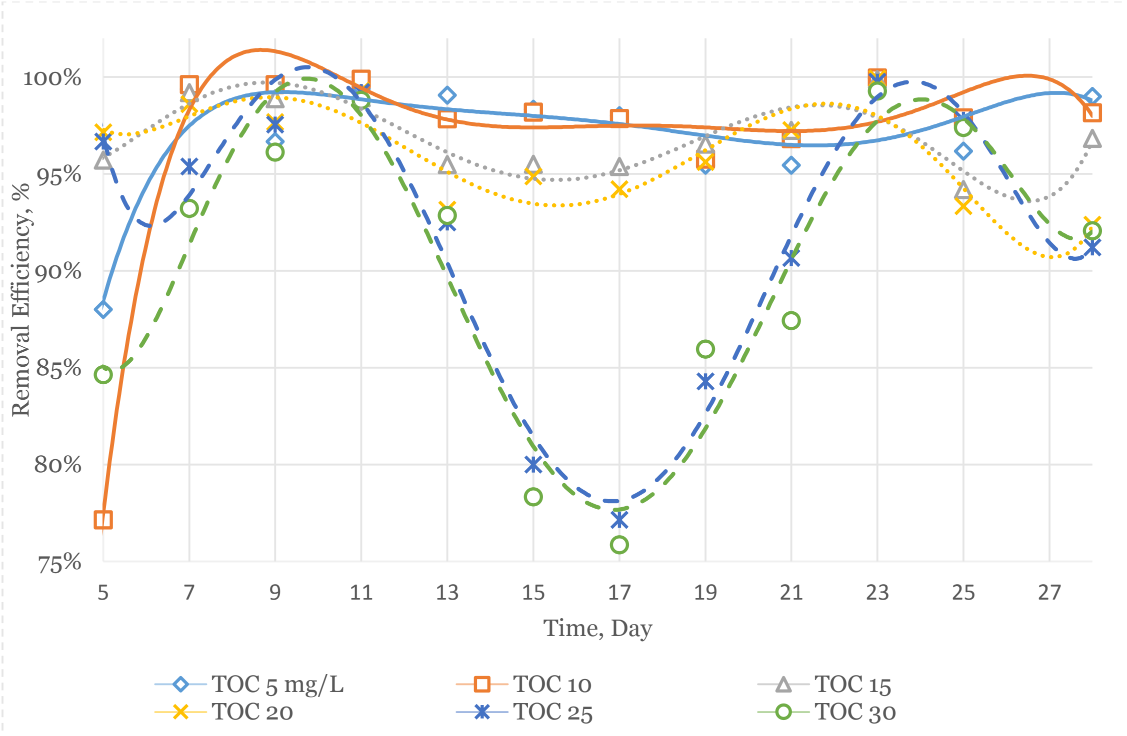

Figure 5: Trial B Bench Scale CFU Results

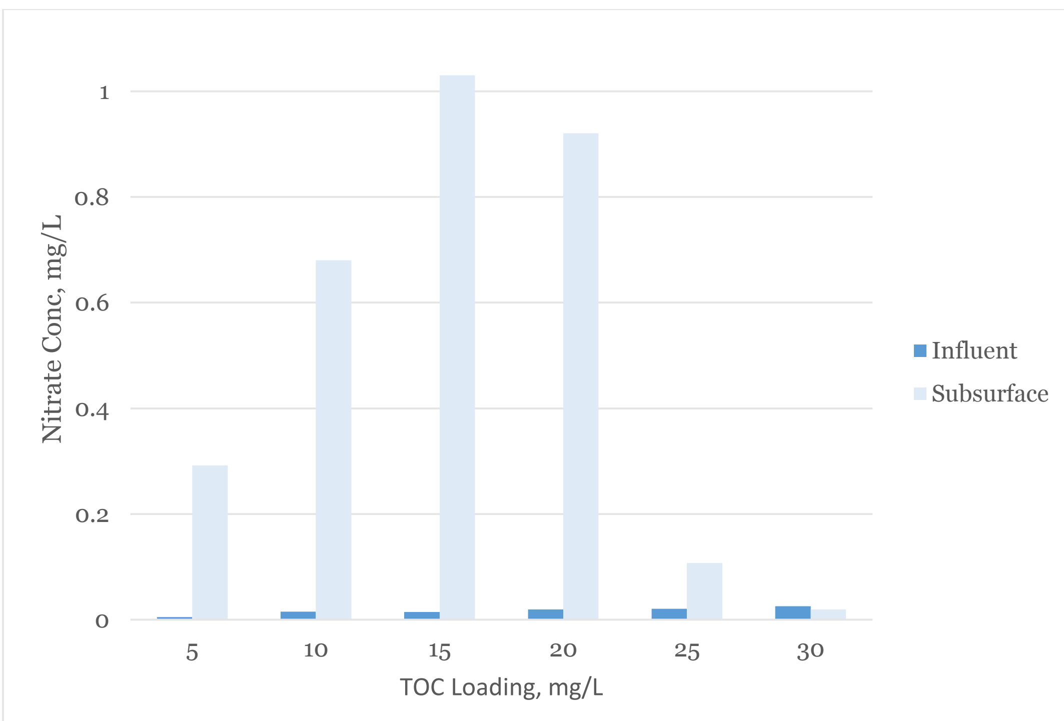

Figure 6: Trial B Bench Scale Nitrate Results

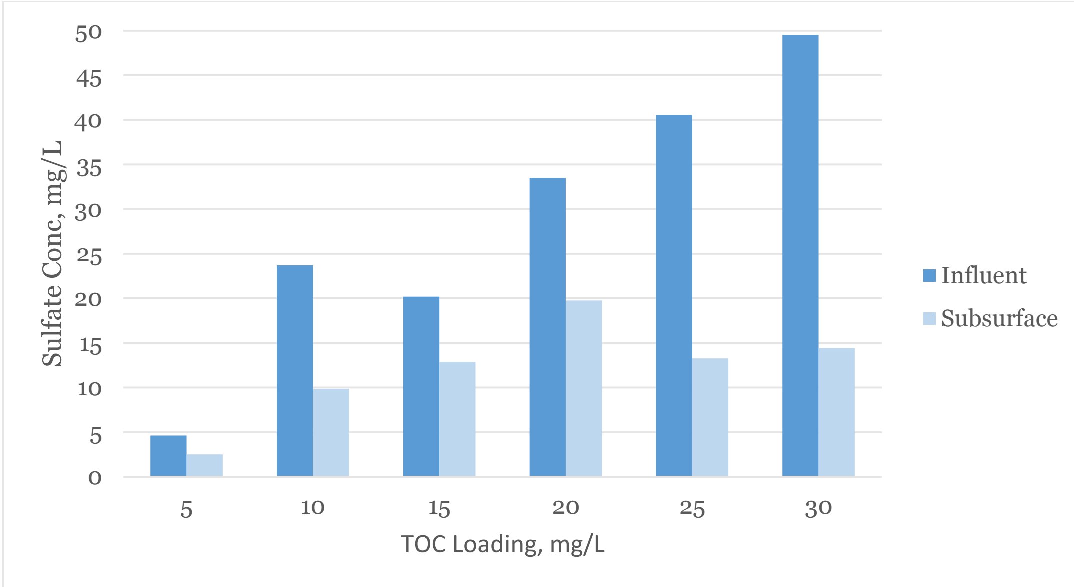

Figure 7: Trial B Bench Scale Sulfate Results

Full Scale Filter

CFU removals, nitrate concentrations, and sulfate concentrations were analyzed within the full scale filter to better understand how the aerobic and anaerobic fractions of the filter affect filtration efficiency. Because the pore volume of the entire filter is replaced at every loading, it stands to reason a certain fraction of the hydraulic loading would only be in the anaerobic fraction. *Figure 8* shows the comparison of coliforms both at t = 0 and t = 24 hours, distributed along the sand column. At the relatively low TOC loading of 6 mg/L, coliform removal occurred along the entire column over the 24 hour residence period. Anion analysis was done on samples after the 24 hour residence period, taken from the sample ports along the full scale filter. *Figure 9* shows a modest amount of denitrification occurring, peaking at six inches below the surface of the sand, and decreasing further down the column. *Figure 10* shows indications of anaerobic conditions from the presence of sulfate only present below the aerobic schmutzdecke. These results, garnered from a 6mg/L TOC loading, are similar to the 5 mg/L loading in the 1/30th scale experiments. This full scale trial shows coliform removal occurs along the entire sand column, achieving higher removal rates in the upper aerobic fractions.

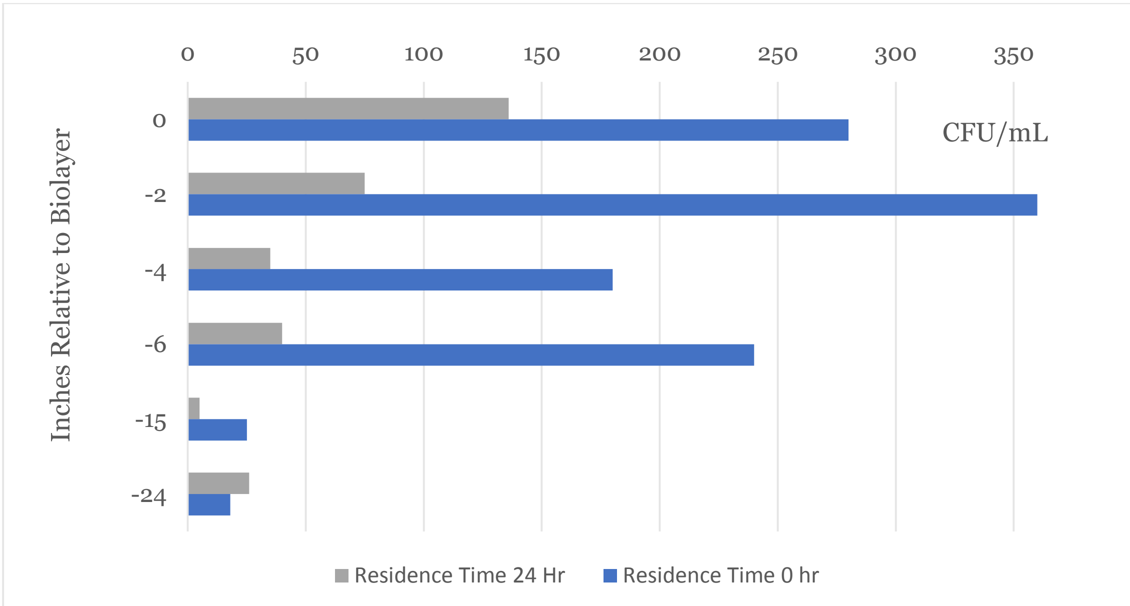

Figure 8: Trial B Full Scale CFU Results Sampled 24 and 0 Hours After Loading

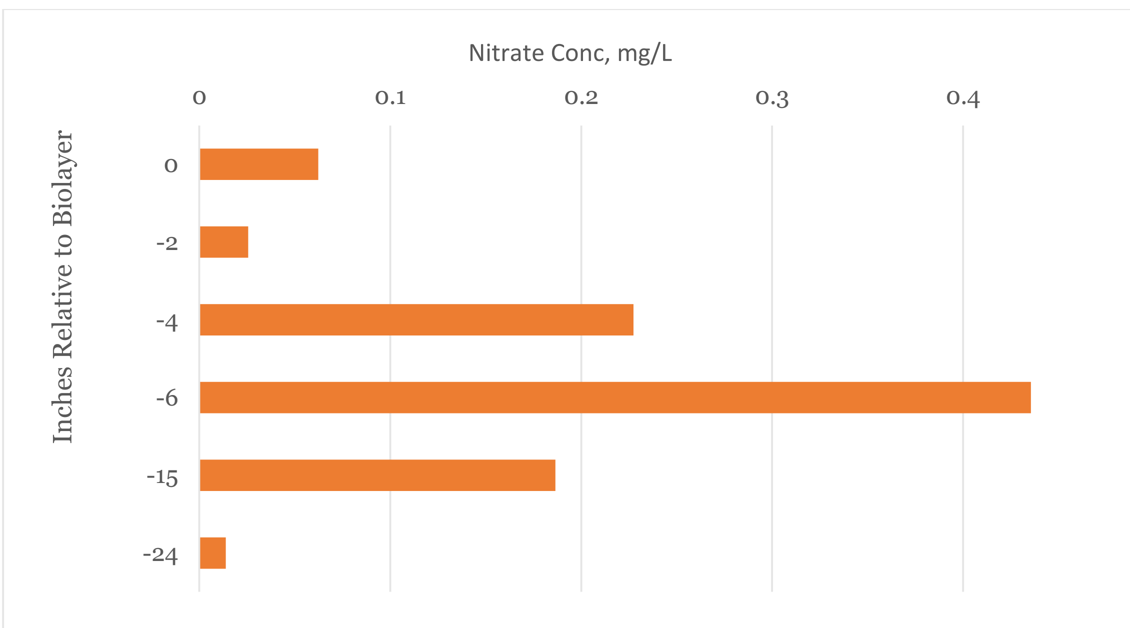

Figure 9: Trial B Full Scale Nitrate Results Sampled 24 Hours After Loading

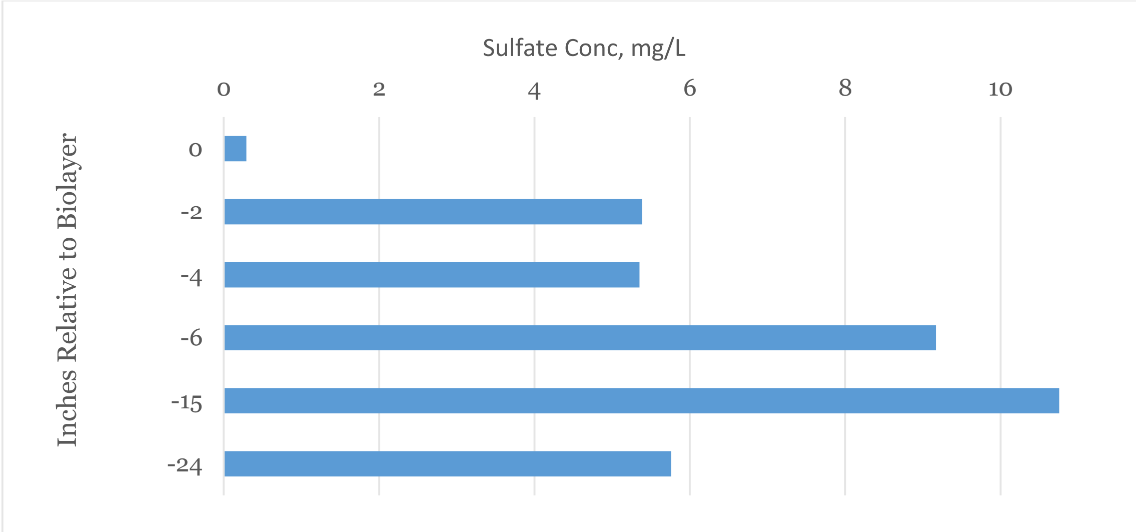

Figure 10: Trial B Full Scale Sulfate Results Sampled 24 Hours After Loading

Trial C

Based on the assumption that most of the non-dissolved TOC was retained within the upper fraction of the sand column, this experiment set out to determine how a higher dissolved TOC concentration would affect the anaerobic fraction of the filters. Because WWTP final effluent was used, influent coliforms were only 10 ± 2 CFU/mL through the run. At day five, the two lowest BDOC loadings, of 5 and 10 mg/L, achieved 80% coliform CFU removal or higher for the rest of the 15 day run. The rest of the tubes exhibited coliform growth during the entire run. The increased BDOC concentration allowed more TOC to bypass the aerobic schmutzdecke to drive anaerobic growth within the un-oxygenated sand column. *Figure 14* shows higher concentrations of BDOC caused an increase in oxygen demand within the system. The filters with a supernatant DO below 3 mg/L had more coliforms in the effluent than in the influent. Coliforms and other human pathogens have gastrointestinal origins, thriving within the filters with lower DO concentrations (Ashbolt, 2004). It stands to reason field filters with negative removal efficiencies may be burdened by excessive TOC and DO demand, causing the aerobic schmutzdecke to become anaerobic. *Figure 12* and *Figure 13* also shows how higher BDOC loadings caused anaerobic conditions to take over the column, exhibiting a lack of aerobic nitrifier activity and higher sulfate reduction from anaerobic bacteria (Sawyer, McCarty, & F, 2003).

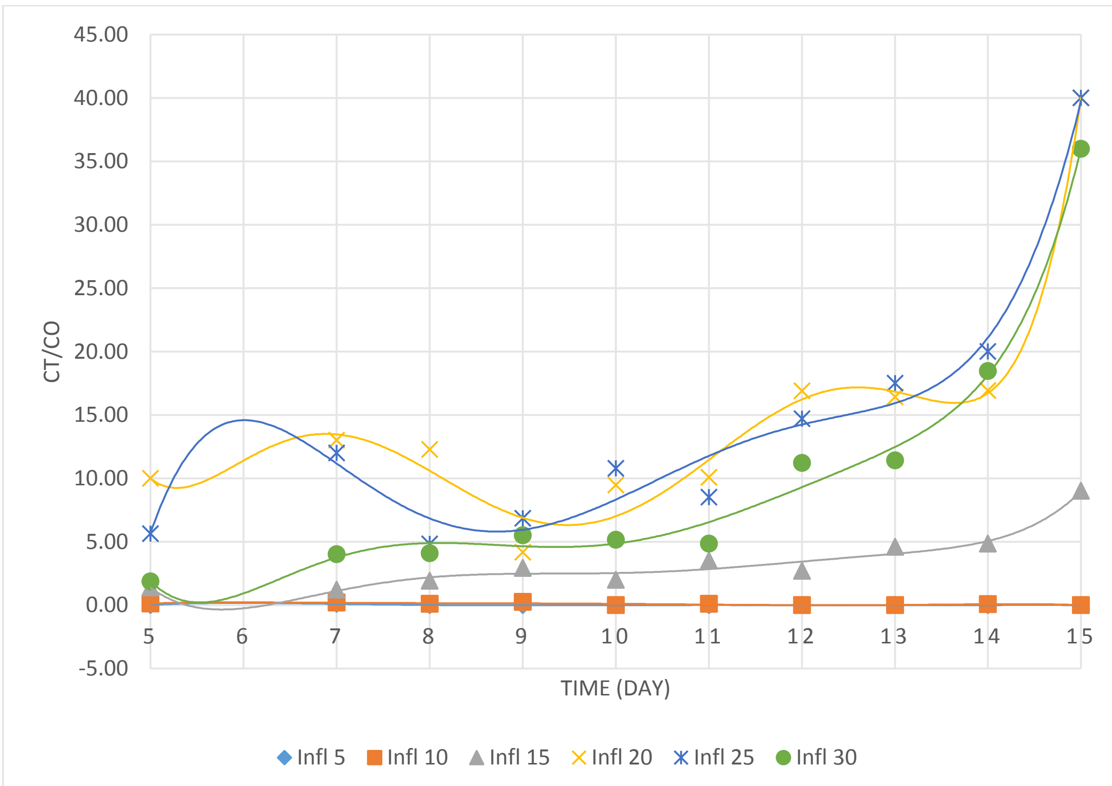

Figure 11: Trial C Coliform Results

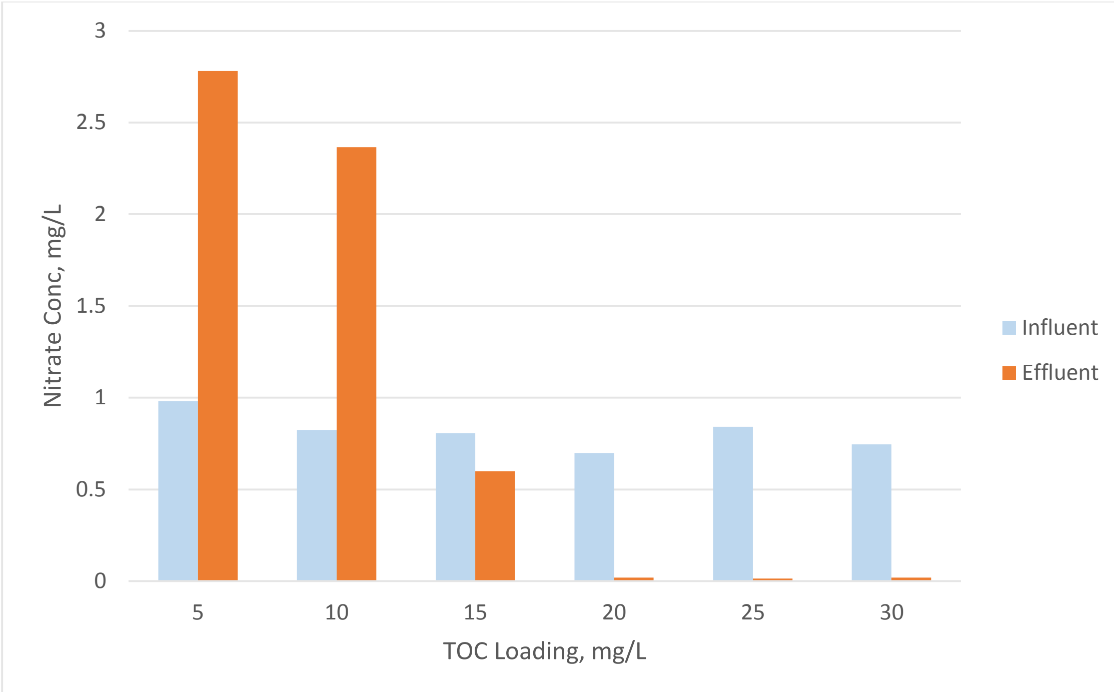

Figure 12: Trial C Nitrate Results

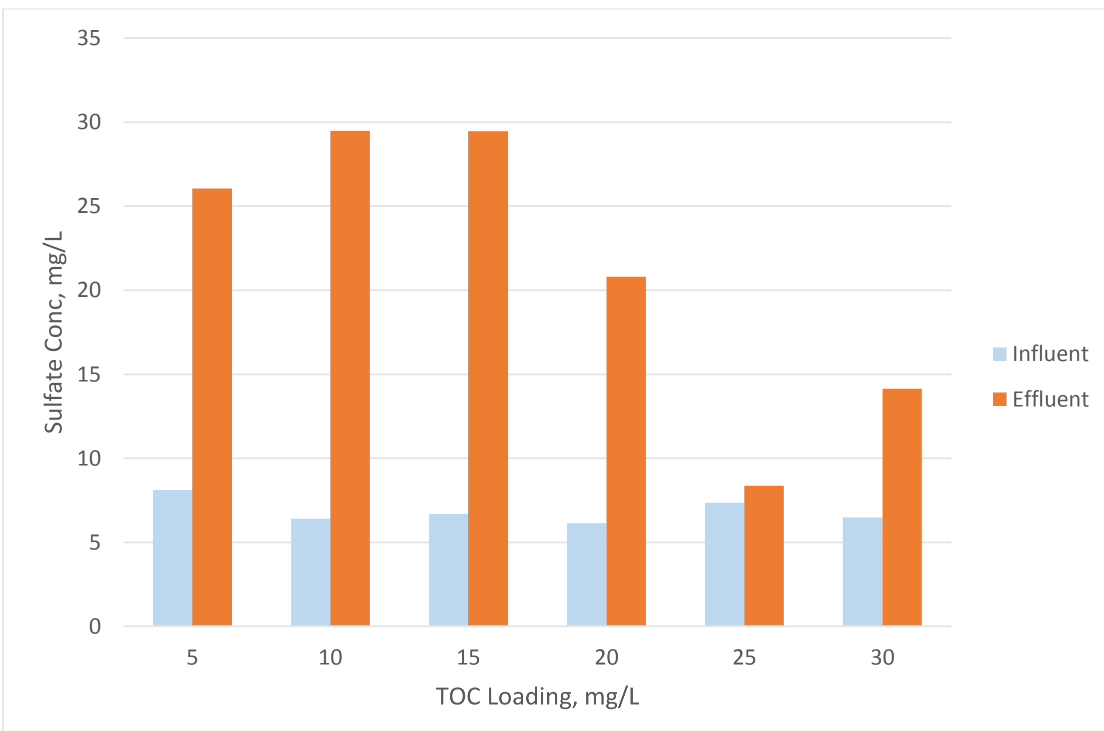

Figure 13: Trial C Sulfate Results

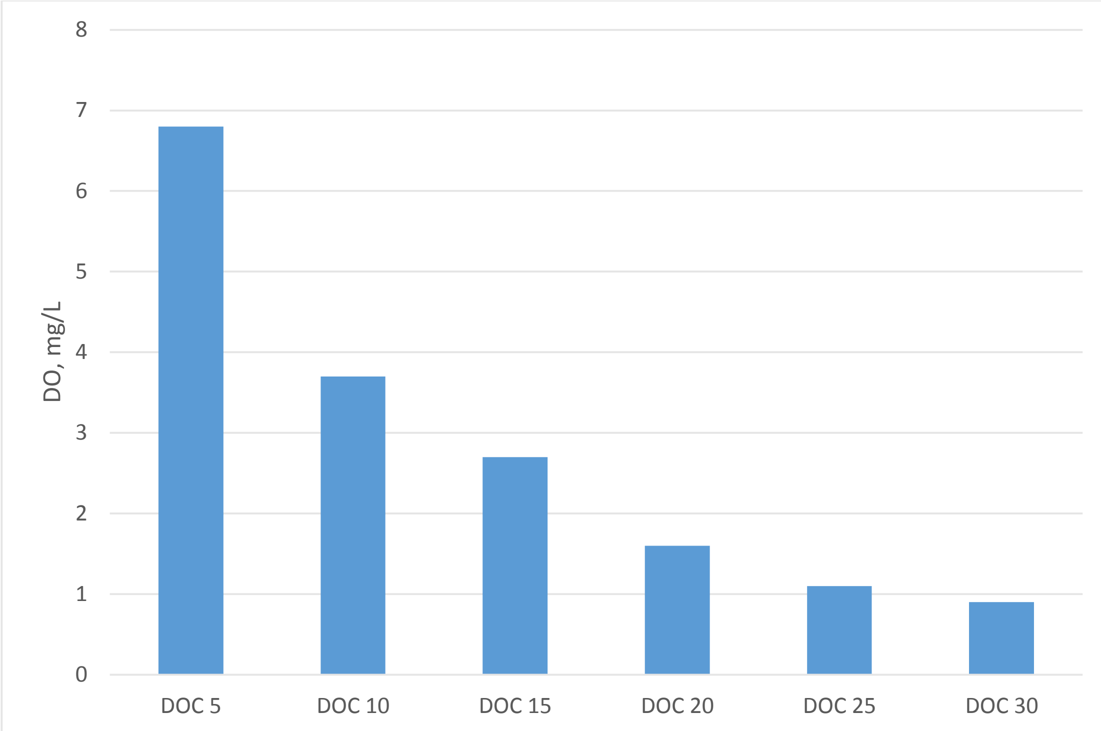

Figure 14: Trial C DO Results

CONCLUSIONS

Existing BSF projects can utilize DO probes during monitoring activities to assess the health of a filter. This additional parameter, included with flow rate and coliform calculations, would allow implementers to better determine if non-functional water filters are due to problems in construction quality, erroneous user operations, or nutrient rich influent composition. Low DO concentrations, below 3 mg/L at standard laboratory conditions, would indicate excessive organic loading. Future research could determine what precise DO concentrations at various field conditions would be detrimental to BSF operations.

Before implementing a BSF project in the field, assessment of communities can use TOC tests, or other indicators of biological oxygen demand, to analyze potential influent sources. Any project relying on influents with TOC concentrations higher than

20 mg/L or BDOC higher than 10 mg/L should be reconsidered. Organic loadings much higher than this would promote anaerobic conditions within BSFs, potentially converting the water filter in to a pathogen incubator. More research should be done to examine how to better maintain aerobic conditions within the upper sand column by changing loading volume, altering retention time, or considering various pre-treatment options such as cascading influents.

ACKNOLEDGEMENTS

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CHAPTER III

COST REDUCTION OF INTERMITTENT SLOW SAND FILTERS THROUGH THE USE OF WOODEN MOLDS AND ROTARY SIEVES

ABSTRACT

By working with communities around the Campana region of Honduras, wooden molds were developed for the construction of intermittent slow sand filters, also known as biosand filters. Entirely sourced from in-country materials and labor, a local production facility and foreman was established to provide the filters and clean water information to the surrounding communities. Rotary style sieves were developed to process the filtration medium, reducing the labor required per filter. Under the moniker of AguaSeis filters, the filters were sold for $25.00 USD with a material cost of $7.50 USD per filter.

INTRODUCTION

Poor quality drinking water is a global problem, gravely affecting the developing world and contributing to approximately 1.8 million deaths per year and 1.1 billion without access to “improved” drinking supplies (WHO, 2007) (Ashbolt, 2004). Consequences from having improperly designed water systems can adversely affect the health and economic productivity of a nation (Poverty-Environment Partnership, 2014).

In countries without well maintained water systems, point-of-use water (POU) treatment technology can be an effective solution to meeting the water quality needs of communities, with the potential to prevent 94% of worldwide diarrheal cases (Sobsey, Stauber, Casanova, Brown, & Elliott, 2008), (WHO, 2007). Most of these interventions require a consumable product that must be purchased, failing to provide clean water during periods of financial strife. Intermittent slow sand filters (ISSF), commonly referred to as biosand filters (BSF), are POU water filters that are installed in the household and can be use continuously without outside intervention (Sobsey, Stauber, Casanova, Brown, & Elliott, 2008). By retaining the microorganisms of a contaminated water supply within a simple sand medium, BSF technology has been shown to have as much as 4 $\log_{10}$ removal of *E.coli*, and 95% removal of bacteriophages (Elliott, Sauber, Koksal, DiGiano, & Sobsey, 2008).

Many clean water interventions see successful initial implementations but fail to sustain (Thompson & Doherty, 2006). One of the higher profile failures in the past ten years was the PlayPump project. The PlayPump was designed to harness the power of children playing on a roundabout to pump water into an elevated water tank, with advertisements on the tanks to draw funding for maintenance (Borland, 2010). After the construction of approximately 1,000 units in ten years, PlayPumps International was shut down due to many short-comings of the technology. First, PlayPumps were not designed to be maintained by locals, contrary to more successful interventions like the Zimbabwe Bush Pump. Second, many PlayPumps were installed over existing pumps, so when they broke there were no water options for the communities (Borland, 2010). A letter produced by the non-governmental organization (NGO) WaterAid recommended against the installation of PlayPumps, at $14,000 each they cost three times that of traditional pump systems and required child labor of 27 hours per day to provide the target volume advertised (Freschi, 2010). This is not a unique story; there are many such interventions that try to adapt developed world thinking to a developing world need while failing to provide lasting results (Thompson & Doherty, 2006).

Water quality interventions are just one of many types of developmental technology available to the developing world. It can be difficult to allow those in need to access these developments, as such, many NGOs have developed methods to improve accessibility. An example of this can be found with The Center for Health Market Innovations, where they attempt to improve access to healthcare in the developing world through systematic analysis of in-field data (Center for Health Market Innovations, 2013). By analyzing components of the medicine supply chain, from production to consumption, CHMI could identify what technologies have the best impact for the lowest cost. Their collaboration with On Cue Compliance used SIM card equipped pill bottles to increase patient compliance from 22-60% to 90% (Center for Health Market Innovations, 2013).

Branding can be important to the viability of a developmental intervention. Some technologies hit a barrier of sustainability where they are not aspirational technologies. A study found that things that were desirable in developing countries were considered “status goods”, where a western brand can hold sway over a local market (Batra, Ramaswamy, Alden, Steenkamp, & Ramachander, 2000). Non-local products are considered to be of higher quality, have perceived better international profiles, and comes with admiration of the lifestyles coincident with developed nations (Batra, Ramaswamy, Alden, Steenkamp, & Ramachander, 2000).

A good example of how to develop a supply chain can be found in Coca-Cola. In a comparison of how Coke succeeds, while some medical interventions fail in having sustained presence in developing countries, researchers identified certain parameters key to a successful supply chain (Yadav, Stapleton, & Wassenjove, 2013). Maintaining a supply chain in these regions can be difficult but the key elements found are in production, information gathering, distribution, retail point of sale, incentive structure, and consumption benefits. Distribution is handled by Coke through what they call Micro or Manual Distribution Centers (MDC), a process unavailable to medical interventions due to tight regulations from safety concerns. MDCs allow for entrepreneurs to be incentivized to become distributors and advertisers while gaining a modest income as part of the Coca-Cola network (Nelson, Ishikawa, & Geaneotes, 2009).

This research aims to apply best practices of developmental interventions, while avoiding the pitfalls endemic in these types of international projects, applied to a water filtration project. To accomplish this, a wooden mold design, rotary sieving method, and customized supply chain was developed. This paper covers the intermittent slow sand filter, also known as biosand filter, project conducted by the Oklahoma State University Engineers Without Borders student chapter in the Campana region of Honduras. The project started in March 2009 and closed out in January 2014.

MATERIALS AND METHODS

Traditional Biosand Filters

BSFs are built in a wide variety of styles. The three most common implementations are the square steel molded CAWST model, the round steel molded BushProof model, and informal plastic and metal barrel adaptations (Lea, 2008). The CAWST and BushProof techniques require steel molds to be constructed, which are then used to form the concrete shell for BSFs. These require sheet metal, metal working machinery and welding expertise, which is prohibitively difficult and expensive to source in Honduras. The round BushProof filter molds were proposed to cost less than the square ones (Mol & Fewster, 2007). However the steel, specialized equipment, threaded rods and other equipment still would require tens of thousands of dollars in capital costs. Other communities around the world have their methods for biosand filtration such as ceramic Koloshis, an attempted Bangladesh development for biological pathogen and arsenic removal (Hussam & Munir, 2007). For the project covered by this paper, a wooden construction method, under the moniker of AguaSeis filters, was developed to adapt to the capabilities of the Honduran community.

Adaptations to Traditional BSF Construction

The AguaSeis filter construction molds was developed for use in the Campana region of Honduras, and were restrained to utilize all locally sourced materials. As such, this design only uses plywood, PVC pipe, plastic sheeting, and ceramic tiles. The plywood is used for constructing molds. One sheet of four by eight feet of plywood will provide all the panels required to build one AguaSeis filter. The wood does not have to be coated with grease like the steel models. This reduces cost and simplifies the construction process. Contrary to the CAWST model, AguaSeis filters do not rely on an entrained outlet pipe. Instead, only a single hole is drilled into the outer mold for a straight length of PVC tubing. This simplicity works better for repairing and emptying filters if necessary. All of these components of construction were chosen to allow for owners to adapt their filters depending on their needs, without compromising the filtration functionality. The construction documents, which were used in Honduras, can be found in Appendix A.

Plywood Molds

There were two designs used for the outer mold section, as seen in *Figure 15*. While jigsaw cuts are more complex and use more wood, there are some advantages over the flat cut design. The jigsaw cut design is stronger because of the way the screws are driven in to the posts, fewer screws can be used and stress from the pressure of the concrete can be isolated to individual sections. Each panel is exactly the same, reducing unique parts required. The jigsaw cut panels also have distinct profiles requiring more craftsmanship, meaning they are less likely to be thrown around or misappropriated. Both types of outer molds have a plywood bottom to form the base of the filter as seen in the flat cut design diagrams in *Figure 16*.

Two blocks are used between the inner mold and outer mold, preventing the inner mold from floating while the concrete is being poured and agitated. Once the concrete is settled and ready for curing, the blocks can be removed and filled with concrete. The inner mold will be held in place by friction while the concrete sets. Alternately the blocks can be left in allowing for a space where, a filter owner can directly pipe influent water as seen in *Figure 17*.

The inner mold uses a collapsible configuration, with removable inner supports to counter inward pressure from curing concrete as seen in *Figure 18*. The tapered sides ensure the inner mold can be easily removed. 6 mm contractor's plastic or standard floor tiles are used to form the bottom of the inner mold, depending on the capabilities or available materials of the construction site. Four support blocks are screwed in to place at the top of the inner mold. One support is wedged in to place towards the bottom of the inner mold. This bottom support is not screwed in to the side panels, but will instead be pulled up. Construction quality is important to ensure the panels do not slip and become channel locked in the cured concrete. The inner mold panels can be easily removed using a fulcrum method to lever the panels out as seen in *Figure 19*.

Figure 15: Outer Molds (Jigsaw Cut on Left, Flat Cut on Right) with Inner Mold and Curing Concrete

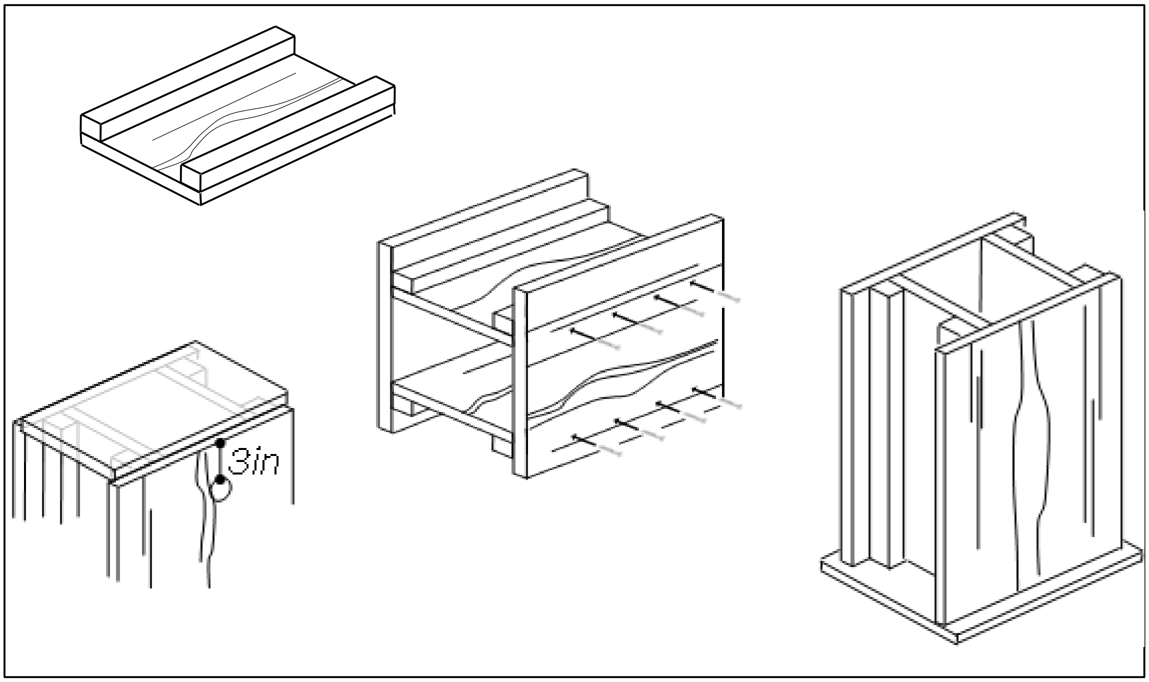


Figure 16: Select Outer Mold Components

Figure 17: Two Examples of Filters Installed in Homes

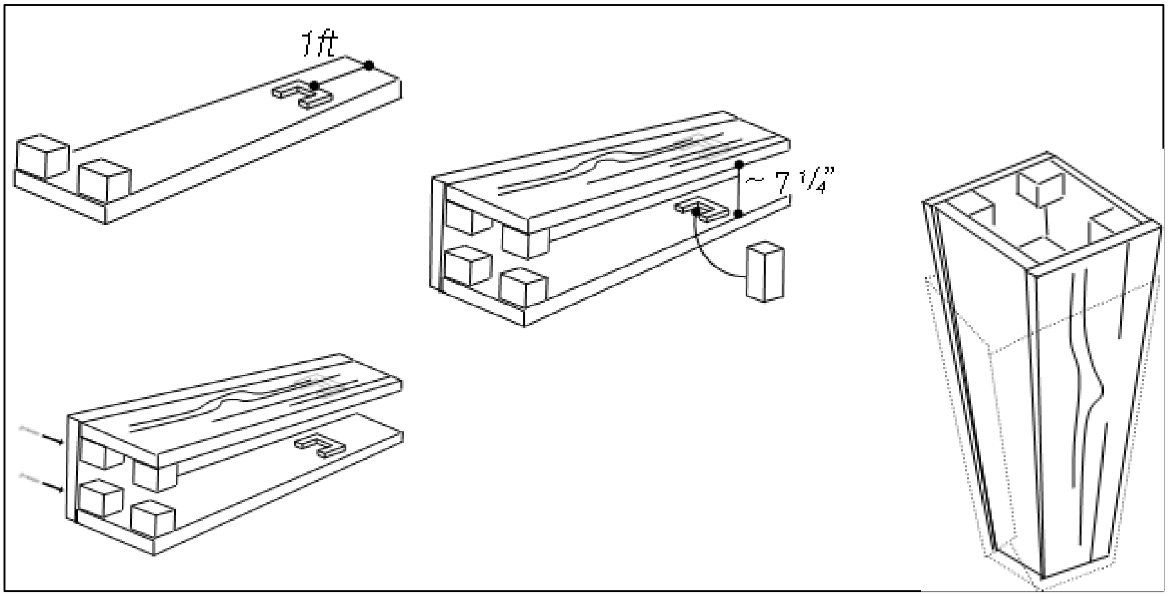


Figure 18: Select Inner Mold Components

Figure 19: Leveraging Inner Mold Panel for Removal

Rotary Sieve

The most time consumptive process of BSF construction is in the processing of sand and gravel for the concrete aggregate and filtration media. As seen in *Figure 20*, the AguaSeis methodology uses a mix of sieves to process the material. The first sieve is a lean-to frame with a one half inch sized hardware cloth. The bulk material is thrown against the screen, where the larger particles are removed and the pass through is diverted to the second sieve. This one contains quarter inch hardware cloth, utilized by two people swinging the frame between them. The retained material is the large gravel forming the bottom most layer of the filtration media. The pass-through then goes to the third and fourth sieves. In the past, these have been constructed as manual swinging frames too. This is highly inefficient, requiring three people to operate and taking a lot of time and energy to process all of the material, as seen in *Figure 21*.

The rotary sieve was developed to make the third and fourth sieving process easier and less time consuming. The device uses all locally sourced material and is easy to build. The sieves are made of window screens to provide the 1/12" and 1/20" spacing needed. The structure of the sieving barrels are made from bicycle rims backed by plywood, as shown in *Figure 22*. Two of these barrels were built along with one sieving platform. The platform currently uses aluminum rails, interchangeable with rollers or casters for the barrels to roll on, as seen in *Figure 23*. This rotary method cuts the required man-hours to 1/3 of the swinging frame method while requiring only one person to operate. If the material to be sieved is wet, the manual swinging method is ineffective because of the tendency for wet sand to clump and stick. Within a rotating barrel, the sand is flipped and forced against the sieve, more effectively processing the sand medium.

After washing the sand, there are a few ways to ensure the filtration sand was sieved to the right size ratios. The most accurate and direct way is to conduct a sieve analysis to reach the desired effective size (ES) between 0.15 to 0.20 mm and uniformity coefficient (UC) less than 2.5 (CAWST, 2012). This is not always possible in-country so the effluent flow rate can be measured, looking for a recommended 0.4 to 0.6 L/min (CAWST, 2012).

Figure 20: Demonstration of Sand Sieving Process

Figure 21: Swinging Sieving Method

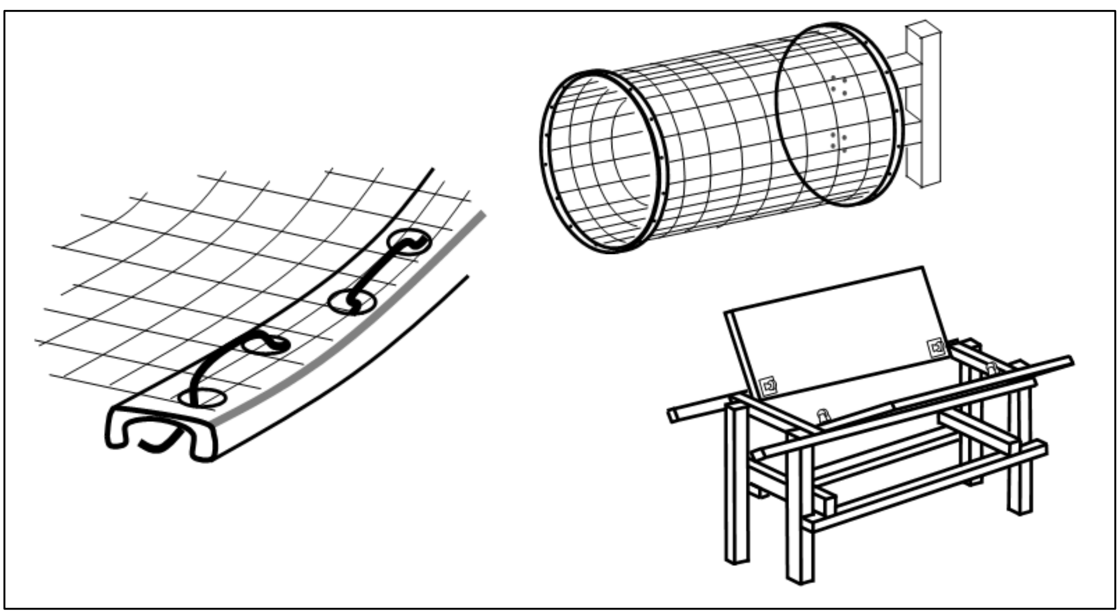


Figure 22: Graphical Representation of AguaSeis Rotary Seive

Figure 23: Image of AguaSeis Rotary Seive

RESULTS AND DISCUSSION

Conducting a clean water intervention can be difficult, more so due to being in a developing country, requiring extensive research in to the materials and skills available in the working country (Ngai & Fenner, 2008), (Wang, Dulaimi, & Aguria, 2004). For an intervention project to be successful, a robust supply chain is required with analysis of production, information, distribution, sales, incentivization, and consumption (Yadav, Stapleton, & Wassenjove, 2013). *Table 4* outlines the supply chain developed around supporting the AguaSeis initiative done in Honduras.

Currently, the production is headed by a local individual named Santos Munoz. Startup of his production facility required an initial investment of $400.00 USD to purchase materials for two BSF molds and construction of 15 filters. Another proposed setup for a new construction facility, utilizing steel molds, was quoted for $2000 USD in 2002 (Ngai, Sen, & Lukacs, 2002). Clean Water for Haiti sells steel molds for $450 USD with others selling them for $750 USD (Clean Water for Haiti, 2010). In Honduras, there were not industrial sieving operations nearby, so the production facility sieves all of the sand and gravel on site contrary to the recommendations of a different study (Bergner, Cashen, Jordan, Pelnik, & Williams, 2012). However, by sieving on site, it allows the operation to have more process quality control to properly source and sort usable sand and gravel, being an important component to a successful BSF operation (White, Sangster, Joy, & Dunekacke, 2013). The materials cost associated with BSF construction can be found in *Table 5.* The labor costs associated with production can be found in *Table 6*, if $8.50 USD are retained for material and upkeep costs.

One study found identifying key personnel, with entrepreneurial qualities can make or break a project (Okeoma, 2010). Our experiences in Honduras support this conclusion. The low cost of operations in setting up an AguaSeis production facility allows for decreased barriers to entry in the clean water market. Santos, whose wife owns a small shop and himself working as a contractor, was equipped to anticipate the investment of time and effort required to run a BSF production facility.

In addition to the production facility are monitoring activities carried out by local personnel. Core information gathered in country includes global positioning system (GPS) coordinates and fecal coliform (FC) colony forming units (CFU) per milliliter. Accounting for products and services delivered can be difficult in a developing country, but important to the longevity of a project (Yadav, Stapleton, & Wassenjove, 2013). All filters built are given a GPS coordinate, using a cheap tablet with a built-in GPS chip, allowing corresponding data (user name, filter age, filtration efficiency, etc.) to be overlaid in a geographic information system (GIS) representation, simply made using

Microsoft Publisher, as seen in *Figure 24*. This tool enables project managers to rapidly and easily draw conclusions from a wide range of filter attributes.

The distribution element of the supply chain includes filters, clean water, and information. The filters are delivered by the foreman of the production facility. This is necessary because proper installation is important to filter functionality, requiring special training. The clean water that is produced by the filters is frequently shared by their owners. It was discovered that pulperias, small shops prevalent in Honduran communities, who own filters will frequently give away filtered water for free. The AguaSeis project now keeps track of those pulperias for use as micro-distribution centers (MDCs). Safe water practices, BSF information, and clean water can now be disseminated from these MDCs. In return the pulperias' filters are tested weekly, for filtration efficiency using 3M Petrifilms determining total coliform removal by a local who works and lives nearby, along with any water from the rest of the community. These MDCs also serve as a way for project managers to find out community concerns about the BSFs and prioritize supply chain extensions as needed.

Sales for filters are contracted to the production facility as needed, from MDCs and NGOs. Currently, the project in Honduras is in contact with two pulperias and the nearby missionaries. The act of establishing a production facility piqued interest in the community, generating work orders for the facility from day one. Currently each filter is being sold for $25.00 USD, approximately 1% of the national minimum wage in 2010, by the foreman. The material cost per filter is $7.50 USD, 30% of the total sale. The rest of the cost goes to labor and facility maintenance as required by the foreman. Comparable operations include a micro-enterprise in Nawalparasi, Nepal charging 2000 Napali rupees, or about $27 USD, per filter built from the steel mold (Ngai, Sen, & Lukacs, 2002). The CDC website for biosand filters states average slow sand filter prices vary from $15 to $60 (CDC, 2012). One Guatamalan estimate values the material cost of a BSF to be $15.00 USD, with a steel mold, capable of building 1500 filters over 5 years, for $2000.00 USD for just the mold (Yung, 2003). The BSF cost for the AguaSeis project accounts for materials cost, based on an estimate of one mold building 20 filters, is priced to be accessible to households in the area while providing an above minimum wage income to the laborers and foreman.

An analysis of 286 randomly chosen biosand filters, considering many BSF factors influencing severity of diarrhea burden and filter operations and maintenance, found chlorinating post-filtration was positively correlated with proper filter use (Divelbiss, Boccelli, Succop, & Oerther, 2012). Based on this, user manuals were produced explaining how to use a filter and how to do post-treatment, as seen in *Figure 25*. Informational posters were also made to explain how the BSFs can save money and protect the health of the users, also in *Figure 25*. These documents are available through the NGOs and associate MDCs. By making these materials present at the pulperias, filter users can have access to the project managers, forming a two way street for information. The pulperias will normally sell bottled water for $1.70 per five gallons from the local bottling company. The BSF filter provides an alternative for the locals where owning a BSF filter would pay back the $25.00 USD cost of a filter in eight days, assuming 10 gallons per day of bottled water consumption.

Table 4: Biosand Project Supply Chain

FACTOR	AGUASEIS SUPPLY CHAIN
PRODUCTION	• Production completely occurs in country. • Heavily relies on dependable entrepreneurs who own land for production facility setup. • Requires capital cost of $400 USD for materials and tools. • Low operating cost, mostly in man-hours (8 hours per filter). Each filter costs $7.50 USD in materials and are sold for $25.00 USD.
INFORMATION GATHERING	• Systematic information gathered using GPS and coliform data from third parties (NGOs and micro distribution centers). • Supply chain planning is based on finding pulperias to serve as MDCs in neighboring communities.
DISTRIBUTION	• Distribution asset investments are placed in improved information gathering and dissemination. • GPS data allows for traceability of filters. • Pulperias serve as MDCs, becoming community hubs for WASH data dissemination and water filtration services.
RETAIL POINT OF SALE	• Sales are contracted through NGOs and the pulperias to the production centers. Common modus operandi is for half cost of the filter upfront and the rest on delivery. • Most filter owners end up sharing filtered water, increasing interest in the product.
INCENTIVE STRUCTURE	• Sales incentives for pulperias were attempted, but they are not interested in selling the filtered water. The value is placed in giving free clean water and important health information. • Production facilities are incentivized to construct filters, albeit in a sporadic nature, when work is hard to find by providing a reliable income source.
CONSUMPTION BENEFITS	• Consumption of filtered water reduces DALYs for filter owners and those who share. • Each BSF can produce 10 gallons of filtered water per day. • Reduces the cost of clean water consumption. While increasing accessibility.

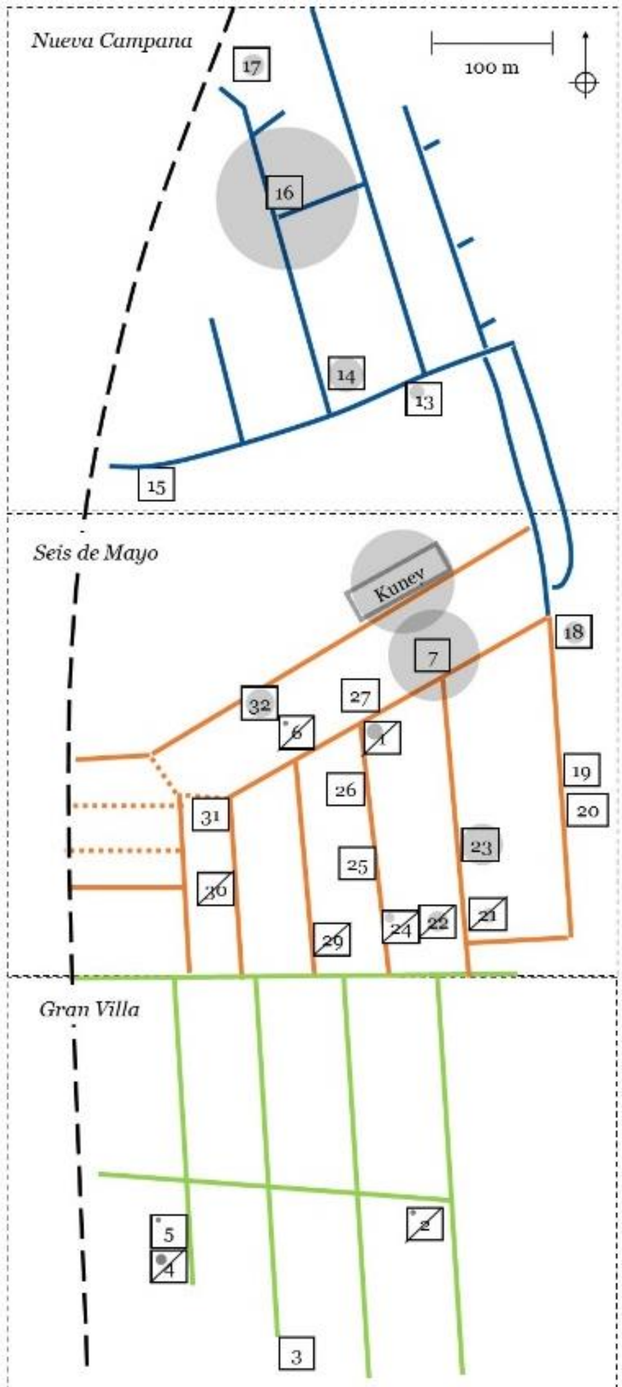
Table 5: Material Costs per BSF

Purchase List in Northern Honduras

	Cost USD	# of Filters Made
1 Pile of Sand and Gravel	$ 65.00	20
1 Four by Eight 1/2" Plywood	$ 28.00	30
20 feet 1/2" PVC	$ 3.50	10
Plastic Diffuser	$ 1.00	1
3 PVC Elbows, 1/2"	$ 0.60	1
1 Bag Cement	$ 5.00	2
2 Ceramic Tiles	$ 1.00	1

Table 6: Profit from Filters Sold at $25USD

Filters Built/Week	*Number of Laborers*	*Labor Hours /Filter*	*Total Profit*	*Profit /Person*	*Hours /Person /Filter*	*Hours /Person /Week*
3	1	10	$990	$990	10	30
5	2	8	$1650	$825	4	20
7	2	8	$2310	$1155	4	28
7	3	7.5	$2310	$770	2.5	17.5



Filter Monitoring Summary

January 2014

ID	Name	Influent Total Coliforms (CFU/mL)	Percent Removal
1	Dunia	12	-356%
2	Martinez	4	-2981%
3	15 47.688 N 87 50.964 W		
4	Fidelia	8	-294%
5	Petrona	4.5	-1900%
6	Doctor	4.5	TNC
7	Estelle	66	-7%
8	Meste	TNC	95%
9	Normita	118	74%
10	Bertillio	3	-1533%
11	Baracoa Tap	28.75	
12	Baracoa Dam	0	
13	Patty	11.5	76%
14	Lydia	24.5	94%
15	Guadalupe	1.5	33%
16	Transita	103	99%
17	Maria	16.5	100%
18	Romona	0	100%
19	Margarita	16	100%
20	15° 47.867`N 87° 50.89`W		
21	Lupe	11	100%
22	Otelia	15	
23	Santos	30	83%
24	Andreas	6.5	100%
25	Enrique	1	100%
26	Pastor	0	100%
27	Manuel	0	100%
28	15° 47.891`N 87° 50.952`W		
29	Maria	3.5	100%
30	Suyapa	0	100%
31	Humberto		
32	Antonio Lazero	20.5	9%
	AVERAGE	18.9	77%

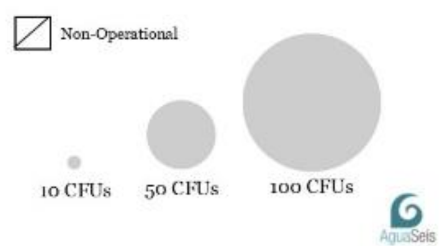


Figure 24: GIS Overlaid Map

Manual de Usuario del Filtro de Agua Bioarena

1 Pregunta: ¿Cómo debo mantener el filtro de agua?

Respuesta: Debes hechar por lo mínimo 2 litros de agua en la parte superior del filtro cada día .

Opción Uno

Vierta 10 litros durante el desayuno, el almuerzo, y la cena.

USOS MAXIMO

Opción Dos

Llena un recipiente de 5 galones al amanecer, y al atardecer.

NOTA El tiempo de descanso después de usos es muy importante para el purificación del agua.

2 Pregunta: ¿Cómo debo limpiar el filtro de agua?

Respuesta: Debes limpiar el filtro una vez al año.

EXAMINA EL CORRIENTE DEL AGUA QUE SALE DEL GRIFO

COMPROBAR	LIMPIAR
• Si el grifo tiene un corriente constante debes reemplazar la arena.	Quita por lo menos 2 pulgadas de arena y remplacelo con arena nueva.
• Si el grifo está goteando lentamente debes limpiar la arena.	Mezcle los primeros 2 o 3 pulgadas de arena y quite el agua sucia.

¡NO!

- No pongas lejía, alimentos, o otras químicas en la parte superior.
- No quitas o acortas el tubo vertical / grifo.
- No vacíes el filtro de agua .

NOTA Mantenga la parte superior cubierta con madera o cerámica para proteger el agua.

3 Pregunta: ¿Cómo debo ahorrar el agua potable?

Respuesta: Debes ahorrar el agua potable en un recipiente con una tapa cerrada hasta que lo necesitas.

Cantidad de agua	1 cuarto o 1 litro	1 galón	5 galones
Cantidad de cloro	3 gotas	12 gotas	½ cuchara

NOTA Agregando cloro es la forma más segura de purificar el agua.

AguaSeis

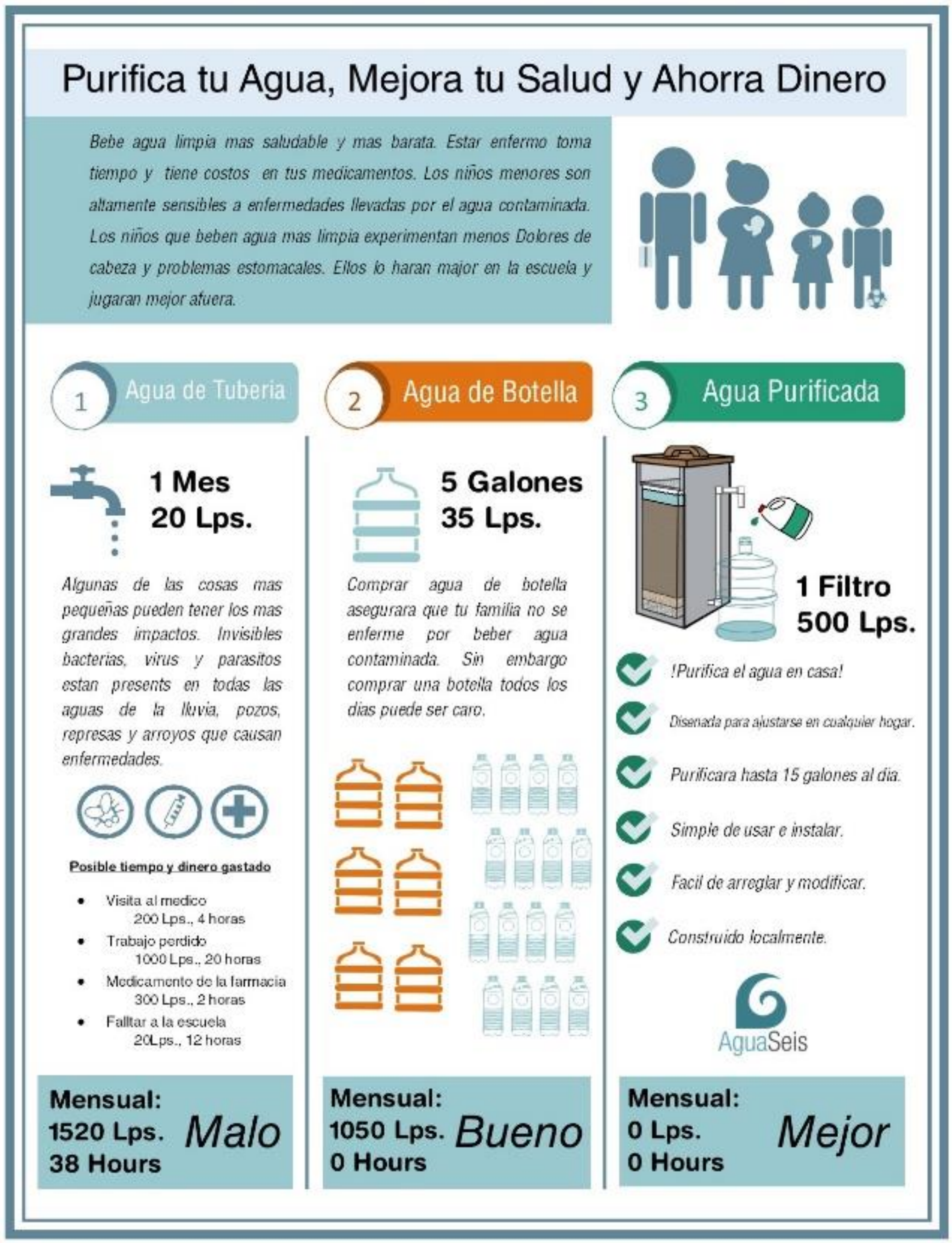


Figure 25: AguaSeis BSF User's Manual on Top, Informational Poster on Bottom

The next logical step would be to assess the process for embodied energy required. Others have looked at two parameters of clean water interventions in Mali. The first was the direct and indirect energy required for pre-manufacturing, manufacturing, and usage (Held, Zhang, & Mihelcic, 2013). The second was the human energy consumption, key to sustainable projects in developing nations. This approach could be applied to conducting a cost-benefit analysis of establishing the AguaSeis supply chain, in Honduras and other countries. The Mali research found BSFs have been found to have a total embodied energy of 140 megajoules per 12 cubic meters per day, relatively low compared to other interventions (Held, Zhang, & Mihelcic, 2013). However, this is based on the steel mold method of construction and would be much less for the AguaSeis method. If the new total embodied energy is calculated, this figure can be used to analyze the amount of social good done by an AguaSeis project (Rogers, Bhatia, & Huber, 1998). This cost-benefit analysis, combined with the results garnered from the AguaSeis construction methods and supply chain, could ensure sustainable adoption of BSF interventions in other parts of the world.

CONCLUSION

The AguaSeis wooden molds and rotary sieves combined with a MDC-based supply chain can effectively provide sources of income, safe drinking water, and sustained operations to communities requiring a clean water intervention. As of January 2014, more than 50 filters have been constructed using the wooden molds.

ACKNOLEDGMENTS

Funding for this research was provided in part by the EPA P3: People, Prosperity and the Planet Student Design Competition for Sustainability. This graduate study could not have been possible without the support of Oklahoma State University, the OSU-Engineers Without Borders organization, the expertise and patience of Dr. Gregory Wilber, and the encouragement of Dr. Paul Weckler.

CHAPTER IV

LONGITUDINAL ASSESSMENT OF INTERMITTENT SLOW SAND FILTER PERFORMANCE IN NORTHERN HONDURAS

ABSTRACT

Lack of access to clean drinking water is a problem stymying the growth of developing nations all around the world. Point-of-use intermittent slow sand filters, also known as biosand filters (BSF), are an effective clean water solution for places without a well maintained clean water system. This study was conducted in the Campana region of Honduras, where a clean water project was started with the express intent of creating sustained, local BSF production and adoption. Implemented in March 2011, 46 filters were made in-country by January 2014 with 72% still in operation. An averaged removal rate of total coliforms, sampled from 27 filters, was found to be 91%.

INTRODUCTION

Poor quality drinking water is a global problem, gravely affecting the developing world and contributing to approximately 1.8 million deaths per year and 1.1 billion without access to "improved" drinking supplies (WHO, 2007) (Ashbolt, 2004). Consequences from having improperly designed water systems can adversely affect the health and economic productivity of a nation (Poverty-Environment Partnership, 2014).

In countries without well maintained water systems, point-of-use water (POU) treatment technology can be an effective solution to meeting the water quality needs of communities, with the potential to prevent 94% of worldwide diarrheal cases (Sobsey, Stauber, Casanova, Brown, & Elliott, 2008), (WHO, 2007). Most of these interventions require a consumable product that must be purchased, failing to provide clean water during periods of financial strife. Intermittent slow sand filters (ISSF), commonly referred to as biosand filters (BSF), are POU water filters that are installed in the household and can be use continuously without outside intervention (Sobsey, Stauber, Casanova, Brown, & Elliott, 2008). By retaining the microorganisms of a contaminated water supply within a simple sand medium, BSF technology has been shown to have as much as 4 $\log_{10}$ removal of *E.coli*, and 95% removal of bacteriophages (Elliott, Sauber, Koksal, DiGiano, & Sobsey, 2008).

BSF performances have been exhaustively studied all around the world. A study in Kianjavato, Madagascar had measured BSF performance from filters processing a variety of water sources. This is a rural community with about 10,000 people where filters were built in 2011 and 2012. They built round concrete filters based off the biosandfilter.org guidelines, using cylindrical steel molds with an interior volume of 53.5 liters. They measured filtration efficiencies using 3M™ Petrifilm™ E.Coli/Coliform Count plates. Loading total coliforms (TC), had concentrations of 200 to 800 colony forming units (CFU)/100 mL from well water and 1600 to 6200 CFU/100 mL from river water (White, et al., 2013). Their loading rate was 18 liters every 24 hours. They found some filters would achieve >85% TC removal by seven days after initial loading, while others would have more TCs in the effluent than influent.

BSFs in Bonao, Dominican Republic resulted in two publications. The first paper had field data collection starting on June 19, 2005 to July 27, 2006. They randomly gave out BSFs in February 2006 to determine impact on diarrheal incidents. They had 187 out of 210 households complete the study. The average BSF influent had an *E. coli* concentration of 21 MPN/100 mL with an average 48% removal (Stauber, Ortiz, Loomis, & Sobsey, 2009). The second paper analyzed the performance of filters approximately one year after installation, plus additional filters constructed by the Bonao Rotary Club. A total of 328 BSF households were analyzed. The influents had *E. coli* measurements of 11% < 1 MPN/100 mL, 22% 1-10, 38% 11-100, 22% 101-1000, and 7% >1000. The average removal found from the effluent was 84-88% (Aiken, Stauber, Ortiz, & Sobsey, 2011). Tests for the presence total coliforms, including *E. coli*, are a good indicator of increased chance of contracting diarrhea causing diseases (Edberg, Rice, Karlin, & Allen, 2000).

The use of plastic housed biosand filters was studied in Copan, Honduras. It is one of three simultaneously conducted trials carried out in Honduras, Ghana, and Cambodia. The Honduran study was carried out between May 5, 2008 and February 25, 2009. This randomly controlled study gave 90 households a filter while 86 families served as control with no filters. Their water sources were 49 to 69% unprotected, 24 to 50% protected, 1 to 11% piped, and 0 to 2% rainwater. The geometric mean for the influent *E. coli* concentration was 60 MPN/100 mL with a BSF effluent of 23 MPN/100 mL. Their plastic BSFs had an average reduction of 61% *E. coli* and 38% total coliforms (Fabiszewski de Aceituno, Stauber, Walters, Sanchez, & Sobsey, 2012). The study in Ghana was a randomized control study with 260 households, beginning June 17, 2008 to

December 23, 2008. 117 plastic filters were given to the communities. 71 to 98% of households used water from surface water, collected from behind earthen dams. The average contamination for the influent *E. coli* was 823 MPN/100 mL. The average removal rates were 97% removal of *E. coli* (Stauber, Kominek, Liang, Osman, & Sobsey, 2012). The study in Cambodia was also a randomized control study between March 13, 2008 and December 20, 2008. Plastic BSFs were installed in July for 90 households. The average influent *E. coli* concentrations were 36.7 CFU/100 mL, and the average BSF effluent 2.9 CFU/100mL for an average removal rate of 93.3% reduction (Stauber, Printy, McCarty, Liang, & Sobsey, 2011).

There are more than 200,000 BSFs implemented around the world (Clasen, 2009). The largest concerted effort for BSF dissemination, providing the bulk of these filters, comes from Samaritan's Purse Canada. An analysis in 2001 surveyed 585 household BSFs in Kenya, Mozambique, Cambodia, Vietnam, Honduras, and Nicaragua. They analyzed TC concentrations and found influents to range from 0 to 10,000 CFU/100 mL, with a BSF world average removal to be 93%. The source of the water was commonly from shallow wells, composing 40% of influents. Deep wells, piped water, and capped wells were the next most used sources, respectively 15.4%, 14.6%, and 9.8%. Their main recommendations for improving BSF projects is to provide labeled influent and effluent containers, have more training material for basic water, sanitation, and hygiene (WASH) practices, and enhance local capacity of technicians, possibly through moving workshops. A recent, updated study of Samaritan Purse's Cambodia program conducted further analysis of their BSFs. Out of 294 users, 63% of BSFs used rainwater as their main influent. Wells deeper than 10m were 48% and rivers or streams were 17%. A 5 month longitudinal study of 107 BSF owning families was analyzed. Of those, 46% used surface water, 46 % deep well water, and 4% rainwater. 51% of influents had *E. coli* concentrations between 101 to 1000 CFU/100 mL, and 22% had more than 1000 CFU/100 mL. Following filtration, 57% of effluents from BSFs had concentrations between 1 to 10 CFU/100 mL and 26% 11 to 100 CFU/100 mL (Water and Sanitation Program, 2010).

Other issues related to BSFs are inconsistencies in how projects are implemented and monitored, affecting overall project performance. One study in the Artibonite Valley of Haiti visted 55 BSFs in March 2011. Their ages ranged from less than one year to twelve years of continued use. 47% of the filters were no longer in use, with 65% of those being less than seven years old. All of the filters were provided for free, but buckets for usage had to be purchased. The eight problems identified, expressed by multiple studies, were improper knowledge of filter maintenance, insufficient training, poor water, sanitation, and hygiene (WASH) understanding, sand clogging, poor follow up from project managers, and construction problems. They recommend distributors provide long-term education and technical support, better understanding of societal and cultural needs, and continued collaborative work with local governments and NGOs to develop educational materials (Sisson, Wampler, Rediske, & Molla, 2013). Another study in Posoltega, Nicaragua analyzed filters installed in 1999 and 2004. At 2007 the filters were eight and three years old. Out of 234 filters, 24 were still being used or 10.3%. The average influents from source waters were 13,000 CFU TC/100 mL and 130 CFU *E. coli*/100 mL. For the filters still in operation, the average filtration rates were 98% TC, and 96% *E. coli*. The main complaint were of cracks developing in the sides of the filters.

No one in the community knew how to fix the filters because they were built by outside implementers (Vanderzwaag, Atwater, Bartlett, & Baker, 2009).

The study in this paper was conducted as part of a clean water project with Oklahoma State University Engineers Without Borders Student Chapter (EWB-OSU) in the Campana region of Honduras. Previous health surveys done by our partner NGOs (Gathering Hearts for Humanity) had determined the community of Seis de Mayo, Honduras had a 25% infant mortality rate stemming from contaminated water supplies. BSFs were chosen to be the best solution to their drinking water problems. This paper covers the longitudinal development of the BSF project from January 2012 to January 2014. Because previous research has well established the health benefits of BSF usage, disease surveillance was not included in the project. Instead, the objective was to see if and how local production facilities can be established with minimal outsider intervention. TC counts were taken of the influent and effluent of filters to determine filtration efficiencies and to indirectly gauge the potential health benefits to the community (Edberg, Rice, Karlin, & Allen, 2000). To monitor the success of the facilities information was taken including data of number of BSFs built, BSF performance, user retention, and general observations of approaches to ensuring a sustainable project.

MATERIALS & METHODS

Research Setting

A total of five monitoring visits were made between March 2011 and January 2014. The communities in the Campana region of Honduras, where Seis de Mayo is located, experience alternating wet and dry seasons. The December and January samples were taken in the midst of their wet, rainy season, while March samples are just at the start of the dry season. Because most of the filters were constructed and purchased by the locals, there was no standing agreement to allow our investigators into homes. The production facilities would have the information of where new filters were built and delivered, where upon BSF owners could volunteer samples and information.

The first concrete POU biosand filters were constructed to meet the water needs of the community in March 2011. The filters were a custom design, marketed in-country as AguaSeis filters, using thicker walls and accompanied by instructional printed materials made in conjunction with locals. Promotional posters were made to sell the filters, an example of one of these posters can be seen in *Figure 26*. Attempts were made to establish BSF production facilities in Seis and surrounding communities, of which a couple have been successful in making BSFs without continued outside intervention. Since the inception of the technology in to the community, filters have been sporadically constructed by EWB-OSU and local producers.

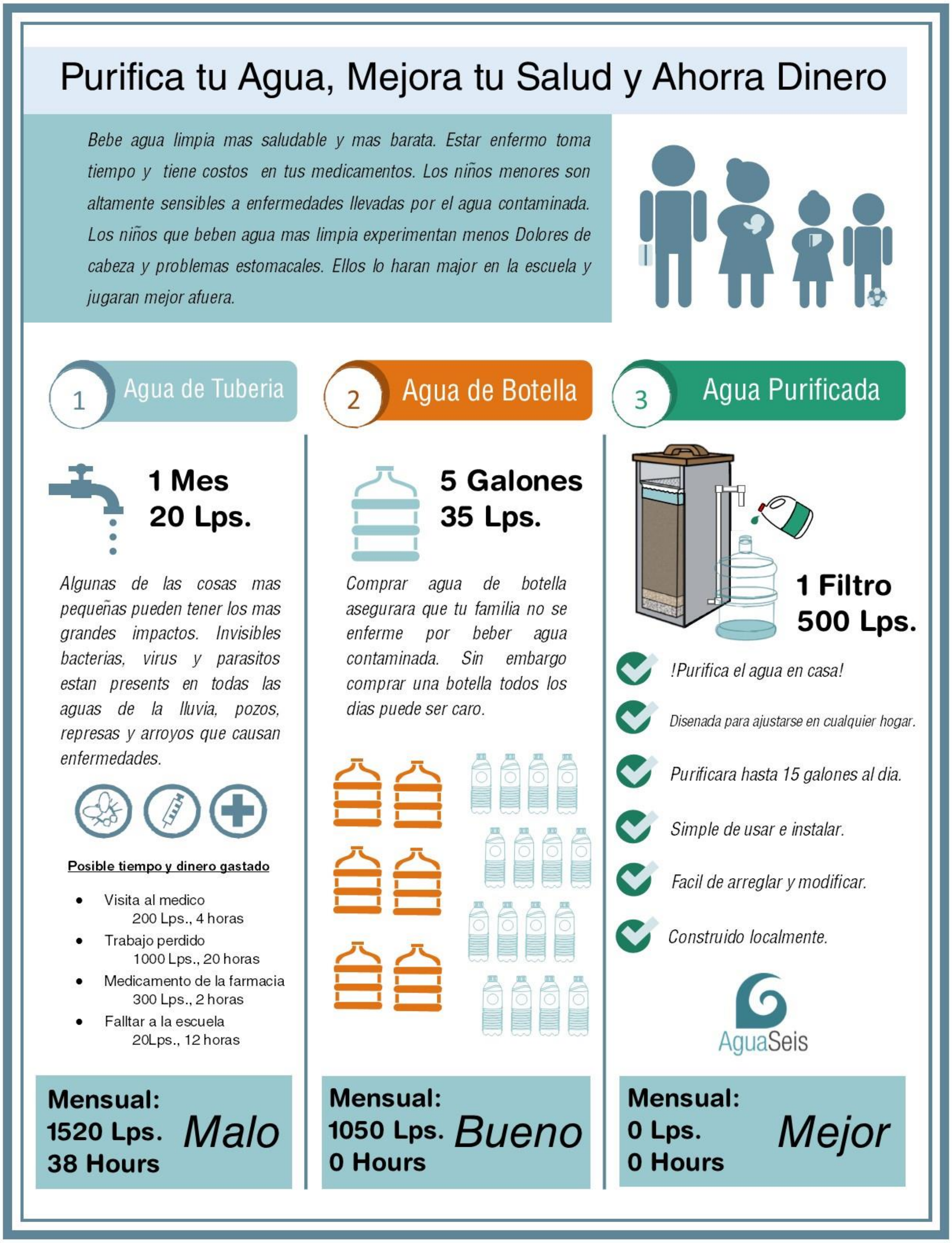


Figure 26: AguaSeis BSF Promotional Poster

BSF Quality Assessment

Over the past few years of monitoring, samples were taken from the influent and effluent of BSFs. The influent was taken from the water sources as if they were about to be poured in to the BSFs. For more than 90% of the homes, this was from water taps in the house piped from outside the communities. For the most part, these taps contained water from a mix of spring water and surface runoff recontaminated by total coliforms on its way to the homes of the BSF users. The effluent samples were taken directly from the water exiting the BSF sampled. The samples were not taken from the normal water receptacles used by the household because this study was over the filtration efficiencies of the filters, not of the overall drinking water quality of the household.

3M™ Petrifilm™ E. coli/Coliform Count Plates (Petrifilm™ EC plates) were used to quantify the coliform CFU concentration, in CFUs/mL, of influent and effluent water related to the test filters (3M, 2014). Total organic carbon (TOC) tests were done using Hach Low Range Total Organic Carbon (TOC) Test 'N Tube™ Reagent Set 2760345, method 10129, with a range of 0.3 to 20.0 mg/L TOC.

Notes were taken about the status of the filters including flow rates, frequency of usage, filter placement, and concrete shell condition. Because BSF owners are not always forthcoming about frequency of filter usage, these types of observations are important to determining if poor filtration efficiencies are due to user error or inconsistent construction quality. For instance, if the home owner has to move a potted plant out of the way to access their filter, that probably means they are not using their BSF all that often. This sort of investigative assessment was useful for properly understanding the local concerns crucial to a successful BSF operation (Sisson, Wampler, Rediske, & Molla, 2013).

RESULTS

As seen in *Table 7*, many filters have been constructed in the region since the project's inception in March 2011. Instructional documents on proper filter maintenance and usage, as seen in *Figure 27* were implemented March 2012. Prior to that, maintenance and operational information were verbally distributed. Out of 46 total BSFs, as of January 2014, 17 were built by OSU-EWB students and the rest by the local production facilities. The ages of filters ranged from two and a half years to only a couple of months. Some of the filters and their locations can be seen in *Figure 28*. Even without active prodding from the EWB-OSU project managers, the local production facilities have sold filters outside of the original target communities. The distance between the first filters, implemented in Seis de Mayo, and the latest ones installed by the local production facilities, in Alto Puente are about five miles.

The data from *Table 8* contains TOC measurements of various samples taken in January 2014. The river, well water, and rain water samples were single point samples of influents that would go in to a BSF. The average piped influent is represented from nine samples and the BSF effluent from four. This information was taken to determine if the influent source TOC affected BSF filtration efficiencies. While more than 90% of the filters are fed with piped water, it is anticipated some of the filters unknown to us may use sources with higher organic content. This study did not see a correlation between filter performance and influent TOC.

The filters sampled for *Table 9* were about two and a half years old at the time of sampling. Out these nine original filters, four were not being used at the final sampling.

Out of these four, two of the users insisted they still used their BSFs every day, but qualitative observations indicated otherwise.

Table 7: BSF Filtration Efficiency Summary

Date of Analysis	Total Filters Built	Filters Still in Use	Filters Sampled	Mean Influent TC CFU/mL	Mean Effluent TC CFU/mL	Mean % Removal	Standard Deviation
Jan-12	9	9	9	14.6	6.89	34.3%	1.61
Mar-12	9	9	9	9.5	4.56	47.6%	0.32
Dec-12	27	22	25	20.1	1.8	94.1%	0.16
Mar-13	32	27	19	64.6	3.7	76.2%	0.32
Jan-14	46	33	27	55.0	12.2	91%	0.17

Table 8: Field TOC Measurments

NAME	TOC, MG/L	STANDARD DEVIATION
CHAMELECOR RIVER	19.7	
WELL WATER	10	
RAIN WATER	13	
AVERAGE PIPED INFLUENT	15.9	2.53
AVERAGE BSF EFFLUENT	11.7	1.57

Manual de Usuario del Filtro de Agua Bioarena

1 Pregunta: ¿Cómo debo mantener el filtro de agua?

Respuesta: Debes hechar por lo **minimo 2 litros** de agua en la parte superior del filtro **cada día** .

Opción Uno
Vierta 10 litros durante el desayuno, el almuerzo, y la cena.

USOS MAXIMO

Opción Dos
Llena un recipiente de 5 galones al amanecer, y al atardecer.

NOTA El tiempo de descanso después de usos es muy importante para el purificación del agua.

2 Pregunta: ¿Cómo debo limpiar el filtro de agua?

Respuesta: Debes limpiar el filtro **una vez al año**.

EXAMINA EL CORRIENTE DEL AGUA QUE SALE DEL GRIFO

COMPROBAR	LIMPIAR
Si el grifo tiene un corriente constante debes reemplazar la arena.	Quita por lo menos 2 pulgadas de arena y remplacelo con arena nueva.
Si el grifo está goteando lentamente debes limpiar la arena.	Mezcle los primeros 2 o 3 pulgadas de arena y quita el agua sucia.

¡NO!
- No pongas lejía, alimentos, o otras químicas en la parte superior.
- No quitas o acortas el tubo vertical / grifo.
-No vacíes el filtro de agua .

NOTA Mantenga la parte superior cubierta con madera o cerámica para proteger el agua.

3 Pregunta: ¿Cómo debo ahorrar el agua potable?

Respuesta: Debes ahorrar el agua potable en un recipiente con una tapa cerrada hasta que lo necesitas.

Cantidad de agua	1 cuarto o 1 litro	1 galón	5 galones
Cantidad de cloro	3 gotas	12 gotas	½ cuchara

NOTA Agregando cloro es la forma más segura de purificar el agua.

AguaSeis December 2012

Figure 27: BSF User's Manual

Table 9: Nine Oldest BSFs FC CFU/mL

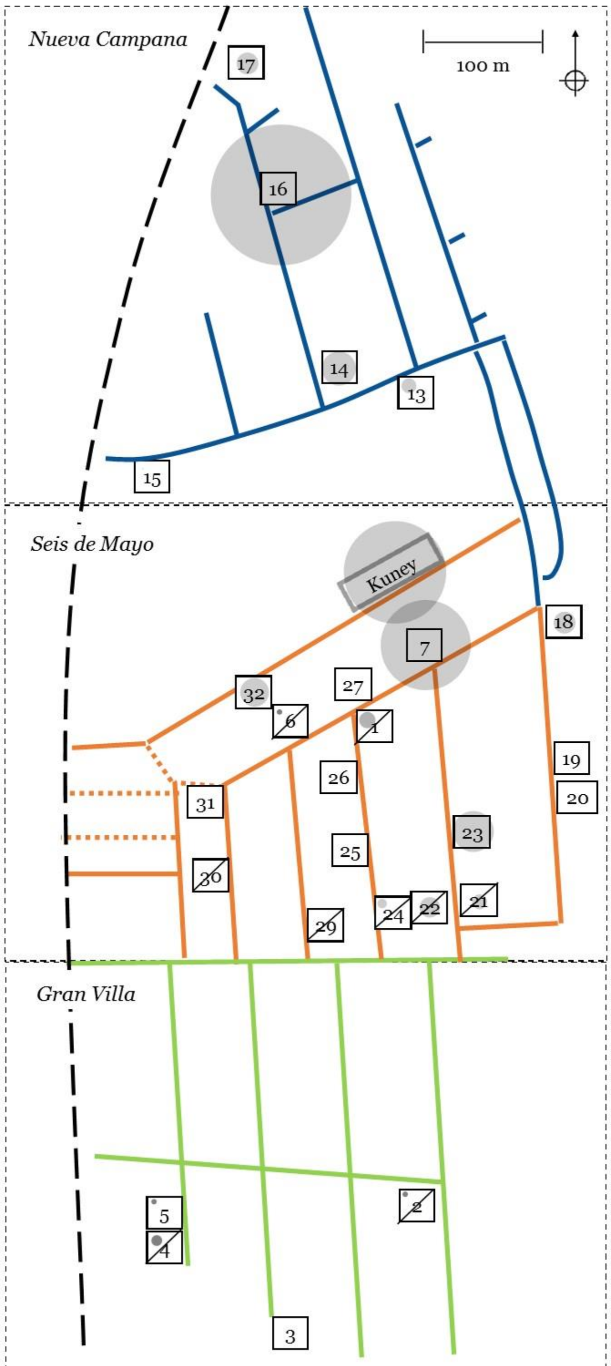
	5-JAN-12			**15-MAR-12**		
	Influent CFU/mL	Effluent CFU/mL	% Removal	Influent CFU/mL	Effluent CFU/mL	% Removal
ROMONA	7	0	100%		0	
MARGARITA	19	0	100%	16	5	69%
OTILIA SALIMIENTO	33	0	100%		5	
SANTOS	9.5	10	-5%	5	2	60%
ANDREAS	10.5	51	-386%		17	
UMBERTO MARTIN	0	1	100%	4	4	0%
ALEJANDRA/LAZARO	41	0	100%	13	5	62%
ANTONIO MARKO	5	0	100%		2	
SUYAPA	6	0	100%		1	

	15-DEC-12			**15-MAR-13**		
	Influent CFU/mL	Effluent CFU/mL	% Removal	Influent CFU/mL	Effluent CFU/mL	% Removal
ROMONA				0	1	100%
MARGARITA	16	12	25%	26	5	81%
OTILIA SALIMIENTO	17	0	100%	9	0	100%
SANTOS	11	0	100%	19	1	95%
ANDREAS	16	6	63%	12	4.5	63%
UMBERTO MARTIN			100%			
ALEJANDRA/LAZARO	137	0	100%			
ANTONIO MARKO	1		100%	20.5	0	100%
SUYAPA	2	0	100%			

	8-JAN-14		
	Influent CFU/mL	Effluent CFU/mL	% Removal
ROMONA	0	0	100%
MARGARITA	16	0	100%
OTILIA SALIMIENTO	15	0	100%
SANTOS	30	5.25	83%
ANDREAS	6.5	0	100%
UMBERTO MARTIN		1.5	
ALEJANDRA/LAZARO	10.5	18.75	-79%
ANTONIO MARKO			
SUYAPA	0	0	

Legend

Not in Use



Filter Monitoring Summary

January 2014

ID	Name	Influent Total Coliforms (CFU/mL)	Percent Removal
1	Dunia	12	-356%
2	Martinez	4	-2981%
3	15 47.688 N 87 50.964 W		
4	Fidelia	8	-294%
5	Petrona	4.5	-1900%
6	Doctor	4.5	TNC
7	Estelle	66	-7%
8	Meste	TNC	95%
9	Normita	118	74%
10	Bertillio	3	-1533%
11	Baracoa Tap	28.75	
12	Baracoa Dam	0	
13	Patty	11.5	76%
14	Lydia	24.5	94%
15	Guadalupe	1.5	33%
16	Transita	103	99%
17	Maria	16.5	100%
18	Romona	0	100%
19	Margarita	16	100%
20	15° 47.867`N 87° 50.89`W		
21	Lupe	11	100%
22	Otelia	15	
23	Santos	30	83%
24	Andreas	6.5	100%
25	Enrique	1	100%
26	Pastor	0	100%
27	Manuel	0	100%
28	15° 47.891`N 87° 50.952`W		
29	Maria	3.5	100%
30	Suyapa	0	100%
31	Humberto		
32	Antonio Lazero	20.5	9%
	AVERAGE	18.9	77%

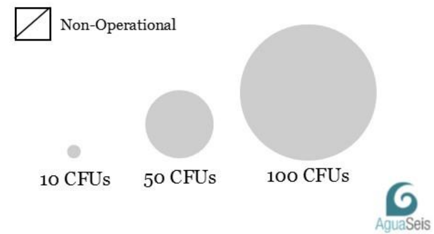


Figure 28: Overlay of BSF Owning Houses and Influent Concentrations of TC CFU/mL

DISCUSSION

The removal rates compare well to other BSF projects, with an overall average TC removal rate of 91% in January 2014 (Stauber, Printy, McCarty, Liang, & Sobsey, 2011) (Stauber, Kominek, Liang, Osman, & Sobsey, 2012) (Stauber, Ortiz, Loomis, & Sobsey, 2009). There were no complaints of cracks in the walls of the filters, apparently because of the additional wall thickness, as found in another study (Vanderzwaag, Atwater, Bartlett, & Baker, 2009). The design used was made to involve the community as much as possible and seemed to have contributed to the increased retention rate of 33 out of 46, or 72%, as compared to the 10% retention in Nicaragua over a similar time frame (Vanderzwaag, Atwater, Bartlett, & Baker, 2009).

On one monitoring excursion carried out March 2012, two filters, one owned by Margarita and the other by Alejandra and Lazaro, allowed our team unique insight in to how the locals perceive the filters. Initial assessment and interviews seemed to indicate their filters were being used correctly and consistently. However, their TC tests came back showing sub-optimal removal rates. When additional interviews are carried out with the filter owners, it was determined the problem was with misunderstanding how to maintain the filters. Margarita’s mother would clean the filter everyday by removing the effluent pipe and washing it in the sink. This would allow air bubbles in to the sand column, detrimental to effective biological filtration. Their family was also over using the filter, not allowing for an adequate rest period between loadings. The other useful user interaction was with Lazaro who had shortened his pipe to increase flow. He would also wash his sand every other day by removing the top two inches of sand and scrubbing it in the sink. The common thread between these two and most of the owners, regarding filter usage and maintenance, is over diligence with cleaning the filter, something that has not been seen in other papers. New user manuals were made to address the issue based on these findings. Later tests of the two filters with our interventions in place resulted in much better performance.

Inclusion of community members in developing the technology and accompanying manuals was important to increasing usage rate. For instance, following conversations with several bilingual residents, it was discovered that in that part of Honduras, the word “potable” is considered to be synonymous with dirty water. It was also recommended to us to sell the idea as “purified” rather than “filtered” water, because of higher user recognition of purified water. Continued involvement in generating educational materials about proper WASH techniques and BSF usage also seems to help with technology adoption and the sustained construction of filters, as recommended by the Haiti study (Sisson, Wampler, Rediske, & Molla, 2013).

The limitations of the BSF technology, to reiterate recommendations of previous findings, are wholly contained in how well project managers integrate local community involvement to meet the long-term educational and technical support required of a sustainable operation. The problem with other projects has been in decline of interest in the filters after implementers left the country. This surmountable problem can be fixed by developing more local expertise in the filter construction and usage. Utilization of locals can allow for the filters to be sold as aspirational devices, rather than merely necessary implements. This approach to marketing the filters, plus a better local support system, has the potential to improve local adoption of BSF solutions.

ACKNOWLEDGEMENTS

Funding for this research was provided in part by the EPA P3: People, Prosperity and the Planet Student Design Competition for Sustainability. This graduate study could not have been possible without the support of Oklahoma State University, the OSU-Engineers Without Borders organization, the expertise and patience of Dr. Gregory Wilber, and the encouragement of Dr. Paul Weckler.

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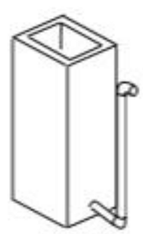
AguaSeis

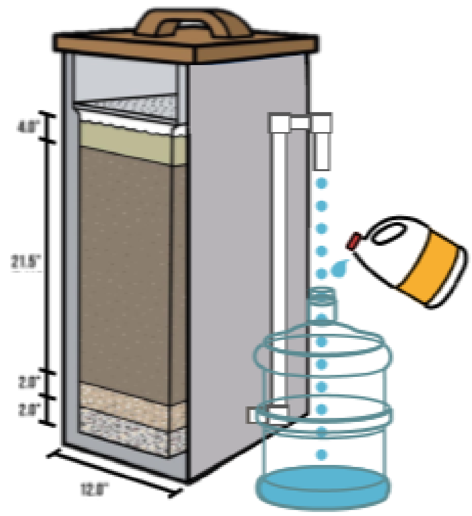
Manual de Construcción

El Filtro de Agua Bioarena de Seis de Mayo
Enero, 2014



SOBRE Filtro de Agua BioArena de Seis de Mayo

En 2008, estudiantes en el grupo "Ingenieros sin Fonteras" (Engineers Without Borders) de Oklahoma State University conocieron a la comunidad de Seis de Mayo, Honduras. Trabajando con la organización de caridad que se llama "Gathering Hearts for Honduras," los estudiantes empezaron a evaluar los problemas con la calidad del agua en la comunidad. En sus investigaciones por una solución efectiva y económica, encontraron un sistema de filtraction con Bioarena desarrollado por el Centro de Agua Asequible y Tecnología Sanitarias (Center for Affordable Water and Sanitation Technology.) Los filtros eran una solución sostenible para resolver los problemas en Seis de Mayo. Sin embargo, los materiales y trabajo aparecieron requerir demasiado dinero. El equipo de ingenieros intentó mejorar el diseño y algunos aspectos de la construcción para que pudiera usarlo en Seis de Mayo y ortos comunidades.



Este documento contiene un aspecto de los cambios diseñados por los estudiantes, específicamente la construcción y montaje del molde de madera, caja de concreto, y los contenidos de arena y grava (arena gruesa.) Eric Lam creó el diseño en La Universidad del Estado de Oklahoma (Oklahoma State University) en Stillwater, Oklahoma, EEUU. Fue probado y implementado en Seis de Mayo, Honduras. Todas las palabras y imágenes son disponibles por uso libre según la licencia Creative Commons.

Más información y los manuales más recientes se puede encontrar por en el sitio web www.aguaseis.org

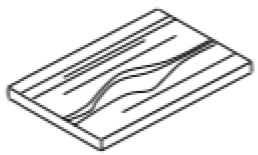
Heidi C.Wallace tradujo este documento diciembre 2013.

UNO	Los Materiales
DOS	Cortar la Madera
TRES	Construir los Moldes
CUATRO	Preparar la Arena y la Grava
CINCO	Verter el Concreto
SEIS	Extraer el Filtro del Molde
SIETE	Instalar el Filtro
OCHO	El Filtro Completado

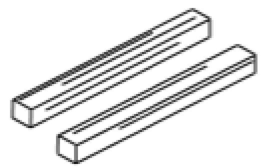
UNO Los Materiales

La lista completa para construir un filtro de agua. La disponibilidad y el tamaño real pueden cambiar en regiones diferentes. Las dimensiones es este hoja son recomendaciones.

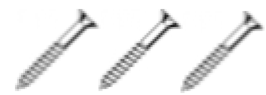
MATERIALES PARA CONSTRUIR LOS MOLDES DE MADERA



1 4X8' 1/2" madera contrachapada gruesa



2 2X4" 8' viga

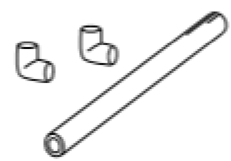


1/2 lb of 2" tornillos

MATERIALES PARA CONSTRUIR LOS CONCRETO

3 80lb bolsa de concreto
-o-
Una bolsa de cemento

Una montón de arena y grava

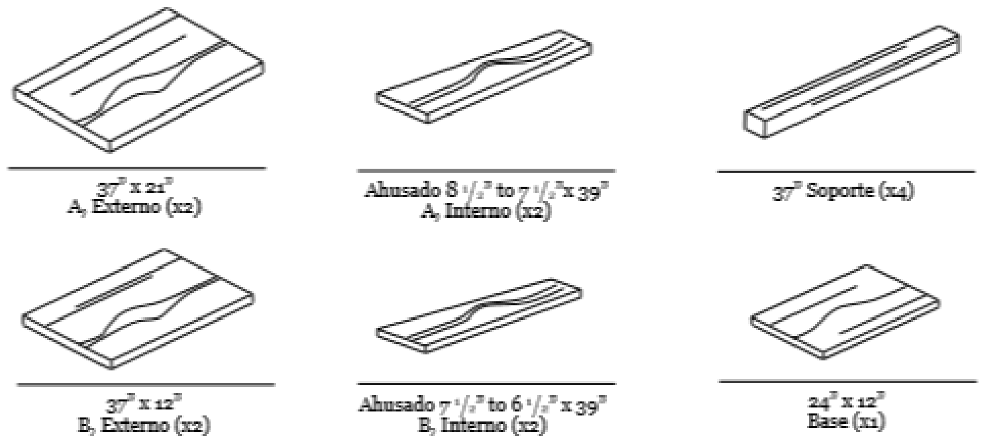


6' of 1/2" Tubo de PVC
+
2 Codo de PVC

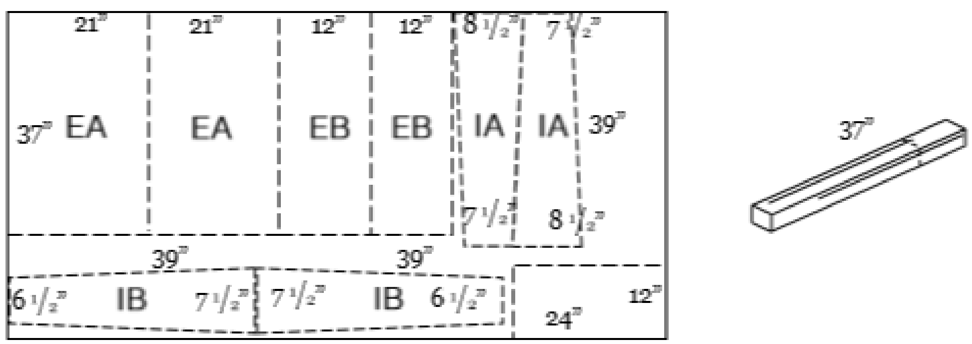
DOS Cortar la Madera

Esas partes son usadas en la construcción de los moldes internos y externos. Todos los cortes pueden ser completados con una sierra circular en la mano. Lo más linear los cortes, lo mejor el molde y por lo tanto el filtro de agua.

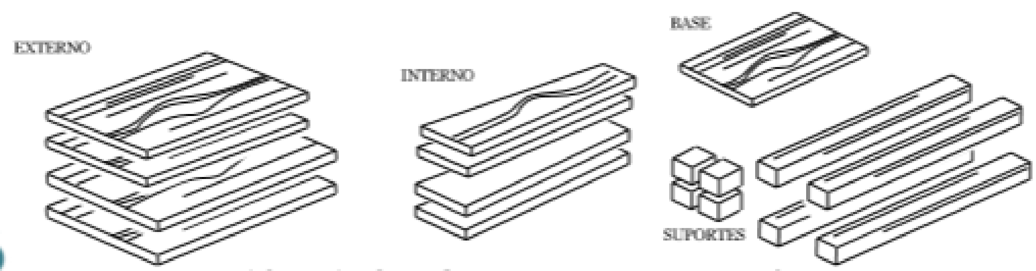
TAMAÑO Y NOMBRE DE LAS PIEZAS



RECOMENDACIÓN PARA CORTAR LA MADERA



LAS PIEZAS COMPLETAS PARA CONSTRUIR UN MOLDE

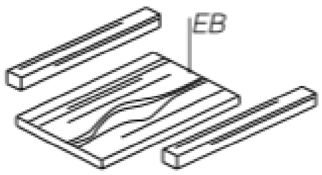


AguaSeis

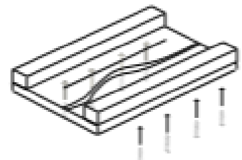
TRES Construir los Moldes (Molde Externo)

El molde externo contiene el concreto y el molde interior.

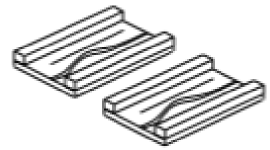
EL PROCEDIMIENTO PARA CONSTRUIR EL MOLDE EXTERNO



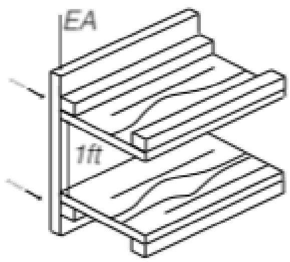
1. Ponga los dos suportes en B externo



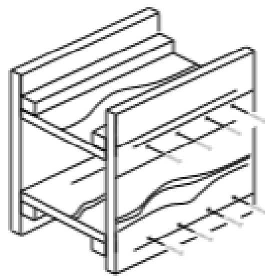
2. Ponga 8 tornillos por pieza EB a los soportes



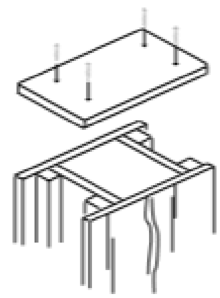
3. Repita pasos 1 y 2 con la segunda pieza externo B



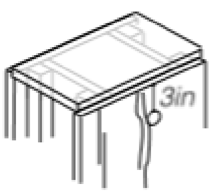
4. Ponga 8 tornillos por una pieza A externo a los soportes/piezas EB. Asegure que hay un pie (12 pulgadas) entre las piezas EB



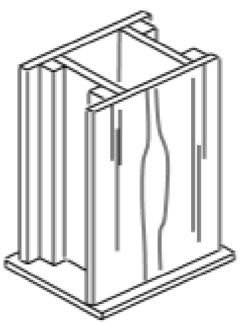
5. Sujete la segunda pieza EA al otro lado del soporte/pieza EB



6. Ponga la parte superior en el suelo y sujete el base



7. Taladre un agujero tres pulgadas por encima del base. El agujero debe ser de tamaño suficiente para insertar un PVC de 1/2 pulgada fácilmente.

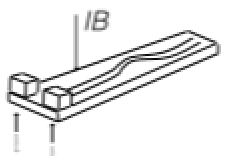


Molde Externo

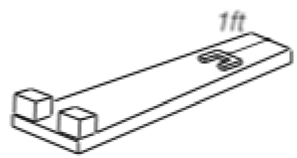
TRES Construir los Moldes (Molde Interno)

El concrete va a estar entre el molde interno y el molde externo.

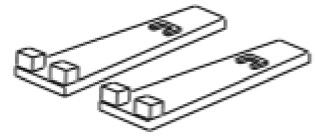
EL PROCEDIMIENTO PARA CONSTRUIR EL MOLDE INTERNO



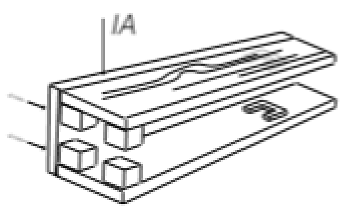
1. Conecte dos soportes pequeñas a la pieza B interno con tornillos.



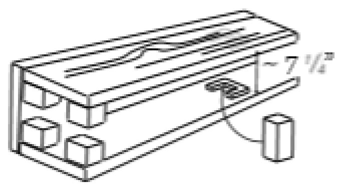
2. Ponga un soporte especial 12 pulgadas encima del lado más corto de la pieza IB.



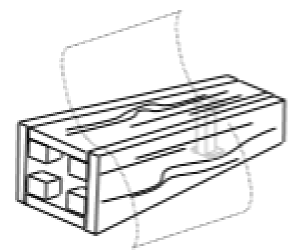
3. Repite los pasos 1 y 2 con la otra pieza IB.



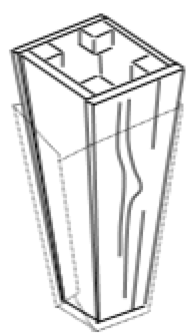
4. Conecte las IA y IB con dos tornillos por sus suportes. Asegure que las piezas IB están al mismo nivel.



5. Mida la distancia entre los soportes especiales y corte un soporte de la misma longitud de la distancia entre los soportes especiales. También asegure que todos los tonillos son accesíbles cuando el molde está rodeado con concreto.

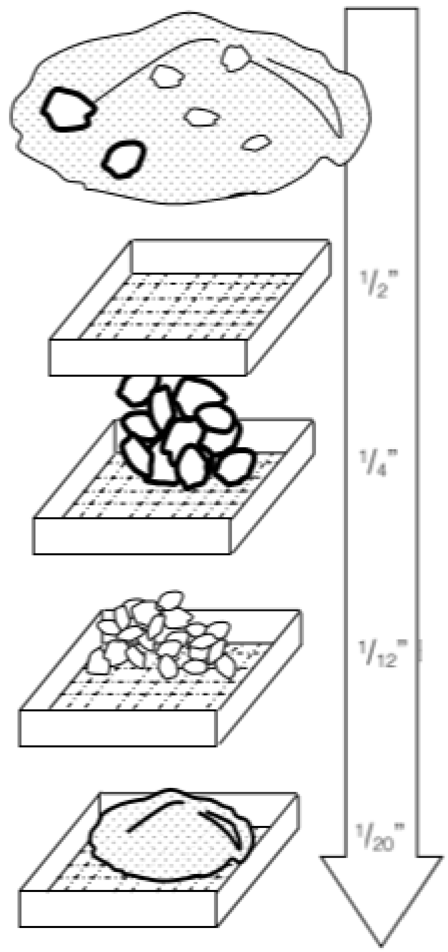


6. Envuelva la parte externo del molde interno con una hoja de plástico asegurando que el soporte del paso 5 no mueve. Asegure que el base está completamente cubierto en plástico.

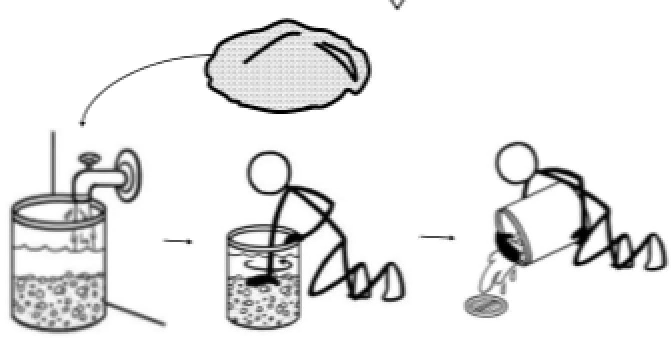


Molde Interno

CUATRO Preparar la Arena y la Grava



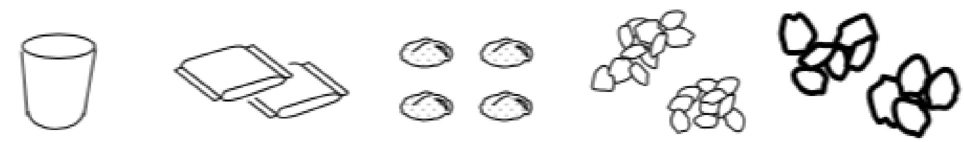
1. Empiece con una pila grande de arena y grava
2. Remueve piedras más grande de 1/2 pulgada (1/2"). No necesita estas.
3. Guarde la grava grande (1/4"-1/2")
4. Guarda la grava pequeña (1/12"-1/4")
5. Guarde la arena grande (1/20"-1/12")
6. Guarde la arena pequeña (less than 1/20")
7. Lave la arena pequeña
   - A. Ponga un poco arena en el contenedor con una cantidad igual de agua
   - B. Revuelve la arena en el agua
   - C. Eche el agua sucia. Repita 3 a 5 veces



CINCO Verter el Concreto

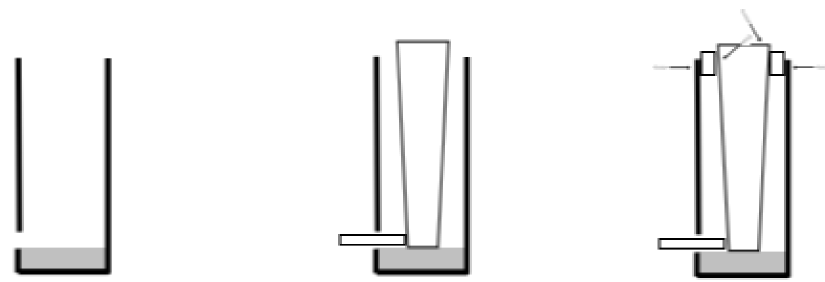
Si usted no tiene concreto prepreparado, puede usar las materiales de parte CUATRO en su concreto

LA RECETA RECOMENDADA



1 parte agua | 2 partes cemento | 4 partes arena grande | 2 partes grava pequeña | 2 partes grava grande

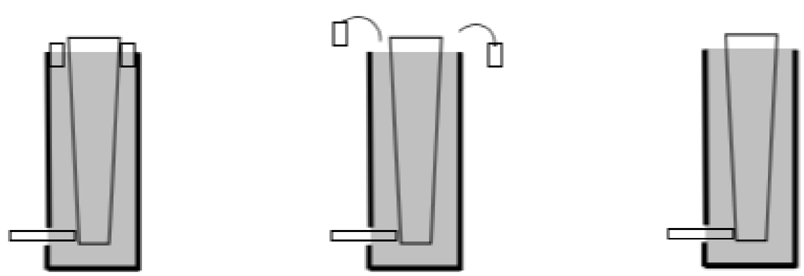
EL MÉTODO PARA CONSTRUIR LA CAJA DE CONCRETO



1. Vierta aproximadamente 2 pulgadas del concreto en el molde externo, debajo del agujero

2. Coloque el molde interno en el molde externo e inserte una sección de PVC en el agujero. El PVC debe tocar el molde interno.

3. Conecte dos soportes a la parte superior entre los dos moldes.



4. Llene el espacio entre los dos moldes con concreto hasta la parte superior del molde externo.

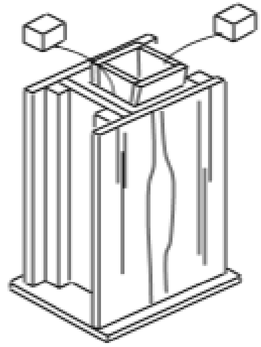
5. Opcional: remueve los soportes y llene los espacios donde estaba con concreto.

Molde de Madera y Caja de Concreto

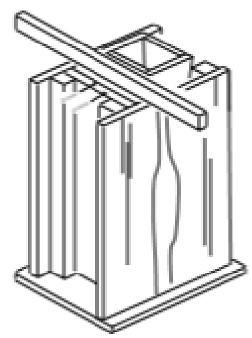
SEIS Extraer el Filtro

A veces es necesario a tratar más de una vez a remover la primera parte del molde interno. Cuando la primera parte está removida, las demás se aflojan fácilmente.

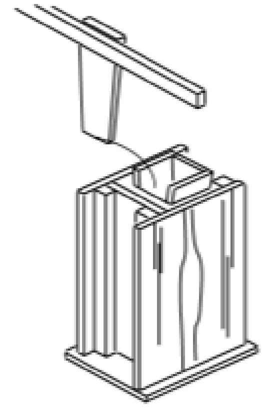
WOODEN MOLD DISASSEMBLY PROCEDURE



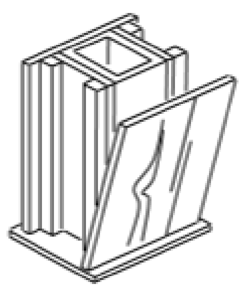
1. Remueve los soportes si no los removió en CINCO paso 5.



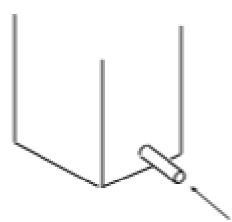
2. Conecte una pieza del molde interno a un soporte largo.



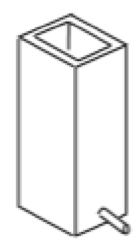
3. Tira la pieza y remueve del concreto. Repita con los tres otras piezas.



4. Quite todos los tornillos y remueve el molde externo con cuidado porque no quiere mover el PVC.



5. Mire en el PVC para estar seguro que no hay concreto en el tubo. Si hay concreto en el tubo, puede usar barras de acero de refuerzo a quitarlo.

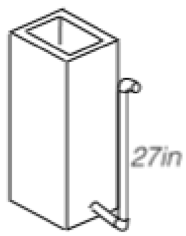


Caja de Concreto

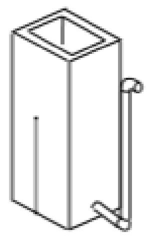
SIETE Instalar el Filtro

Es importante que el filtre contiene agua antes de llenarlo con arena para prevenir la formación del espacios en la arena

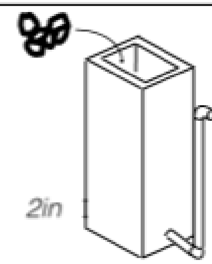
FILTRATION MEDIUM LOADING PROCEDURE



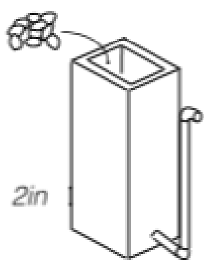
1. Adjunte el PVC largo al PVC que ya está en el concreto.



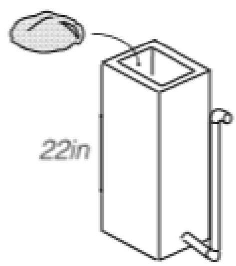
2. Llene el filtre a medias con agua. Si hay algunas fugas, llene los espacios con concreto.



3. Con el agua en el filtro, vierta grava grande hasta que hay 2 pulgadas en el filtro.

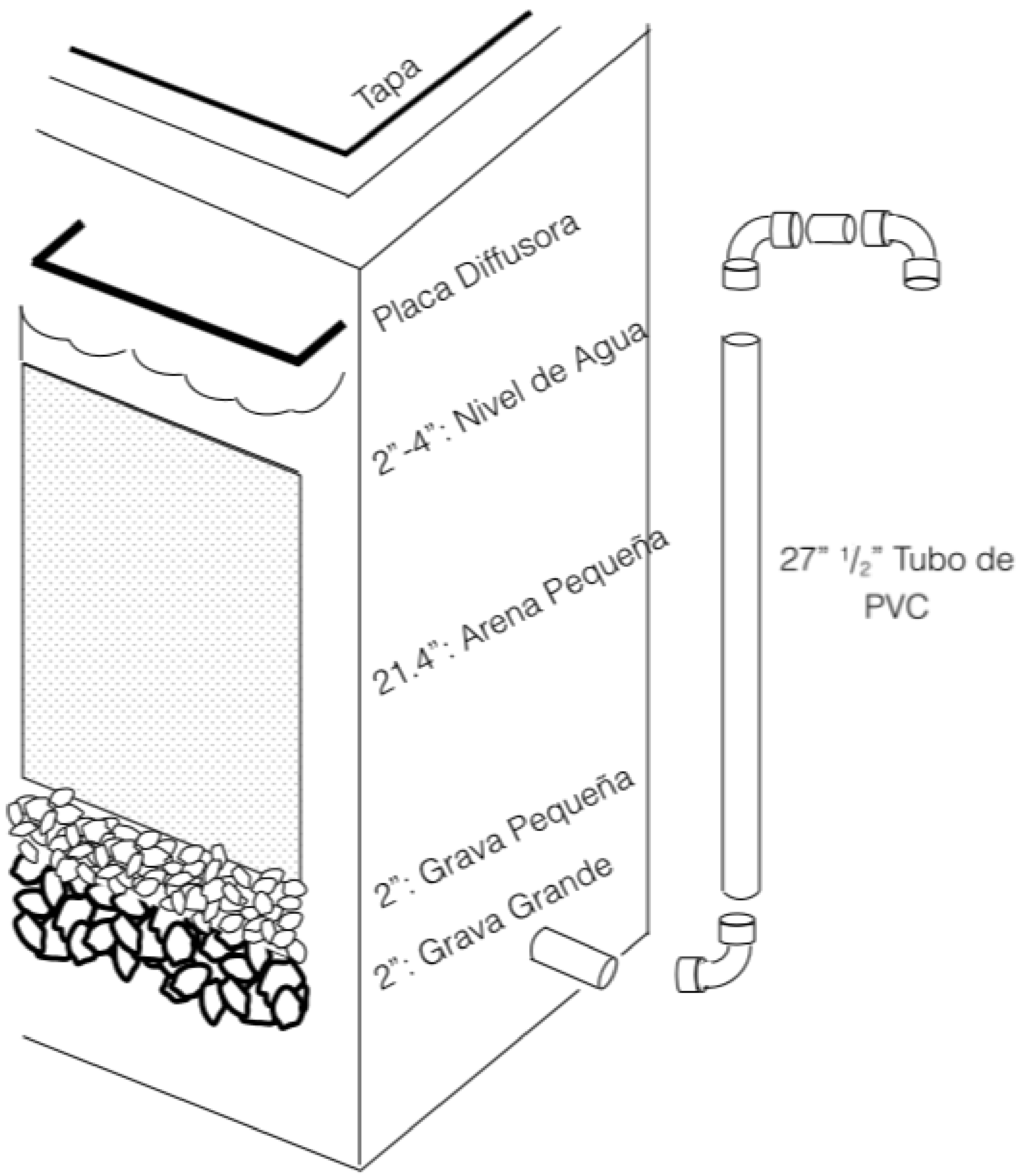


4. Con el agua en el filtro, ponga dos pulgadas de grava pequeña en el filtro.



5. Con agua en el filtro, ponga 22 pulgadas del arena pequeña (que estaba limpiada en CUATRO paso 7) en el filtro.

OCHO El Filtro Completado



VITA

Eric Lam

Candidate for the Degree of

Master of Science

Thesis: INVESTIGATIONS IN TO THE EFFECT OF INFLUENT TOTAL ORGANIC CARBON CONCENTRATIONS ON BIOSAND WATER FILTRATION EFFICIENCIES AND IMPLEMENTATION IMPLICATIONS IN HONDURAS

Major Field: Environmental Engineering

Biographical:

Education:

Completed the requirements for the Master of Science/Arts in Environmental Engineering at Oklahoma State University, Stillwater, Oklahoma in May 2014

Completed the requirements for the Bachelor of Science/Arts in Biosystems and Agricultural Engineering at University/College, City, State/Country in Year.

Experience:

Developed the Greenseeder seed planter for use in the developing world, in Stillwater, Oklahoma, from November 2010 to present.

Worked on software for Microfirm Incorporated used on agricultural machinery, in Stillwater, Oklahoma, from May 2012 to January 2013.

Professional Memberships: NA