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THE BIOSAND FILTER, SIPHON FILTER, AND RAINWATER HARVESTING:

Strategic Recommendations for New Water Treatment Technologies and Safe Water Storage to Pure Home Water

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by

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ABSTRACT

Unsafe drinking water is a major cause of water-related diseases that predominantly affect people living in developing countries. In Northern Ghana, the area of focus of this research, 37.5% of people use unimproved, unsafe drinking water sources leading to a high incidence of water-related disease. Diarrhea is the most prevalent water-related disease in the area, contributing to 12% of deaths in children under five and 5% of death across all age groups. Guinea worm is also a major concern, with Ghana recording 147 new cases in the first three months of 2009, the highest incident rate in the world.

This research focused on provision of safe drinking water through the use of household and community scale technologies use in Northern Ghana. The siphon filter is a new household-scale water treatment technology that was evaluated in households in Northern Ghana using water quality analysis and an Effective Use survey, which determined how properly the technology was used. The average percent removals were 90.7% for total coliform and 94.1% for *E. coli* (excluding samples showing negative percent removals). However, these values may have been affected by recontamination and true filter performance may have been more effective. The distinction between middle and lower class households was not found to influence how effectively the siphon filter was operated. Use of high turbidity water was found to affect siphon filter performance in households: the filter clogged frequently with high turbidity water, partially because study participants did not consistently maintain the filter. Recontamination of filtered water was also found to be an issue. If this issue were resolved, the siphon filter would be recommended for households drinking low turbidity water in Northern Ghana over other treatment options considered (i.e. the *Kosim* pot filter and chlorine). Alum plus chlorine treatment is recommended for most households drinking turbid water, with the siphon filter as an alternative treatment method for households desiring a more permanent treatment technology, again if the siphon filter recontamination issue were resolved.

The biosand filter, an established household-scale slow sand filtration water treatment technology, was modified through the addition of a second sand layer for use with high-turbidity surface water commonly used in Northern Ghana. Field testing of the dual sand layer biosand filter showed this filter achieved 59% turbidity reduction, 38% higher than an unmodified control filter; and at least 85% *E. coli* and 95% total coliform reductions, comparable in performance to unmodified control filters. Laboratory testing demonstrated minimum average reductions of 93% turbidity, 97% *E. coli* and 71% total coliform after filter maturation, comparable to unmodified control filter results.

Rainwater harvesting presents an opportunity to extend water supply to rural dwellers where few other alternatives are available. Rainwater supplies ranged from low (1 to 10

E. coli CFU/100ml) to intermediate risk (10-99 *E. coli* CFU/100ml.) Time-based reliability ranges from five percent to ninety-nine percent. The unit cost of water from designs surveyed by Barnes (2009) ranged between approximately $\$1/m^3$ and $\$10/m^3$. At the lower end, this cost is comparable with the cost of Ghana's municipal piped water supply. On the upper end, it is approaching the cost of sachet water. Those with the most ability to pay in urban areas are those who are in least need of rainwater harvesting. The feasibility of low-cost underground storage should be investigated. Also, means of improving informal rainwater harvesting efforts should be pursued. A Kosim filter is recommended to improve both rainwater quality and supplementary source water.

Recontamination of treated or collected water is also a major concern and it is recommended that siphon and biosand filter treated water and harvested rainwater be stored in a dedicated container with tight fitting lid and tap dispenser.

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APPENDICES

LIST OF ABBREVIATIONS

BSF	Biosand Filter
BWN	Basic Water Needs Foundation
CAWST	Centre for Affordable Water and Sanitation Technology
CFU	Colony Forming Units
CWSA	Community Water and Sanitation Agency
DO	Dissolved Oxygen
E. coli	*Escherichia coliform*
E.U.	European Union
GDWQ	*Guidelines for Drinking Water Quality,* produced by the World Health Organization
HWTS	Household Water Treatment and Safe Storage
IU	Instructions of Use
JMP	Joint Monitoring Programme
LPD	Local Plastic Design
MDG	Millennium Development Goals
MF	Membrane Filtration
MIT	Massachusetts Institute of Technology
NTU	Nephelometric Turbidity Unit
PHW	Pure Home Water
POU	Point-Of-Use
SFFS	Siphon Filter Fact Sheet
TWF	Tulip Water Filter
UNICEF	United Nations Children's Fund
USA	United States of America
USD	United States Dollar
WHO	World Health Organization

Introduction

This report evaluates the potential of two household water treatment and safe storage (HWTS) technologies, the siphon filter and the biosand filter, for marketing by PHW. Sara Ziff researched the siphon filter, a household scale ceramic water filter, in order to determine technology performance, social acceptability and an appropriate marketing strategy based on household income and water source types. Clair Collin researched design modifications to the biosand filter for use with high turbidity water as a technology that PHW could develop further and market.

Additionally, rainwater harvesting (RWH) was evaluated as a potential household- or community-scale water supply technology. David Barnes researched current RWH practices in Northern Ghana, and identified successes and areas for improvement.

Further details of the siphon filter, biosand filter and rainwater harvesting technologies and research in Northern Ghana are available in the following Master of Engineering Thesis reports written at MIT, 2009:

Ziff, S., Siphon Filter Assessment for Northern Ghana

Collin, C., Biosand Filtration of High Turbidity Water: Modified Filter Design and Safe Filtrate Storage

Barnes, D., Assessment of Rainwater Harvesting in Northern Ghana

Clean Water Supply in Developing Countries

Access to safe drinking water is critical to maintaining good health. The World Health Organization (WHO) and United Nation's Children's Fund (UNICEF) Joint Monitoring Programme for Water Supply and Sanitation estimate that 1.5 million children will die of diarrheal disease this year resulting from the lack of access to sanitation (JMP, 2008). The water-borne disease rate is much higher than this figure if other water-related illnesses due to pathogenic microorganisms such as guinea worm, cholera, typhoid and schistosomiasis are considered. Additionally, access to safe water and sanitation is fundamental to gender equity, as 71% of household water is collected by women or girls (JMP, 2008). Figure 1 shows the percentage of population, by country, with access to safe water.

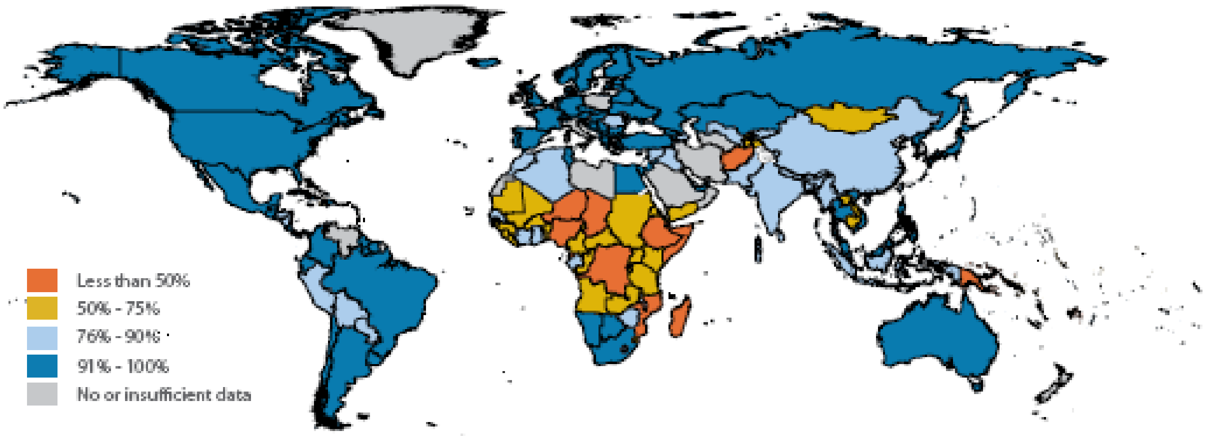

Figure 1: Global Drinking Water Coverage 2006 (WHO-UNICEF JMP, 2008)

In a move to eradicate poverty the United Nations set eight Millennium Development Goals (MDG) to meet the needs of the world's poorest by 2015 (UN, 2008a). Goal 7: Environmental Sustainability, Target 10 is to "Halve, by 2015, the proportion of people without sustainable access to safe drinking water and sanitation" (UN, 2008a). Since the implementation of the MDGs, it is estimated 1.6 billion people have gained access to safe water (UN, 2008b), however, it is estimated that 784 million people worldwide need to gain access to safe drinking water in order for the drinking water goal to be met (JMP, 2008). Even assuming this goal is met, the world will still be millions of people short of "Clean Water for All," as 11% of the population in developing regions will still lack access to safe drinking water. Information to date indicates that Sub-Saharan Africa is making the slowest progress towards meeting the MDG target, making up one third of the population still needing safe drinking water (JMP, 2008).

Clean Water Supply in Ghana

Ghana Country Profile

Ghana is a West African country bordered to the north by Burkina Faso, to the west by Côte d'Ivoire, to the east by Togo and to the south by the Atlantic Ocean. It has a population of 23 million people. The climate in the Northern Region is dry and hot, while the climate in the South is more humid. Agriculture accounts for 37.3% of total GDP and 56% of the labor force is employed in farming. Ghana is rich in natural resources and its industries include mining and lumbering (CIA, 2008). The life expectancy in Ghana is 59 and 60 years respectively for men and women (Ansah, 2006). Figure 1.2 shows the Northern Sector of Ghana, which is comprised of three regions: the Northern, Upper West and Upper East. The field study for this thesis was conducted in the city of Tamale, which is the capitol of the Northern Region.

Clean Water Situation

Ghana currently suffers from shortages in clean drinking water, particularly in the Northern Region, where 40% (CWSA, 2009) of people use unimproved[1] sources of drinking water. As a result, incidence of water-borne disease is high. Water-borne diseases in Ghana include diarrhea, hepatitis A, typhoid, cholera and guinea worm. While guinea worm has been eradicated in almost all places in the world, Ghana still experienced 501 cases in 2008 (CDC, 2009), the second highest rate in the world, after Sudan. Over the period January to March 2009, Ghana recorded 147 new cases of guinea worm, the highest number of cases for any country (The Carter Center, 2009).

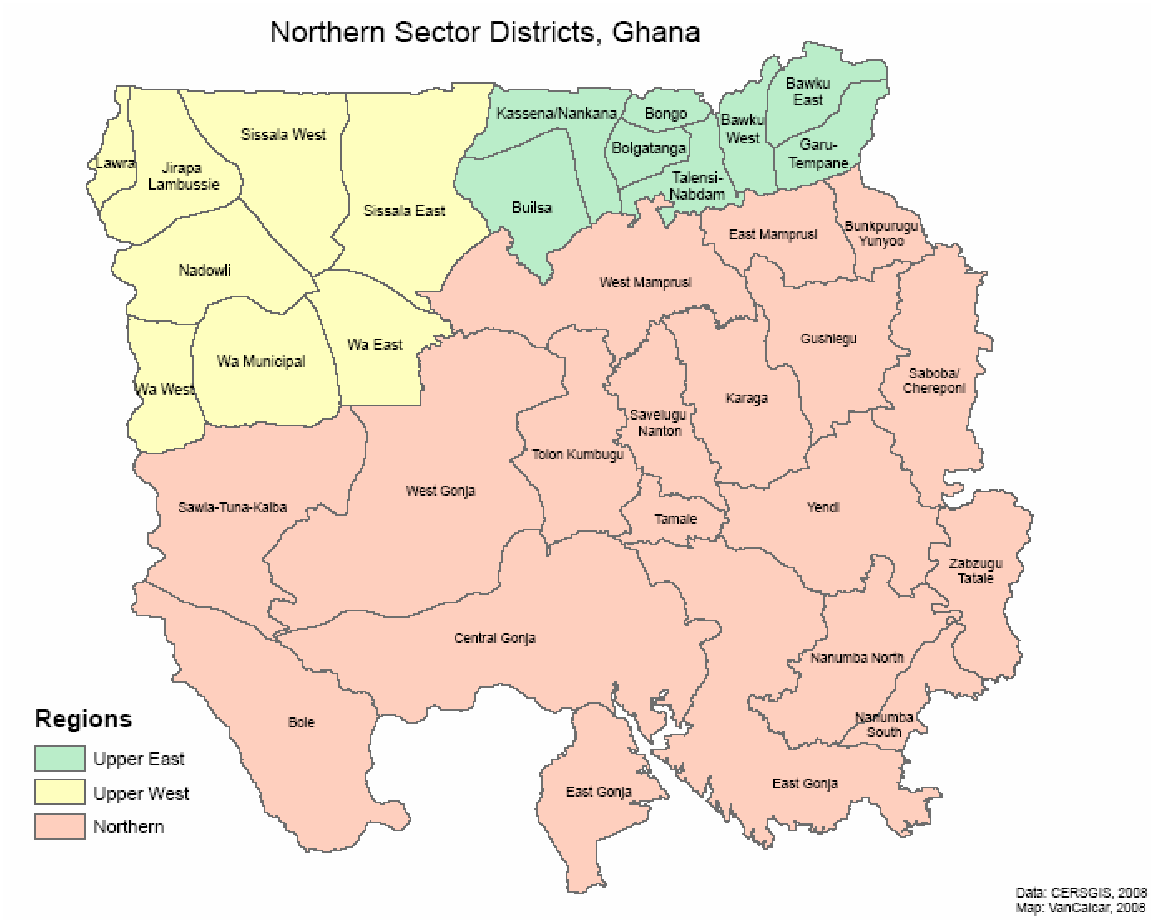

Figure 2: Map of Northern Sector districts of Ghana (VanCalcar, 2008)

[1] The JMP defines an improved drinking water source as one that is likely to protect the water source from outside contamination. Improved drinking water sources include the following: piped water in dwelling, plot or yard; public tap / stand pipe; tube well / bore hole; protected dug well; protected spring and rainwater collection. Unimproved drinking water sources include: unprotected dug well; unprotected spring; cart with small tank / drum; tanker truck; surface water (river, dam, lake, pond, stream, canal, irrigation channel) and bottled water

Waterborne diseases are spread through contaminated drinking water supply and through inadequate sanitation and hygiene practices. In the Northern Region, 37.5% of people use unprotected ponds, lakes or streams for drinking water supply. This problem is exacerbated by a lack of safe sanitation, again particularly in the Northern Region where 92% lack access to improved sanitation (VanCalcar, 2006). Figure 3 shows diarrhea prevalence among children under five years of age in the Northern Region. Diarrhea, which can result in severe dehydration, is a major contributor to morbidity and mortality of children under the age of five. Incidence of diarrhea in the Northern Sector of Ghana ranges between 15% and 27% in this age group (Ansah, 2006).

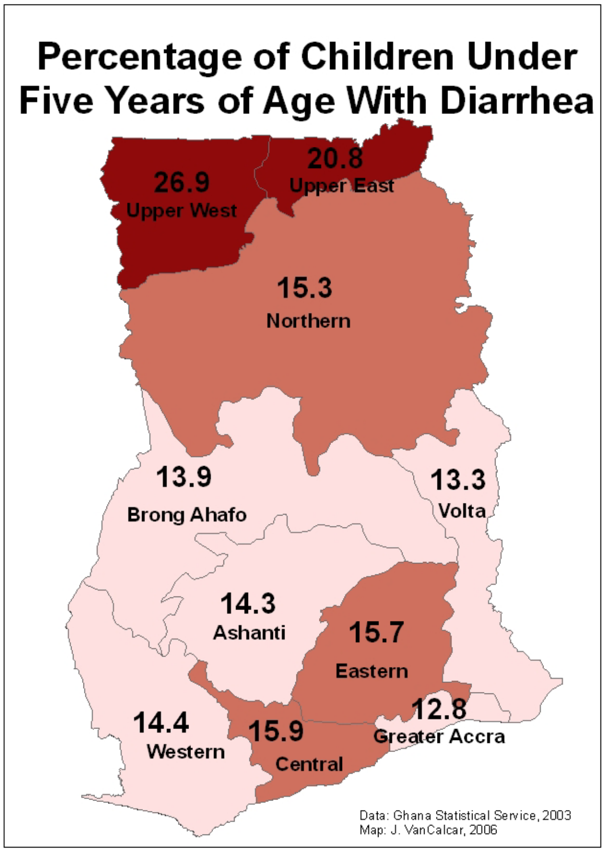

Figure 3: Percentage of children under five with diarrhea in the Northern Region (VanCalcar, 2006)

The WHO estimates that the Northern Region has a child under-5 mortality rate between 155 and 180 for every 1,000 live births (2003 data), of which 12% are attributed to diarrheal disease (WHO, 2006b). Diarrheal illness accounts for 5% of deaths across all age groups in Ghana (WHO, 2006b).

The goal of this report is to address this pressing issue and to help bring clean drinking water on a household and community scale to Northern Ghana.

Household Water Treatment and Safe Storage

In regions where safe water supply is not available, including areas in Northern Ghana, household water treatment and safe storage (HWTS) technologies are an effective alternative (Clasen, 2008). Additionally, HWTS can provide safe water more rapidly and affordably than it would take to design, install and deliver a piped community drinking water supply (Nath et al, 2006).

A meta-analysis of water, sanitation and hygiene interventions studying diarrhea morbidity as a health outcome carried out by Fewtrell and Colford (2004) concluded that water quality interventions, specifically HWTS treatment, reduced diarrheal illness levels in developing countries. Common HWTS technologies used in developing countries include the following:

- Boiling, thermal microbial deactivation
- Solar Water Disinfection (SODIS), UV radiation microbial deactivation
- Safe Water System, sodium hypochlorite disinfection combined with safe water storage
- NaDCC (sodium dichloroisocyanurate) dosing, chlorine disinfection
- Ceramic filters, filter usually impregnated with silver for its bactericide and viricide properties
- Biosand filters, mechanical and biological filtration through a sand bed
- Flocculation and disinfection systems, particle removal through flocculation combined with disinfection

Of these HWTS technologies, a technology involving a flocculation step is one of the most effective methods for treating water with high turbidity. The most common flocculation/ disinfection product available is PuR© produced by Proctor and Gamble. A study conducted in western Kenya using source water 100-1,000 NTU showed drinking water treated with PUR© had a turbidity of 8 NTU compared to 55 NTU using sodium hypochlorite treatment or traditional settling methods (Crump et al, 2005). Currently 60 million sachets of PUR© are produced each year which will increase to 160 million sachets per year in June 2009 (Allgood, 2008). Each PUR© sachet costs 10 US cents and is capable of treating 10 liters of water (CDC, 2009a). However, for many people living on less than a dollar a day in the developing world, this represents a significant ongoing expense. Furthermore, the PUR© product is not currently available in Ghana.

It is estimated there were 18.8 million people using HWTS (excluding boiling and emergency HWTS product use) in 2007, less than 2% of people without access to an improved drinking water source. Nevertheless, the use of HWTS has seen an annual growth rate of 15% over the last three years, although other than boiling no HWTS product has yet to reach scale in its coverage. (Clasen, 2008)

HWTS technologies currently used in the Tamale region to treat water collected from unimproved sources include ceramic filters, biosand filters, cloth filters, flocculation products (alum) and chlorine disinfection products (NaDCC). The United

Kingdom/South African joint venture, Biwater International, together with the Ghana Water Company Limited recently undertook expansion and rehabilitation of the Tamale Water Supply system (Biwater, 2009), providing improved drinking water to new parts of Tamale and outlying communities and improved service to existing parts of the system. Water sampling of Biwater reticulated supplies at the PHW office and in Kpanvo village, Tamale, undertaken in January 2009 by Collin (2009) indicated it was free from microbial contamination (as E. coli) and had low turbidity (1 NTU).

Pure Home Water Organization

Pure Home Water

Pure Home Water (PHW) is a social enterprise founded in 2005 by Susan Murcott and local partners in Ghana. PHW is the first organization of its kind seeking to disseminate and scale up household drinking water treatment and safe storage in the challenging environment of Northern Ghana, a region with high poverty rates, low population density, multiple tribes and local languages, strong religious identities – Christian, Muslim, Animist – water scarcity, and limited infrastructure. As a social enterprise, Pure Home Water operates on a break-even basis with retained earnings being fully reinvested into its work in the form of product quality monitoring, outreach and training, and capacity building.

Pure Home Water Organizational History

After receiving two year start-up funds from the Conrad N. Hilton Foundation in 2005, Pure Home Water (PHW) began selling a range of household water treatment and safe storage (HWTS) products in the Northern regions of Ghana including candle filters, safe storage containers and ceramic pot filters. During this time, PHW struggled with a lack of local management capacity and a general lack of awareness of HWTS. In response to these issues, PHW decided to concentrate on promoting and distributing a single HWTS product in order to gain the focus necessary to succeed. Accordingly the product line was narrowed to the Potters for Peace-type ceramic pot filter, which is locally branded as the *Kosim*[2] filter. Subsequently from 2006-2008, PHW focused solely on demand generation and sale of the *Kosim* filter.

PHW has faced many challenges and has taken some important steps to establish its organization, management and presence in the Northern Sector of Ghana. In 2007, PHW hired a managing director, a field manager and several new sales staff to cope with distribution and sales growth. As a result, the *Kosim* filter can currently be found in over 14,000 households in Northern Ghana, providing safe drinking water to over 100,000 people. Moreover, PHW has monitored filters in over 1,000 emergency distribution households during June to August 2008, as well as approximately 250 direct sales households as part of the Master's Thesis by Clopek (2009), gaining valuable feedback from customers as to how to improve the *Kosim* filter and outreach.

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[2] *Kosim* is a Dagbani word meaning "water from a ceramic pot" and "the best water." It is the drinking water that is served to guests.

But while PHW currently promotes and markets the *Kosim* filter, a mid-term goal is to market a variety of drinking water products successfully so that consumers have a range of choices. To this end Master of Engineering students from the Massachusetts Institute of Technology (MIT) (Cambridge, Massachusetts, USA) support PHW with research, development, monitoring, social impact and business studies. In the past this has included testing of existing products and actively researching potential new products to add to PHW's product line. This research is accessed on the Web at: http://web.mit.edu/watsan/project_ghana.htm.

Siphon Filter

Siphon Filter Introduction

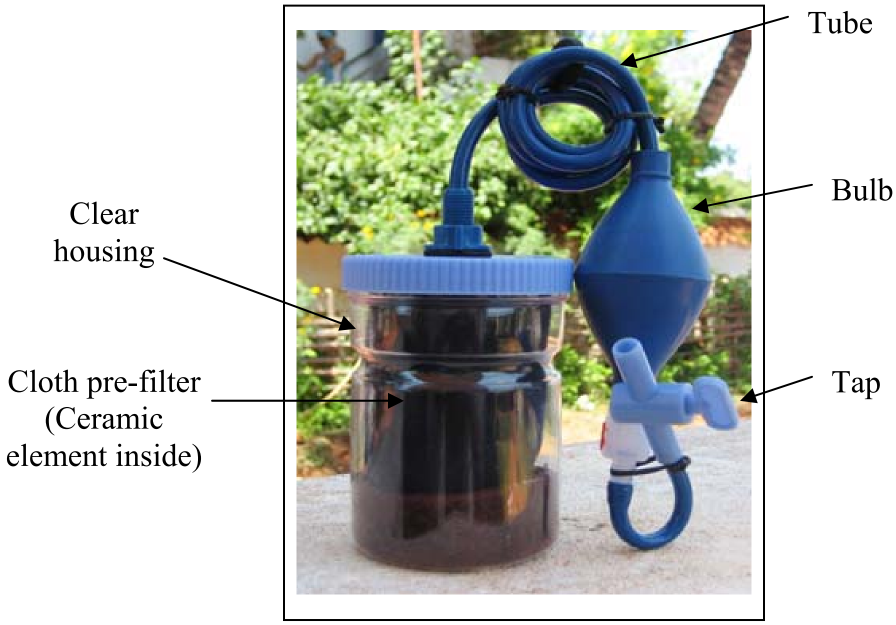

Figure 4: The siphon filter (BWN-SFFS, 2008)

The siphon filter is a household water filter developed by the Basic Water Needs Foundation (BWN) based on the design of ceramic candle filters. The siphon filter is marketed under brand names CrystalPur and Tulip and is currently sold for roughly US$8-12 (BWN-SFFS, 2008), though a new, third generation version of the filter[3] will cost roughly US$5 (Holtslag, 2009). An independent Dutch laboratory found log reductions of 4.4-5.5 for the filter (Wubbels, 2008), and the filter features flow rates of roughly 3-5 liters per hour (BWN-SFFS, 2008).

Lifetime

The manufacturer states that the siphon filter ceramic element can filter approximately 7,000-10,000 liters before needing to be replaced, depending on the turbidity of the water. This corresponds to roughly 1-1.5 years of use for a family of 2.5 people with a daily per person water usage of 7.5 L per day (BWN-SFFS, 2008; WHO, 2006). When used with extremely turbid source waters, this lifetime may be shorter. Basic Water Needs does not state an estimated lifetime for filter parts (e.g. tube, bulb, tap) other than the ceramic element for the current (second generation) version of the filter. However, the third generation version of the siphon filter is currently being developed to withstand five (5) years of use in full sun (van der Ven, 2009).

[3] The current (as of May 2009) version of the filter is the second version.

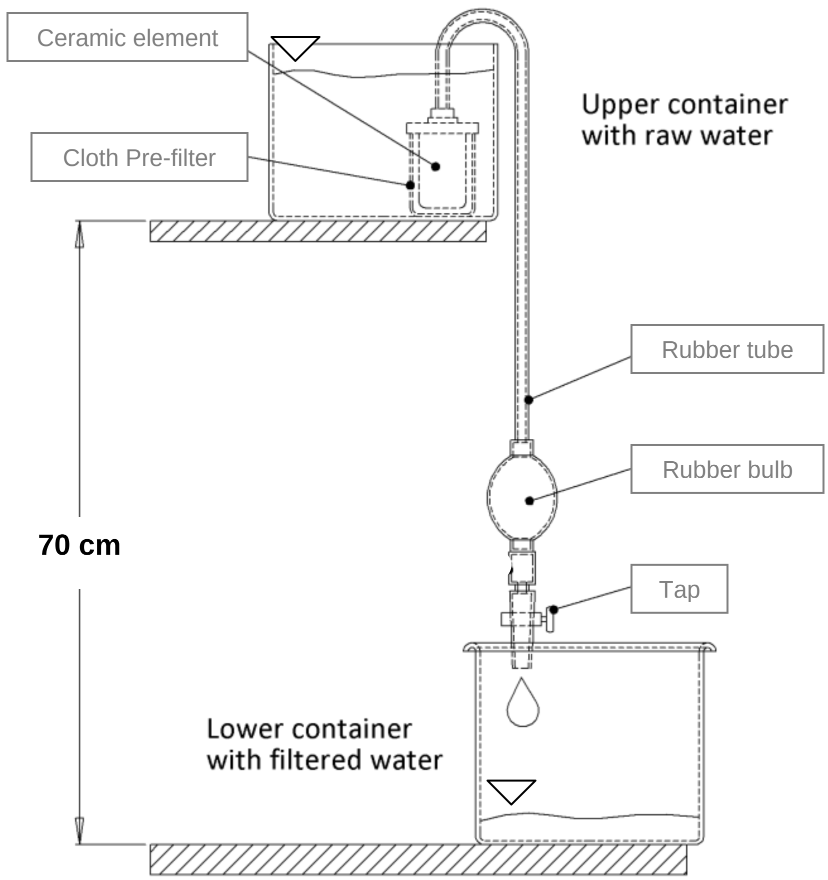

Figure 5: The siphon filter set-up (Tanzaniaqua, 2008)

Siphon Filter Use

A diagram of the siphon filter set-up is shown in Figure 5. To use the siphon filter, the ceramic filter element is removed from its plastic housing and placed in the user's own household water storage container. This upper container is ideally elevated to table height, approximately 70 cm above the height of a lower container for filtered water. The lower container is also the user's own. The filter tube transports water from the upper to lower container. Flow rate for the filter is greatest when there is maximum distance between the upper container water level and the level of the filter tap. If the upper container water level sinks below the level of the tap (which is typically impossible with a raised upper container), water will cease to flow.

Settling Turbid Water

When water is highly turbid, the manufacturer recommends settling the water for one (1) hour to reduce turbidity before filtration. This practice reduces the necessary frequency of scrubbing the ceramic element and lengthens filter life.

New Filter Use

When the filter is new, pressing the bulb must be repeated a few times to rid the filter of air before water flows. The manufacturer recommends soaking new filters in water overnight to cause water to flow more readily upon using filters the first time. The manufacturer also recommends discarding the first twenty (20) liters of filtered water, as ceramic particles from the element may leach when the filter is new. The ceramic particles may give an unpleasant taste or appearance to the water, but do not pose a health risk.

Cleaning the Filter

When particles build up within the ceramic filter element due to routine filtration, the flow rate decreases. Two mechanisms allow the user to clean the ceramic element to restore the flow rate: backwashing and scrubbing. Additionally, the cloth pre-filter catches large particles before they reach the ceramic element, and this cloth filter can be washed by hand.

To backwash the filter, the user closes the tap and presses the bulb, forcing water currently in the filter out through the ceramic element. This process washes clogged particles out of the filter. Basic Water Needs recommends backwashing once per day to maintain filter flow rate and to extend the life of the filter. When the filter is clogged, the user may need to backwash multiple times to restore the flow rate. To backwash more than once, the user waits after each press of the bulb until the bulb fills again with water.

If backwashing does not restore flow rate, the user can use the included scrub pad to remove a thin layer of ceramic material from the filter element. This action removes clogged particles from the filter, restoring flow rate. The user should scrub off as little ceramic material as possible, as scrubbing thins the filter and eventually reduces its effectiveness.

Replacing the Filter

An included end-of-life gauge indicates when the siphon filter element is too thin to work effectively. This gauge is located underneath the lid of the filter. When the gauge fits around the thinnest part of the ceramic element, the filter is too thin and must be replaced. To replace the filter element, the user removes the tube, unscrews a wing nut on the filter lid and replaces the old filter element with a new one.

Appendix B: Siphon Filter Instructions for Use Guide presents additional details of filter use.

Study Results

Ziff evaluated the siphon filter in twenty-four (24) households in Northern Ghana, including middle and lower class households using a variety of non-turbid and high turbidity water sources (Ziff, 2009). Microbial water quality tests (including Colilert ® and 3M™ Petrifilm™ tests, as detailed in *Appendix A*) were conducted on household stored water (i.e. upper container water for the siphon filter) and siphon filtered water; and an Effective Use survey was carried out to determine how properly the technology was used.

Initially, the field study was designed to avoid recontamination of siphon filtered water samples by taking filtered water samples directly from filter taps rather than sampling lower (post-filtration) container water. However, six (6) of forty-eight (48) total filtered water samples showed higher levels of contamination than household stored water samples, indicating that recontamination occurred despite sampling directly from taps. Two possible causes of recontamination included bacterial regrowth within the filter, and filter taps resting in dirty lower water containers or touched by dirty hands. Recontamination is believed to have been due to the latter cause, but further research is needed to confirm this conclusion.

The average percent removal of total coliform was 90.7%, and the average positive percent removal for *E. coli* of 94.1% (these values do not include the five and three samples respectively showing negative percent removals for total coliform and *E. coli*). However, these values may have been affected by recontamination and true filter performance may have been more effective.

Lack of proper filter maintenance by households was found to be a problem. Neither backwashing nor settling turbid water was readily adopted by households as methods to prevent filter clogging. Only six (6) of the twenty-four (24) households (25%) remembered when and how to backwash, and only two (2) households (8%) backwashed during the study. Since backwashing was not commonly practiced, this implies that scrubbing was the primary cleaning mechanism for the ceramic element for most households. Scrubbing was more easily understood and practiced: eight (8) households (33%) scrubbed the filter during the study; in all cases these households scrubbed before backwashing.

The distinction between middle and lower class households was not found to influence how effectively the filter was operated. Use of high turbidity water *was* found to affect filter performance in households: the filter clogged frequently with high turbidity water, partially because study participants did not consistently maintain the filter. Filter maintenance is less crucial for households drinking low turbidity water, and the filter clogged infrequently for these households, even with little maintenance.

Recommendations to PHW Regarding the Siphon Filter

Training and Instructions

The siphon filter is a fairly complicated technology, and it is crucial that users understand the filter in order to effectively treat their water and to ensure a long filter life. Maintenance practices such as backwashing are especially important for users of turbid water, and these practices were often neglected in the field study. Therefore, in order to help ensure that siphon filter users operate and maintain the filter properly, PHW should educate potential buyers. Two methods are recommended for siphon filter education: literature and training.

Filter Literature

Two forms of literature are recommended for PHW to distribute with the siphon filter and to use as a teaching tool during workshops:

- The *Instructions for Use* sheet (see *Appendix B*; modeled after the BWN IU guide, 2008) is recommended for users who can read English. The guide is also recommended for PHW employees to learn about the filter.

- The *Pictorial Guide* (see *Appendix C*) is recommended for all users. However, it is especially important that these pictorial instructions be used as a supplement to PHW instruction, rather than as the primary mode of learning about the filter. This is because some elements of filter use are not easily expressed succinctly by pictures (e.g. the importance of only scrubbing the filter if backwashing has been attempted and does not restore flow rate).

The pictorial instructions provided in *Appendix C* are specific to a conventional set-up: the upper container depicted is a bucket, which is elevated to table height. A second set of pictorial instructions should be developed that replaces this upper container depiction with a large clay pot used at ground level (Figure 6). This set-up is a reality for many rural and even urban households in Northern Ghana, and a specific pictorial diagram could address issues that arise with the set-up, namely the upper container water level sinking near to (or below) the level of the tap and reducing (or eliminating) flow rates.

Figure 6: Woman with large ceramic pot used as upper container for siphon filter

Filter Training by Pure Home Water

Although siphon filter literature is helpful for understanding filter use and maintenance practices, both at the time of initial use and in the home throughout use, Pure Home

Water should provide instruction to potential filter buyers through demonstrations of filter components and practices. It is important that users understand how to use the filter before purchasing it, to ensure the technology is right for them. PHW salespeople and trainers should also be able to answer any questions that arise while potential users learn about the filter.

Potential Marketing Groups and Comparison to Other Treatment Technologies

The siphon filter is one of several water treatment options applicable for Northern Ghana. These treatment options each have advantages and disadvantages that make them more useful for some groups of users than for others. The treatment options analyzed here are established options considered for marketing by Pure Home Water: alum (coagulation), chlorine (Aquatabs), the *Kosim* pot filter and the siphon filter.

Two criteria for screening the choice of treatment option are a customer's socioeconomic class and the type of water source used (turbid or non-turbid). The siphon filter was studied in middle and lower class households drinking a variety of non-turbid and turbid source water types, and the filter was found to be more appropriate for some of these household types than for others.

Socioeconomic Level

The results of this study indicate that the siphon filter is equally applicable to lower and middle class households in Northern Ghana. Although lower class households surveyed in this study more often drank high turbidity water, issues involving siphon filter use in these households were found to be a function of water type rather than of class level.

Households Drinking Low Turbidity Water

If the siphon filter recontamination issue were resolved, the siphon filter would be recommended for households drinking low turbidity water in Northern Ghana over the other treatment options considered. Table 1 shows a comparison of the treatment options considered for low turbidity water.

Table 1: Comparison of Treatment Options for Low Turbidity Water

Treatment Option	Pros	Cons
Siphon Filter	Low cost	Safe storage not included
	Small	
	Fast flow rate	
***Kosim* Pot Filter**	Integrated safe storage	Higher cost
		Large
		Slow flow rate
Siphon Filter	Infrequent purchase	Recontamination issue
	No wait	
	Fast flow rate	
Chlorine	Effective disinfection	Consumable
		Wait required
		Disinfection byproducts

The siphon filter is recommended over the *Kosim* pot filter because of the siphon filter's relatively low cost, small size and fast flow rate. However, the *Kosim* filter does offer integrated safe storage and is attractive for this reason over the siphon filter.

The siphon filter is recommended over chlorine for low turbidity water because chlorine is consumable and requires a substantial wait for treated water, while the siphon filter is more permanent and requires little wait for treated water.

The siphon filter is recommended for users with low turbidity water of any kind. Note that out of ten (10) households drinking piped water supplies for both household visits, only one (1) household (10%) showed undetectable levels of total coliform in both HSW samples, and 60% of these households showed greater than 10 CFU per 100 ml for *E. coli* (indicating intermediate risk or higher) in at least one HSW sample. (Piped water in Northern Ghana is also unreliable in terms of consistent delivery.) This indicates that the siphon filter is appropriate for use with piped water supplies in Northern Ghana as well as for dug well and borehole water, which typically are low turbidity (i.e. roughly under 30 NTU).

Pure Home Water employees should explain the siphon filter to all potential customers using a specialized siphon filter demonstration, and filter literature should be disseminated both during the demonstration and with the filter to buyers. While it is important for all users to understand filter use and to practice maintenance tasks such as backwashing, these tasks are not quite as crucial with low turbidity water. Additional practices such as settling and coagulation are not necessary for filter use with low turbidity water.

Households Drinking High Turbidity Water

Highly turbid water is defined for this siphon filter study as showing greater than 30 NTU. Table 2 shows a comparison of the treatment options considered for highly turbid water.

Table 2: Comparison of Treatment Options for High Turbidity Water

Treatment Option	**Pros**	**Cons**
Siphon Filter	Infrequent purchase Low cost	**Extensive maintenance** Recontamination issue
Alum plus Chlorine	**Simple** Effective disinfection	Consumable Relatively expensive Disinfection byproducts
Siphon Filter	**Cleaning options other than scrubbing** Fast flow rate	**Extensive maintenance required**
***Kosim* Pot Filter**	Less maintenance required	**Scrubbing only cleaning option** Slow flow rate

Alum plus chlorine treatment is recommended for most households drinking turbid water, with the siphon filter as an alternative treatment method for households desiring a more permanent treatment technology, again if the siphon filter recontamination issue were resolved.

The alum plus chlorine option requires the least maintenance of the treatment options for highly turbid water, a factor which is expected to be important for customers. Additionally, the chlorine residual provided means that safe storage is less crucial (though still important). However, alum plus chlorine is relatively expensive long-term, requires multiple purchases and a reliable supply chain for long-term use, and creates disinfection byproducts. Therefore alternative options were explored.

The siphon filter is preferred over the *Kosim* filter as an alternative to alum plus chlorine because while the *Kosim* filter can only be cleaned by scrubbing and features a slow flow rate, the siphon filter can be kept clean by other methods (e.g. backwashing) before scrubbing is needed, and has a considerably faster flow rate. Educating potential customers of the siphon filter is vital to ensure cleaning mechanisms are well understood and practiced, but the presence of these mechanisms makes the siphon filter a stronger technology than the *Kosim* filter for high turbidity water.

- *Pre-Filtration Coagulation with Alum*
  Coagulation of highly turbid water is expected to significantly lengthen siphon filter element life by removing a substantial fraction of particles from water before filtration, thereby decreasing the frequency of necessary scrubbing. However, the purchase of alum and the coagulation process would require additional money, time and effort. Therefore, Pure Home Water should explain and encourage coagulation with alum to potential siphon filter users drinking highly turbid water, but should not discourage siphon filter use altogether if users do not wish to adopt this practice.

The most appropriate option for users with highly turbid water in Northern Ghana seems to be alum plus chlorine for its simplicity of use and for the familiarity and availability of alum. However, the siphon filter may offer an attractive treatment device, and could be effective for users who diligently maintained the filter (if the post-filtration recontamination issue were resolved). The addition of alum is anticipated to make the siphon filter easier to maintain and longer lasting, but might entail too much effort or cost for some users. PHW should discuss these options with potential customers in order to encourage the most appropriate treatment option for each household.

Biosand Filter

Biosand Filter Introduction

Biosand filtration is a point-of-use (POU) water treatment technology widely used in developing countries to improve drinking water quality. The biosand filter (BSF) is a modification of slow sand filtration, a biological treatment process, which has been adapted for use where centralized facilities do not exist or have limited reliability/accessibility. The biosand filter was developed by Dr. David Manz at the University of Calgary, Canada, in the early 1990's by modifying traditional slow sand filtration technology for household use.

In Northern Ghana, plastic HydrAid™ brand BSFs have been distributed by International Aid and the E.U./UNICEF I-WASH program to selected villages. These filters are manufactured in the USA and available commercially for US$75 (International Aid, 2009), which is a significant cost for many people in the region who live on less than US$2 /day. Concrete filters are also available in Northern Ghana, typically constructed locally by attendees of one of several BSF construction, operation and training sessions organized by the Canadian Centre for Affordable Water and Sanitation Technology (CAWST). While these filters are a lot cheaper that the HydrAid, costing US$12-30, they are labor intensive to construct and when full weigh around 160 kg. Both of these filters are designed for use with low turbidity water (<50 NTU).

In 2008, Izumi Kikkawa constructed a plastic BSF entirely from locally available materials that cost US$16 (Kikkawa, 2008). In 2009, Collin continued this study, further modifying the local plastic design (LPD) BSF for use with the high turbidity water commonly used for drinking water in the region (Collin, 2009). This section of the report summarizes the findings of Collin's research and recommendations made to PHW for further BSF design optimization. Full details of this research are available in Collin's thesis: Biosand Filtration of High Turbidity Water: Modified Filter Design and Safe Filtrate Storage (2009).

Biosand Filter Set Up

A schematic layout of a plastic biosand filter, designed using products locally available in Tamale, is provided in Figure 7. The LPD BSF, originally constructed by Kikkawa, and reconstructed for Collin's research by PHW staff, is shown in Figure 8.

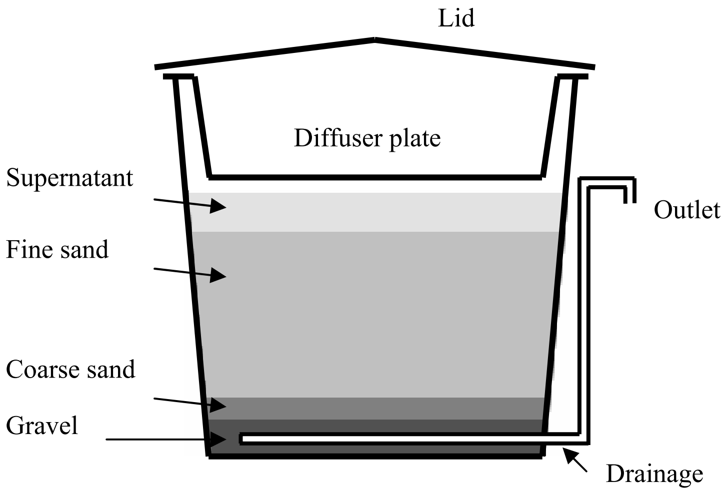

Figure 7: Schematic layout of a biosand filter

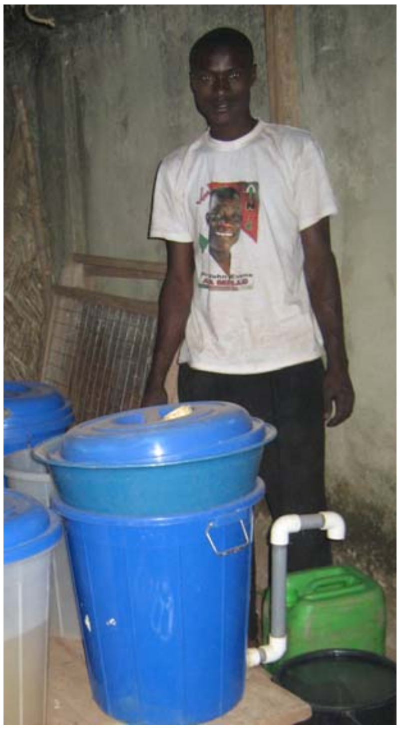

Figure 8: Local Plastic Design Biosand Filter

The key elements of biosand filter are outlined in Table 1.

Table 3: Biosand Filter Elements

Element	Description	Function
Filter shell	A 50 L plastic bucket locally available in Ghana (e.g. Decorplast brand)	Contains the sand filter media and water.
Filter lid	Tightly fitted to filter shell (e.g. Decorplast brand)	Prevents contaminants from entering the system
Diffuser plate	330 mm diameter plastic basin with ~45 1-2 mm diameter holes drilled or melted into the bottom.	Minimizes disturbance of the *schmutzdecke* during the filling cycle
Outlet pipe	½- or 1-inch PVC piping	Drains water from the bottom of the filter and hydraulically controls the top water level of the supernatant
Gravel layer	6 to 15 mm diameter gravel	Supports the sand in the filter
Coarse sand layer	3 to 6 mm coarse sand	Prevents the fine sand from dropping in to the gravel and either leaving the system with the filtered water or clogging the outlet pipe
Fine sand layer	<1 mm fine sand	Sand media that facilitates the mechanical and biochemical filtration of the water
Supernatant	5 cm deep water layer	Prevents the fine sand from drying out and allows oxygen to flow from the air to the sand for biological filtration

Filter operation

The BSF process works by passing raw water through a sand filter bed, where it is purified. The raw water initially enters the supernatant and then passes through the fine sand layer. On the surface of the fine sand layer, algae and other organic material from the raw water form a thin slimy zoogleal layer (Huisman and Wood, 1974), known as the *schmutzdecke* from the German for "sludge blanket" (AWWA, 1991).

The *schmutzdecke* is extremely active consuming dead algae and living bacteria from the raw water and converting them to inorganic salts. Simultaneously, a significant proportion of inert suspended particles are mechanically strained from the raw water. (Huisman and Wood, 1974)

As the water passes deeper into the filter, beyond the *schmutzdecke*, a sticky zoogleal mass of microorganisms, bacteria, bacteriophages, rotifers and protozoa, known as the biofilm, forms and coats the sand particles. Organisms in the biofilm feed on adsorbed impurities and other organic material (including each other) carried by the raw water, which becomes attached to the sand through mass attraction or electrical forces of attraction. The organic matter is broken down into inorganic matter such as water, carbon dioxide, nitrates, phosphates and similar salts that are removed by the flowing water. (Huisman and Wood, 1974)

When the filter is not being filled, during the pause phase, oxygen is depleted in the *schmutzdecke* and biofilm and the concentration of oxygen towards the bottom of the sand bed can become too low to support aerobic respiration. Live pathogens that reach this sand depth typically die as a result of the lack of oxygen (Ngai, 2009) and leave the BSF with the effluent.

The efficiency of the oxidation filtration process is also affected by disturbance of the biology. Disturbance typically occurs when the filter is cleaned or moved. Filter cleaning, by stirring the top 1 to 2 cm of supernatant to resuspend settled particles and decanting the dirty water, is required to maintain a sufficient filter flow rate. This method of cleaning is commonly referred to as “swirl and dump” cleaning. Movement of the biolayers during “swirl and dump” cleaning disturbs the system equilibrium and the biolayer must re-establish itself before optimal filter performance is achieved again, which often takes up to a week (CAWST, 2008). Movement of the filter should be avoided to prevent disturbance.

The filter should be stored away from direct sunlight to prevent algal growth in the system. Children and animals should be kept away from the BSF to prevent damage to the system from hanging off the outlet pipe, knocking the filter and causing disturbance of the biologically active layers or playing with the outlet pipe and contaminating the filtrate. Additionally, filtrate should be stored safely to prevent recontamination.

Filter Performance, Health Impact and Flow Rate

The BSF can achieve significant pathogen and turbidity reductions when used with low turbidity water, as shown in Table 4. Additionally, Stauber (2007) conducted a field trial of biosand filters in Bonao, Dominican Republic, and reported a 47% reduction in diarrhea amongst BSF users in comparison to non-users.

A summary of the removal efficiencies for the BSF is provided in Table 4.

Table 4: Biosand Filter Performance

Contaminant	Baseline reduction	Maximum reduction
Bacteria[1]	1-log	3-log
Viruses[1]	0.5-log	3-log
Protozoa[1]	2-log	4-log
Turbidity	84%[2]	96%[3]

1- Sobsey et al., 2008
2- Lee, 2001
3- Buzunis, 1995

The water flow rate through a BSF is controlled by the height of water above the fine sand layer (i.e. the pressure head) and the porosity of the fine sand. The design flow rate for the local plastic design (LPD) BSF is 15 – 20 L/hour, significantly faster than the *Kosim* Filter's 0.5 – 2.5 L/hour flow rate.

Study Results

Collin's (2009) research investigated options to modify the BSF such that it can be used to improve the quality of highly turbid source water. The design process involved two main steps:

1. Development of several design options, field testing of designs and selection of one design for further testing.
2. Optimization of selected design based on theoretical calculations and laboratory testing.

Field Tests in Tamale

Five filters, four LPD BSFs (BSFs 1 – 4) and one concrete BSF (BSF C) were set up at the PHW office and tested over a three week period. Prior to this test period, the filters had been fed for four weeks to ripen the filters. The water used to feed the filters was collected from the nearby Fuo Mwale dugout, which was used by locals as a domestic water supply source, and had an average turbidity of 115 NTU, *E. coli* concentration of 1,200 CFU/100 mL and total coliform concentration of 3,900 CFU/100 mL (for testing method details refer to Appendix A).

The first test run in Tamale involved operating all five filters under the same conditions to compare performance and to establish baseline performance for each filter, to which its modified performance would be compared. Each filter was fed 10 L of water from Fuo Mwale daily. Samples of the filtrate were collected after 5 L of water had passed through each BSF. The filtrate quality was then analyzed for turbidity, *E. coli* and total coliform concentrations (for testing method details refer to Appendix A). The filter performances during this control test are summarized in Appendix D Table D1.

Modifications were then made to some of the filters to test the effectiveness of the modification in improving filter performance. The modifications made are outlined in Table 5. Schematic diagrams of all five filters are provided in Appendix E.

Table 5: Biosand Filter Modifications, Tamale

Biosand filter	Modification	Aim of Modification
BSF 1	Double filling volume to 20 L	Investigate effects of exceeding filter capacity on filtrate quality
BSF 2	Addition of a second, separate fine sand layer	Additional filtration through separate sand layer
BSF 3	Addition of a 5 cm deep superfine sand layer (<0.7 mm)	Additional filtration though smaller sand pore size
BSF 4	No modifications	Control filter for comparing modified filter performance
BSF C	No modifications	Compare concrete filter performance of modified filters

The performance of the filters was then monitored for turbidity and total coliform quality and the results are shown in Appendix D Table D2. The performance during the modified filter tests was the compared to the filter performance during the control tests, as shown in Table 6.

Table 6: Change in BSF Performance after Modification, Compared to Control Tests

Biosand Filter	Flow Rate (L/min)	Average Turbidity Removal	Average *E. coli* Removal[1]	Average Total Coliform Removal
BSF 1	+79%	-4%	N/A	+2%
BSF 2	-59%	+38%	N/A	+4%
BSF 3	+52%	+16%	N/A	-7%
BSF 4	+50%	-9%	N/A	-3%
BSF C	+56%	+4%	N/A	+4%

1- Note: so many *E. coli* tests results fell into the range 10 – 99 CFU/100 mL, that performance results could not be accurately compared.

From the results, the modified dual sand layer BSF (BSF 2) performed better than the control BSFs and the superfine sand layer BSF (BSF 3) for both turbidity and total coliform removal efficiency. Due to the method of testing microbiological water quality (Colilert and 3M Petrifilm assays) the filter performances for *E. coli* reduction efficiency were inconclusive.

Considering that turbidity is an indirect measure of microbial count (Reynolds and Richards, 1996) the increased turbidity reduction achieved by BSFs 2 and 3 suggests that increased *E. coli* could have occurred and further testing of these systems should be conducted. The low flow rate of the dual sand layer BSF (BSF 2) resulted from the decreased filter freeboard available, which is a parameter that can be optimized through modifications to the filter layout.

The field testing of the dual sand layer BSF (BSF 2) showed promising turbidity and total coliform removal efficiencies and this filter was selected for further study and design optimization in the MIT laboratory.

Laboratory Tests at MIT

Two LPD BSFs, one single sand layer (BSF A) and one dual sand layer (BSF B) were operated and compared in the MIT laboratory to further study the dual sand layer filter design. The filter layouts are detailed in Appendix E. The filters were studied under four sets of operating conditions as outlined in Table 7. Prior to the commencement of the tests the filters had been fed for four weeks to ripen the filters. The water used to feed the filters was collected from the Charles River and dosed for turbidity with clay and for indicator bacteria with sewage. The feed water had an average turbidity of 180 NTU. *E. coli* concentration of 250 CFU/100 mL and total coliform concentration of 2,200 CFU/100 mL (for testing method details refer to Appendix A).

Table 7: BSF Tests Performed at MIT

Test	Type of Test	Aim of Test
1	10 L water feed per day. No "swirl and dump" cleaning.	Monitor filter baseline performance
2	Same as for Test 1, except "swirl and dump" cleaning included	Monitor effects of "swirl and dump" cleaning on filtrate quality, expected to be carried out in areas with high turbidity water every 3 days
3	Same as for Test 2, except filters filled 10 L water twice per day	Monitor effects of filling filters twice per day on filtrate quality
4	Same as for Test 2, except filters filled 20 L water	Monitor effects on filtrate quality of filling filters with more water than filter storage capacity

Filtrate samples were collected after 5 L of water had passed through each BSF. The filtrate quality was then analyzed for turbidity and microbiological quality through *E. coli* and total coliform concentrations (using Colilert tests, 3M Petrifilms and Membrane Filtration; for testing method details refer to Appendix A), the results of which are detailed in Appendix D.

The conclusions from the MIT laboratory study were as follows:

- *Water quality.* Comparing the performance of the two BSFs in this optimization study, the dual sand layer BSF performed slightly better in terms of indicator bacteria removal. There was no significant difference in the ability of the filters to remove turbidity.
- *BSF cleaning.* Comparing the results of tests 1 and 2, the 3-day cleaning program did not appear to have adverse effects on the quality of the filtrate. However, the BSFs were determined to have ripened only at the end of test 1, further testing of these scenarios should be conducted to confirm the results.
- *BSF filling frequency.* The effect of increasing the BSF feed frequency studied in test 3, showed that effluent quality both in terms of turbidity and microbiological concentrations decreased with increased frequency.
- *BSF filling volume.* The double of the fill volume in test 4, such that a volume of water greater than the filter storage capacity was poured into the filter during a filling cycle that lead to a notable decrease in effluent quality, both for turbidity and indicator bacteria concentrations.

Recommendations to PHW Regarding the Biosand Filter

It is recommended that the dual sand layer biosand filter be studied further, in particular in Tamale under local conditions. This would allow the use of high turbidity and microbially-compromised source water that is more representative of that found in dugouts and other unimproved drinking water sources in Northern Ghana. The use of the Charles River for water and the addition of clay for turbidity and sewage for indicator bacteria may not have truly represented the quality of dugout water and further investigations with local dugout water and other unimproved, high turbidity water sources should be conducted.

The "swirl and dump" cleaning program did not appear to have a significant impact on the filtrate quality, although theoretically it can be expected to have some impact. Longer-term studies investigating the effects of the swirl and dump cleaning method on the filtrate of both single sand layer and dual sand layer biosand filters would be beneficial in future design optimizations.

Experiments with the depth and layout of the upper sand layer in the dual sand layer BSF can lead to further system optimization. This would allow for a maximum amount of oxygen to reach the lower sand layer and support the *schmutzdecke* and biofilm.

The effect of reducing the depth of the lower sand layer to allow the dual sand layer BSF to fit into a 50 L plastic bucket should be further investigated to identify any impacts on the filtrate quality.

Further rigorous comparative testing of the single and dual sand layer BSFs in the field is highly recommended.

Safe Water Storage

Safe storage of filtered water is paramount to maintaining the quality of treated water, and therefore the health benefits that can be achieved with the siphon and biosand filters. Ensuring that safe storage practices and technologies are implemented as part of filter operation is critical to the success and sustainability of both the filters.

Unhygienic handling of water during transport or within the home can contaminate previously safe water (JMP, 2008). In particular, pathogens of fecal origin often recontaminate water that is initially of an acceptable microbiological quality when unhygienic handling practices are carried out (WHO, 2008).

Siphon Filter Safe Storage Container

In order to maintain the microbial quality of siphon filtered water and to help ensure that filtered water is clean at the point of consumption, a post-filtration safe storage container is recommended for marketing with the siphon filter. The safe storage container design in Figure 9 would connect directly to the siphon filter tap to prevent excessive touching of the tap with dirty hands and to prevent dust from entering the safe storage container. The safe storage container tube would be the same type as the siphon filter rubber tube.

Pure Home Water could modify an existing safe storage container for use with the siphon filter, and this safe storage container could be sold with the siphon filter. Potential buyers should be encouraged to purchase a safe storage container with the siphon filter, although they should be given a choice to use their own lower safe storage container instead. Safe storage should be emphasized in PHW siphon filter demonstrations (see *Training and Instructions* section, below). PHW should also instruct users to wash their safe storage containers with siphon filtered water (or with water disinfected by another method) to prevent contamination.

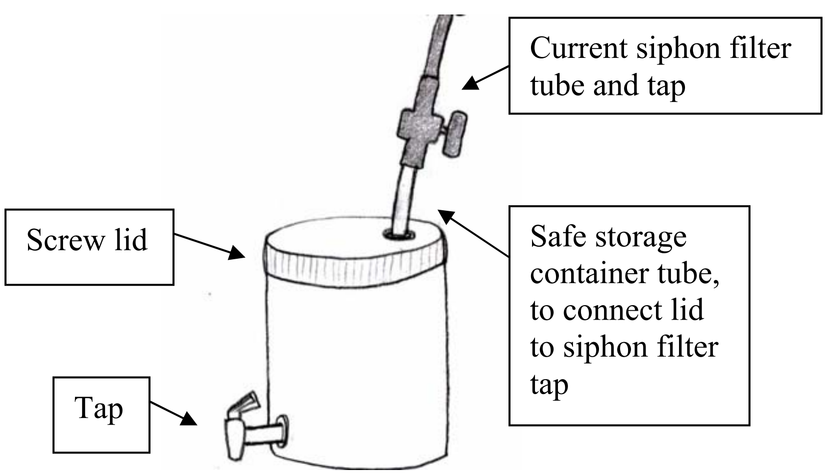

Figure 9: Possible safe storage container design

Additional testing of the siphon filter with a safe storage container is advised. If safe storage is found to remedy the siphon filter recontamination issue found by this study, then the filter would be more trustworthy.

Biosand Filter Safe Storage Container

This study originally intended to investigate the feasibility of integrating a safe storage vessel within the biosand filter. However, upon observing the practice in villages of filling the filter as the filtered water was required, and not storing water for later use, it was clear that this was a safer practice. By filtering water as it was needed, the risk of recontamination of the filtrate would be decreased by the reduction in exposure to contaminants such as children, animals and dirty hands and utensils. It is recommended that BSF distribution should be coupled with strong emphasis on using the filter as the water is required.

A safe storage container should be coupled with the BSF, and the vessel should be dedicated to use with BSF filtrate only and have a tight fitting lid to prevent contaminants from entering, people dipping in hands or contaminated utensils and animals causing contamination. A spigot tap should also be included as it removes need to dip cups, hands or utensils in to vessel. A clean water storage vessel, such as the safe storage bucket produced by Community Water Solutions, shown in Figure 10, is recommended.

Figure 10: Safe Filtrate Collection Container for the BSF

Rainwater Harvesting

Rainwater Harvesting Introduction

Broadly, rainwater harvesting can be considered any human practice that deliberately captures and stores rainwater for future use. Pure Home Water could consider promotion of household and/or community scale rainwater harvesting in order to provide water for domestic consumption. Rainwater harvesting systems are conceptually made up of five components: a catchment area, conveyance mechanism, first flush diversion, storage area, and a delivery mechanism.

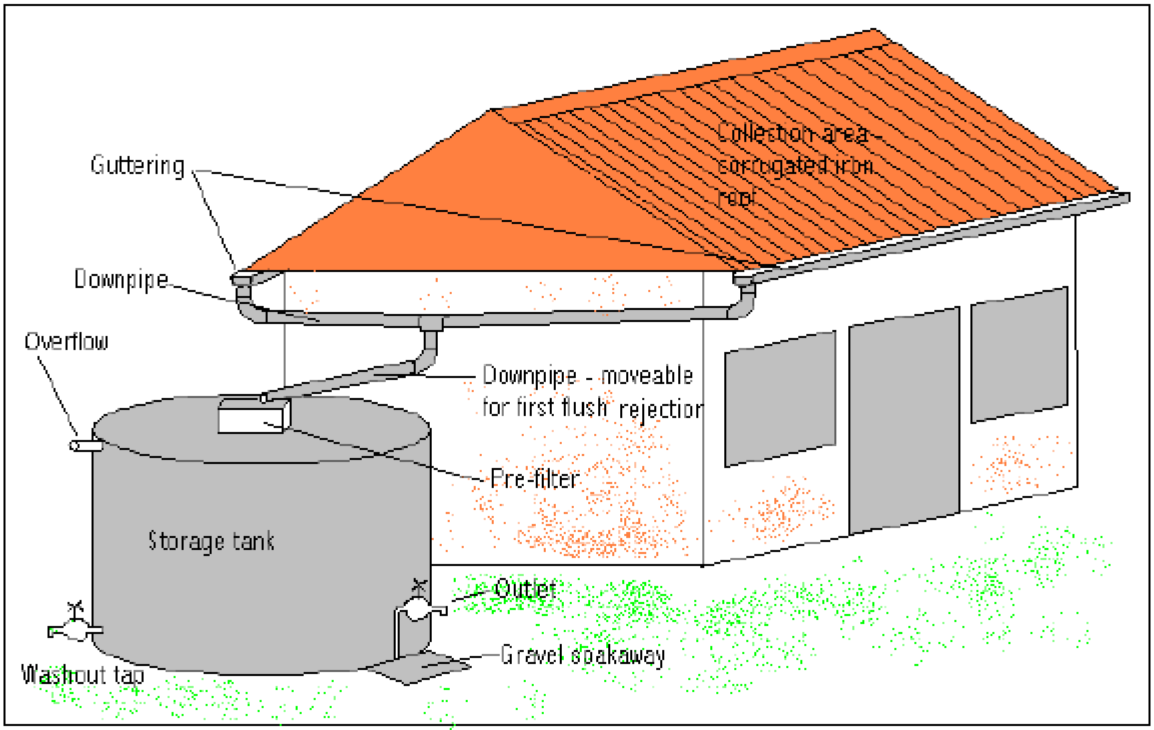

Figure 11: Schematic of typical rainwater harvesting system (DTU, 1999)

A critical component, often the most expensive, is the means of storage. There are a wide range of tank designs, both above and below ground, composed of various materials. The movement to lower the cost of storage and promote quick adoption of RWH in the 1980's led to the hasty adoption of untried and untested construction techniques involving basket and bamboo reinforced concrete. These designs proved faulty due to structural decay and failure of bamboo basket reinforcement. Widespread adoption of these technologies had already occurred. (Gould and Nissen, 1999) Successful materials for constructing storage tanks, both above and below ground, include ferrocement, galvanized steel, plastic, brick, and stone masonry. (Gould and Nissen, 1999) Above ground storage makes access to and maintenance of the tank easier. Advantages of below-ground tanks include structural support of the soil, temperature moderation and protection from vandalism. However, it is more difficult to detect and repair leaks in these storage containers. Also, soil properties are a concern. Expansion and contraction of soil, particularly clay-rich soils, can lead to cracking, leaking and structural damage if proper reinforcement of the tank is not present.

Study Results

Barnes assessed the current state of rainwater harvesting in the Northern Region of Ghana and has made recommendations regarding if and how rainwater harvesting could be used to address Pure Home Water's goal of reaching 1 million people in Northern Sector, Ghana in the next five years with a safe drinking water supply (Barnes, 2009.) First, current rainwater harvesting practices are described and design successes and failures highlighted. Second, quantity and reliability is analyzed by simulation modeling and a storage-reliability-yield relationship developed and graphed for the Northern Region of Ghana. Third, quality of water stored in tanks and cisterns, both rainwater and other sources, is assessed using bacteriological testing. Finally, unit-cost analyses are conducted and the cost of harvested rainwater is compared to alternative water sources.

Rainwater harvesting (RWH) in the Northern Region of Ghana is currently promoted and supported primarily by three non-profit organizations: World Vision, the Presbyterian Church, and New Energy. Rainwater harvesting seems to have undergone a resurgence recently with new interest on the part of these organizations. Previously, in the 1990's, Oxfam, Canadian Children's Fund and Tumakavi supported RWH projects, but currently do not.

In total, Barnes visited 6 community scale RWH systems and 15 household scale systems. Community surveys were conducted from January 6th through January 10th. Community sites were located in Savelugu, Pong Tamale, and Tamale. Only the community storage tanks at Pong Tamale Veterinary College contained rainwater. All community tanks were filled with piped or trucked water, as their rainwater supplies had run out. Surveys of household level RWH sites were conducted in Tamale, Kakpaille, Vogyili and Sakpalua.

Figure 12: Site Locations

Unit Cost Of Rainwater Harvesting:

The unit cost per m^3 of water delivered by RWH which falls in the range of $1-10/$m^3$ is competitive with other water supply and treatment technologies available in Ghana. Also, benefits of water supply at the home could further favor RWH over other technologies. High initial capital cost and low ability to pay contribute to financial difficulties that prevent more rapid dissemination of the technology. Currently, subsidy is required. Lowering the cost of storage is a primary concern.

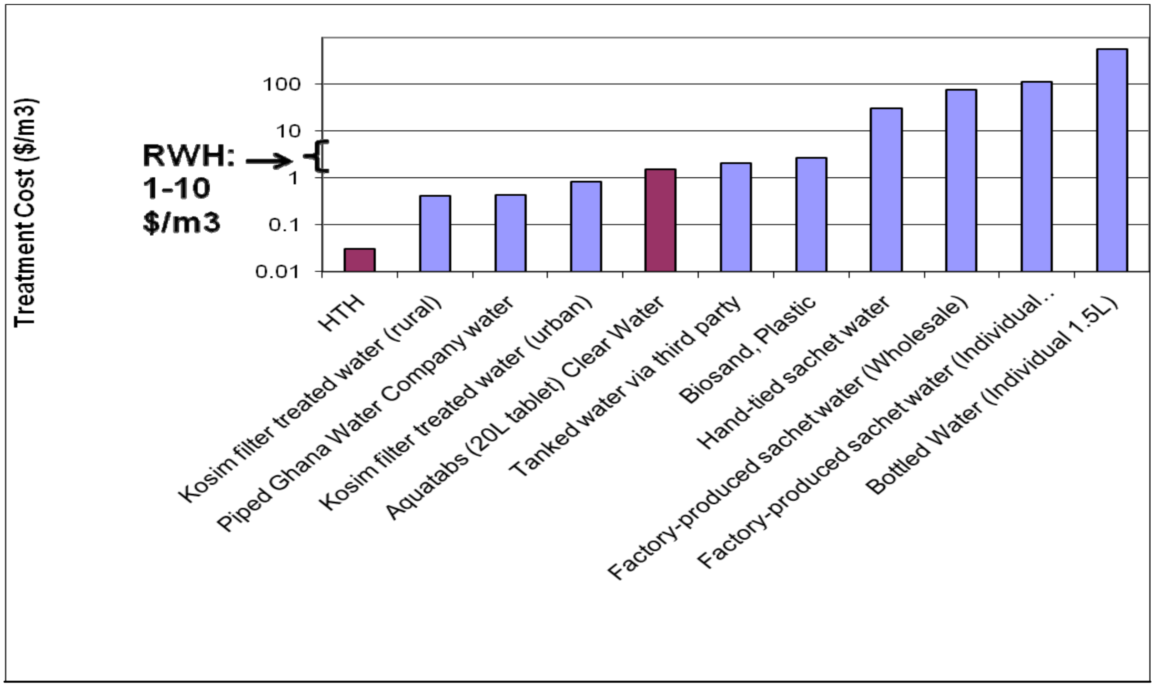

Figure 13: Cost of Alternative Water Sources (Green et al)

Water Quality

Community water supplies, with the exception of the Veterinary Laboratory, no longer contained rainwater, and had been filled with an alternative water source(pipe or trucked water.) Unprotected surface sources had the worst water quality. (Vogyili Dugout, Pong Tamale Dugout, Pong Tamale WTP Pretreatment Water)

Table 8: Risk Level Interpretation from E. coli Results (WHO, 1997)

Risk Level (WHO, 1997)	*E. coli* in sample CFU/100ml (WHO, 1997)
Conformity	<1
Low	1 to 10
Intermediate	10 to 100
High	100 to 1000
Very High	>1000

12 out of 14 rainwater samples from Presbyterian household tanks qualified as low risk (1 to 10 *E. coli* CFU/100ml) (as defined by WHO, 1997), with only two samples qualifying as posing an intermediate risk(10-99 *E. coli* CFU/100ml.) Samples from dugouts ranged from intermediate risk (10 to 99 *E. coli* CFU/100ml.) to very high risk(>1000 *E. coli*

CFU/100ml.) Ziff's mean results for pipe, borehole and dam all indicate a mean high risk level (100 to 999 E. coli CFU/100ml.) In contrast, harvested rainwater and water stored in RWH tanks poses a low to intermediate risk, which is a substantial improvement over alternative sources. Only two samples qualifyed as posing an intermediate risk. Samples from dugouts ranged from intermediate risk to very high risk. Ziff's mean results for pipe, borehole and dam all indicate a mean high risk level. Harvested rainwater and water stored in RWH tanks poses a low to intermediate risk, which is a substantial improvement over alternative sources.

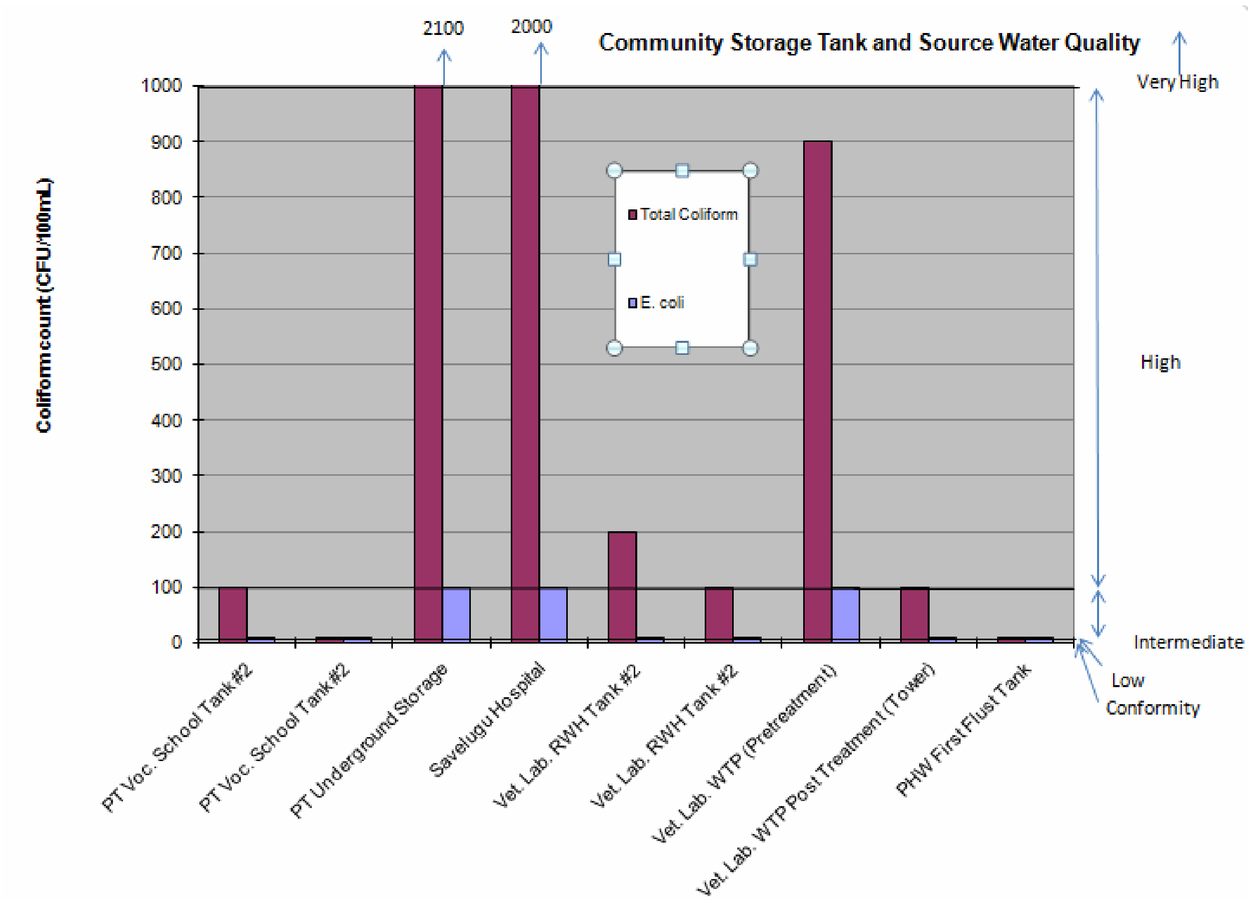

Figure 15: Community Water Quality Results (Barnes, 2009)

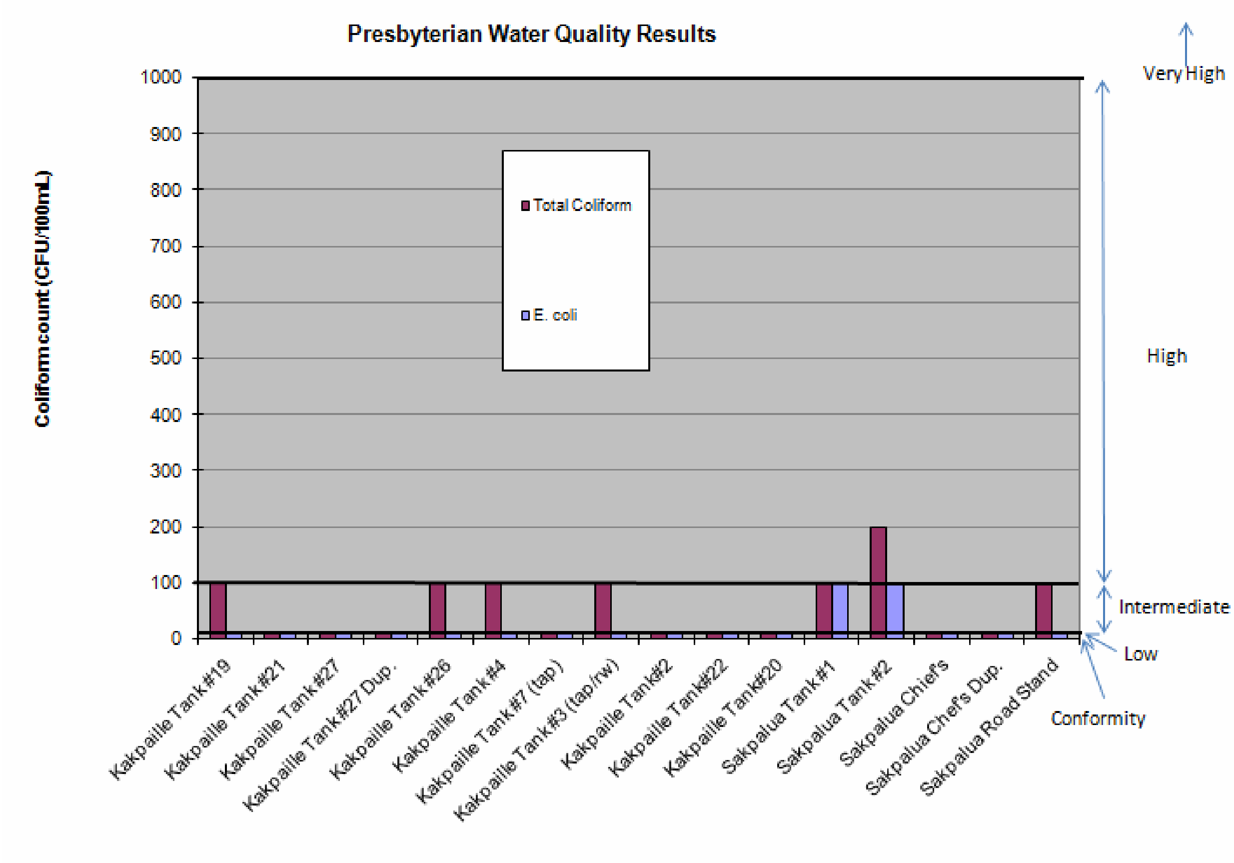

Figure 16: Water Quality of Presbyterian Tank Program (Barnes, 2009)

In general, water quality data indicate that household rainwater supply tanks implemented by the Presbyterian Church in Northern Ghana have generally low levels of *E. coli* contamination and fall into the WHO low risk water supply category. Large community cisterns and tanks show higher levels of contamination. The Veterinary Laboratory fast-sand filtration plant showed total coliform contamination post-treatment. In comparison to other available sources, water stored in household rainwater tanks, represents a significant improvement in bacterial quality over local unimproved sources, however all locations should not be considered “safe” if “safe” is defined as a low risk water <10 CFU/100ml.

Recommendations to PHW Regarding Rainwater Harvesting

Difficulties in marketing RWH:

High initial capital cost for rainwater harvesting tanks is a primary difficulty. Subsidy was provided for all household and community systems visited by Barnes (2009,) through government or NGO sources. Another difficulty in marketing RWH as a product is that often the most effective designs require community training, trained technicians, and onsite construction. In terms of scale, it is not something that can be sold in the same manner as other HWTS interventions.

If PHW were interested in developing a RWH program as a water supply in the Northern Region of Ghana, a few key questions should be looked into:

Water Quality:

- Further research should be conducted to characterize the chemical quality of harvested rainwater in Tamale and the Northern Region. Air pollution, particularly surrounding Tamale, could pose a threat to the quality of harvested rainwater. The question of chemical quality was not addressed in this study.
- Also, during the rainy season, following Doyle's work in Rwanda on the sizing of first flush devices, a study should be conducted to properly size devices in Northern Ghana. Her recommendations were site specific but her methods could easily be applied and recommendations made for this region.

Low Cost Storage:

The feasibility of low-cost underground storage should be investigated. The geology and soil conditions in the Tamale region might provide a suitable match for a cheaper storage mechanism using plastic tarps and constructed pits. Latrite soils with low rooting depths could be ideal for the longevity of such designs, as root growth and puncture of liners tend to be a big problem but would be less likely in the Northern Ghana context. Digging is very difficult and soils are hard but the labor could prove to be worth it. If the cost of storage could be lowered, rainwater harvesting could contribute in a larger way to PHW's mission and reach more people.

Implementation:

Currently, the most successful design and implementation at the household level is the Presbyterian $10m^3$ ferrocement tank. It is also the only RWH intervention being promoted at the household level.

Marketing Opportunities for PHW: Do-it-yourself rainwater harvesting in the Northern Region of Ghana is a fairly widespread. Finding ways to improve the quantity and quality of informal rainwater harvesting is a potential means for improving water supply for many in the Northern Region. Do-it-yourself systems typically consist of pots, barrels or household storage containers placed under the eaves or under homemade guttering constructed of bent roof sheet. It might be possible to market a low-cost plastic to serve as a clean catchment surface. Sizing could be determined using the SRY curve developed for the region. (Appendix G)

Rainwater harvesting as household safe storage:
Another interesting way to view a rainwater storage tank is as a household safe storage container. If properly constructed and sealed, a rainwater storage tank could be used in a complimentary way with other interventions already being provided by PHW. Often, in Northern Ghana, rainwater is used conjunctively with other improved and unimproved sources of water. For rainwater harvesting to be considered a complete water quantity and quality intervention, it would need to be able to provide clean water year round. Dugouts and unimproved surface sources are often the supplementary source. Kosim filters could be marketed to households conducting rainwater harvesting both as a means of improving the quality of rainwater and filtering the supplementary, unimproved source.
Furthermore, both the siphon filter and the biosand filter currently lack a means of safe storage. The rainwater storage tank could provide a means of safe storage for filtrate, and filtered water fetched from other sources could be used to augment the rainwater supply. However, bacterial removal of the filters must be such that conjointly using the tank for rainwater and filtrate storage would not pose a health risk (i.e. contaminating stored rainwater with filtrate of poor bacteriological quality.)

Further Research:
In conclusion, PHW should investigate:
1. Low cost storage in underground tanks,
2. Ways to improve informal RWH and lower the cost of RWH.

Also, existing designs of rainwater harvesting in Northern Ghana are recommended where no other improved water source is available and at locations where water storage tanks are required anyway. It is competitive with other water provisioning technologies such as piped water on a unit cost basis, but large capital investment is required.

Strategic Plan for Pure Home Water

Based on the studies conducted, the siphon filter, biosand filter, and rainwater harvesting all have the potential to be marketed by PHW. All three technologies require further research before implementation, as outlined in the following strategic plan:

Short-Term Recommendations

- Resolve siphon filter recontamination issue
- Develop a safe storage container for use with the siphon filter
- Conduct further field studies of the dual sand layer biosand filter to better understand performance
- Optimize dual sand layer BSF upper and lower sand layer depths and layout to improve filter performance
- Kosim for rainwater harvesting both as a means of improving the quality of rainwater and filtering the supplementary, often unimproved source.

Long-Term Recommendations

- Market the siphon filter with the associated safe storage container to households drinking low turbidity water, and to households drinking high turbidity water as an alternative to alum plus chlorine
- Market the dual sand layer biosand filter as an alternative to the expensive, imported HydrAid filter and the low-cost but heavy concrete filter. Ensure safe filtrate collection vessel and education are included in the filter sales
- The feasibility of low-cost underground storage should be investigated
- Investigate way to improve informal rainwater harvesting.

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Appendix A: Water Quality Test Procedures

All tests were conducted in a manner that reduced possible contamination of samples from external sources.

Flow rate

Biosand filter only:

Maximum flow rates (in liters per minute) were measured immediately after the filters had been filled by holding laboratory type 1 L plastic beaker under the outlet for one minute and measuring the volume.

Turbidity

Turbidity measurements in nephelometric turbidity units (NTU) were made using a Hach Model 2100P Portable Turbidimeter. The turbidimeter was calibrated with formazin solution and in accordance with the manufacturer's instructions. Initial calibration was carried out upon arrival in Tamale and the turbidimeter accuracy was checked daily by reading a formazin standard (20 NTU or 100 NTU). If the turbidimeter reading of the formazin solution was more than 1 NTU off the actual value the turbidimeter was recalibrated.

The sample vial containing the water to be tested was rinsed three times with the water to be tested prior to the reading to ensure the sample was not contaminated with water previously tested. The outside of the vial was dried and wiped down with a lint free cloth prior to reading.

The turbidimeter was run in signal averaging mode as high turbidity samples tended to give a noisy signal.

Microbiological Quality

All of the microbiological testing was carried out in a sterile environment in the laboratory at the Pure Home Water office. All surfaces were wiped down with isopropyl alcohol and testing equipment was sterilized in boiling water before each testing session commenced.

Water samples were collected in sterile 100 mL polyethylene bag containing 10 mg sodium thiosulfate to neutralize chlorine (NASCO Whirl-Pak® Thio-Bag®). When samples could not be tested immediately, sample bags were stored on ice or in the laboratory refrigerator until testing could be conducted. Stored samples were tested within 6 hours of the sample being taken on all except 2 occasions, when testing occurred 8 and 10 hours after sampling.

Testing for both *E. coli* and total coliform counts in coliform forming units (CFU) per 100 mL was conducted using two methods:

- IDEXX Colilert presence/absence test, which reads total coliform and *E. coli* presence down to <10 CFU/100 mL
- 3M Petrifilm™ *E. coli* / Coliform Count Plates, which has a detection limit of 100 CFU/100 mL

The Colilert and 3M Petrifilm tests were incubated in the PHW laboratory at 35°C for 24±2 hours using a Millipore XX631K230 Incubator.

Tests were duplicated for accuracy monitoring of results and blank samples were tested for accuracy monitoring of the test methods.

In the case less than 100 CFU/100 mL were registered using the 3M Petrifilm and the Colilert test registered positive for more than 10 CFU/100 mL a value of 99 CFU/100 mL was assigned to the sample as the upper contamination limit. Therefore all results show the performance that the filter has achieved and likely surpassed.

Some laboratory testing of the biosand filters was conducted using membrane filtration (MF). MF tests were conducted in accordance with Millipore guidelines, which are adapted from the U.S. Standard Methods for the Examination of Water and Wastewater (20^{th} Edition, 1998). Samples were cultured using m-ColiBlue24® Broth Coliform and *E. coli* Detection Media for use with Membrane Filter Technique marketed by the Hach Company, USA. A Millipore Portable Membrane Filter XX6300120, Robens (Surrey, United Kingdom) recyclable petri dishes, Millipore all metal syringe XX6200035, Pall Corporation GN-6 grid 47 mm 0.45 µm filters and Pall Corporation pads for 47 mm filters were used.

Tests were duplicated for accuracy monitoring of results and blank samples were tested for accuracy monitoring of the test methods. The MF petri dishes were incubated in the MIT CEE laboratory at 35°C for 24±2 hours using a Millipore XX6310000 Incubator.

Dissolved oxygen concentration

Biosand filter only:

Dissolved oxygen concentrations were measured using a YSI Model 57 Oxygen Meter with YSI Model 5239 probe. Prior to testing each day the precision of the probe membrane was confirmed by measuring the concentration of dissolved oxygen saturated water and compared to the theoretical value for water at the same temperature. Cambridge Water Department potable reticulated water which had been allowed to sit in the laboratory for a minimum of 24 hours to become saturated was used for the saturation test. To accurately measure the dissolved oxygen concentration the probe was swirled in the water to create flow past the probe membrane.

Dissolved oxygen readings were taken *in situ* for the supernatant of BSFs A and B and for the water layer between the upper and lower sand layers for BSF B. Recordings were taken immediately above the sand surface for consistency and to gauge the oxygen concentration reaching the sand. Minimal swirling of the probe was required for the readings and was undertaken in a manner to cause least disturbance to the sand and *schmutzdecke*. The BSF effluent was captured in a polyethylene bag for immediate reading. Contact between the air and the effluent was kept to a minimum to protect the integrity of the sample.

Appendix B: Siphon Filter Instructions for Use Guide

USING YOUR FILTER

1. When source water is visually dirty, let it settle for an hour in your traditional storage vessel to allow particles to sink to the bottom. Pour settled water (top level only) from this vessel into the upper water container for filtration.
2. Remove housing jar and place filter in upper water container full of water to be filtered. Leave cloth pre-filter covering ceramic element.
3. Place tap over lower storage vessel.
4. Open tap and press bulb (see figure). Wait until bulb slowly fills and water starts flowing out of the tap. This has to be repeated a few times when using a dry filter element.
5. Using a new filter element, let the filter element stay in the water during one night and do not use the first 20 liters of filtered water!

Tap is open.

Guidelines for Filtration

- Do not use the filter regularly in full sun.
- If water from the lower container is taken out with a cup, make sure cup and hands are clean.
- Use filtered water the same day. Empty the lower water container each evening into the upper water container to avoid long-term storage of filtered water.
- Pre-treatment of very dirty water using coagulant will lengthen filter life.

CLEANING YOUR FILTER

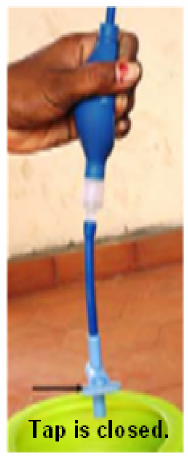
Pre-filter Washing

When the cloth pre-filter becomes dirty, remove it from the ceramic element and wash it in clean water.

Backwashing

The ceramic element will eventually become clogged due to particles in the contaminated water. This will reduce the water flow. To restore flow, backwash the filter using the following steps:

1. Close tap and press bulb.
2. Wait until the bulb is again filled with water.
3. Open the tap.
4. Repeat a few times if the flow is not increased.



Tap is closed.

- It is advised to backwash the filter once every day.
- Frequent backwashing will result in a longer life of the ceramic element.

Scrubbing the Ceramic Element

If backwashing does not increase the flow, you must scrub the ceramic element.

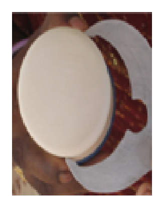
- Remove the cloth pre-filter, unscrew the lid and scrub the ceramic element using the included scrub pad.
- Remove only as little ceramic material as possible, as ceramic removal will shorten the lifetime of the element.
- Rinse with clean water.
- Store scrub pad in a safe place in your kitchen.

CHANGING YOUR FILTER

When to change your ceramic filter element

- At a certain point, your filter will become too thin to effectively remove bacteria and parasites.
- To check when replacement of the ceramic element is needed:

1. Unscrew the wing nut a few turns and remove the plastic sensor attached to the lid.
2. When the sensor fits around the thinnest part of the ceramic element, the element has become too thin to deliver safe water and has to be replaced.



How to change ceramic element

1. Remove hose from ceramic element by turning and pulling the hose.
2. Hold ceramic element in one hand and unscrew wing nut.
3. Replace old ceramic element with a new ceramic element.
4. Remount wing nut and hose.

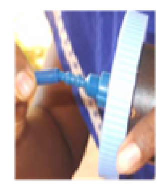
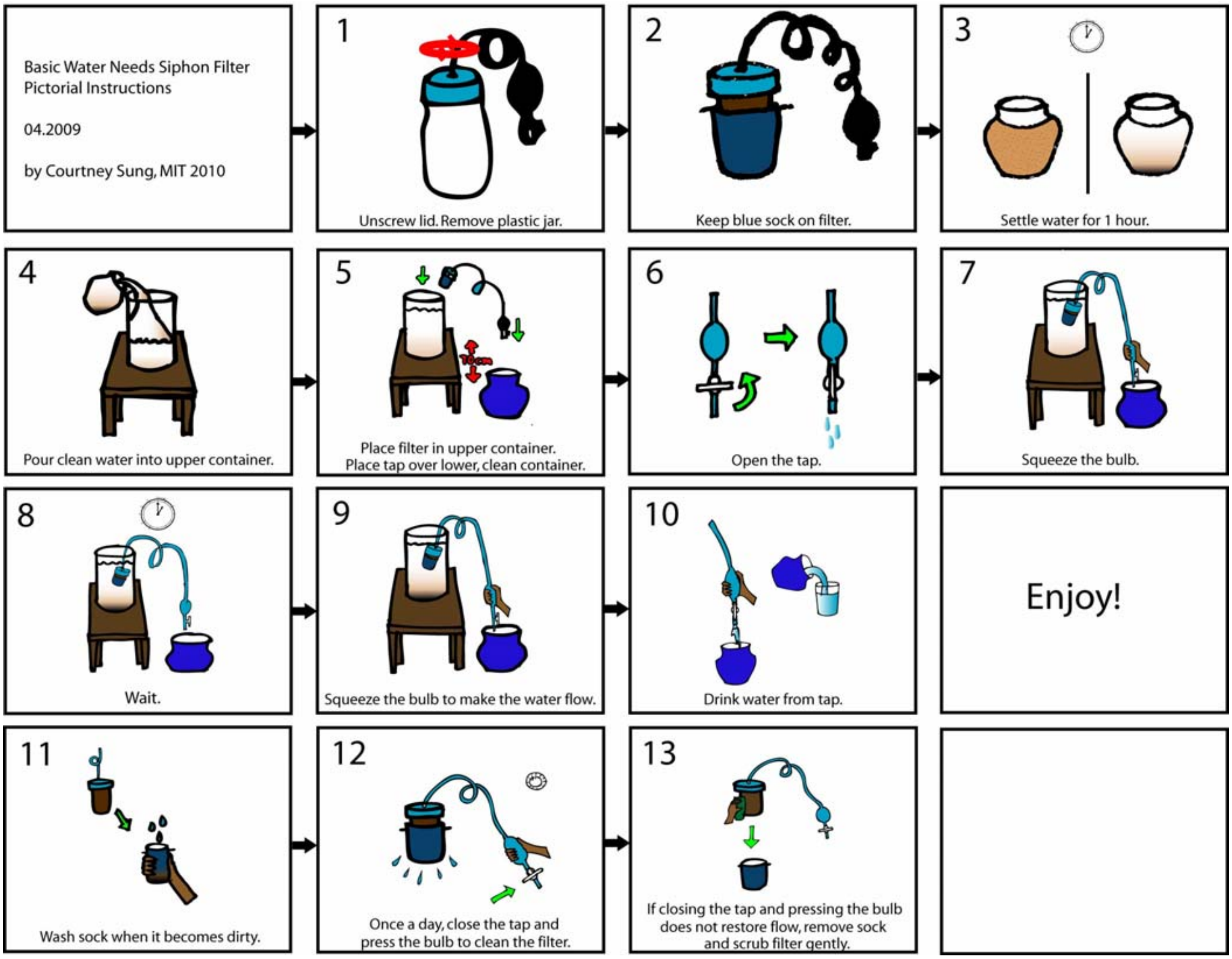


Figure: Removing the hose for replacement of the ceramic element.

Appendix C: Siphon Filter Pictorial Guide



Appendix D: Biosand Filter Test Results

Table D1: Biosand Filter Performance, Control Tests, Tamale

Biosand Filter	Flow Rate (L/min)	Average Turbidity Removal	Average *E. coli* Removal	Average Total Coliform Removal
BSF 1	0.29	32%	91%	89%
BSF 2	0.35	21%	93%	91%
BSF 3	0.25	37%	91%	92%
BSF 4	0.20	33%	91%	94%
BSF C	0.48	49%	89%	91%

Table D2: Biosand Filter Performance, Modified Filter Tests, Tamale

Biosand Filter	Flow Rate (L/min)[1]	Average Turbidity Removal	Average *E. coli* Removal	Average Total Coliform Removal
BSF 1	0.52	28%	83%	91%
BSF 2	0.22	59%	85%	95%
BSF 3	0.38	53%	83%	85%
BSF 4	0.30	42%	85%	91%
BSF C	0.75	53%	85%	95%

1- Note: Table D2 shows the flow rate in BSF 1 increased during the modified filter tests compared to the control test (results shown in Table D1), which was attributed to the increased pressure head driving water through the filter resulting from filling SF 1 with 20 L water during the modified BSF test stage. BSFs 4 and C were operated as single sand layer for both control and modified operation tests, and it is uncertain why an increase in flow rate greater than 50% was recorded for these filters. BSF 3, the very fine sand layer filter showed an increase in flow rate in the modified operation test compared to the control test, similar to the increases experienced by BSFs 4 and C. While there may be some influence by the very fine sand layer on the flow rate this could not be determined. BSF 2 showed a significant decrease in flow rate in the modified operation test compared to the control test, mostly likely caused by reduced pressure head available as a result of constructing the upper sand layer and decreasing filter freeboard to 2 cm.

Table D3: Biosand Filter Performance, Test 1, MIT

Biosand Filter	Flow Rate (L/min)	Average Turbidity Removal	Average *E. coli* Removal	Average Total Coliform Removal
BSF A	0.4	98%	75%	82%
BSF B	0.7	98%	79%	85%

Note: filter ripening occurred at the end of this test

Table D4: Biosand Filter Performance, Test 2, MIT

Biosand Filter	Flow Rate (L/min)	Average Turbidity Removal	Average *E. coli* Removal	Average Total Coliform Removal
BSF A	0.4	99%	99%	93%
BSF B	0.7	98%	98%	93%

Table D5: Biosand Filter Performance, Test 3, MIT

Biosand Filter	Flow Rate (L/min)	Average Turbidity Removal	Average *E. coli* Removal	Average Total Coliform Removal
BSF A	0.4	93%	94%	75%
BSF B	0.7	93%	97%	71%

Table D6: Biosand Filter Performance, Test 4, MIT

Biosand Filter	Flow Rate (L/min)	Average Turbidity Removal	Average *E. coli* Removal	Average Total Coliform Removal
BSF A	0.4	76%	76%	49%
BSF B	0.7	74%	78%	70%

Appendix E: Biosand Filter Schematic Diagrams

Biosand Filters Tested in Tamale

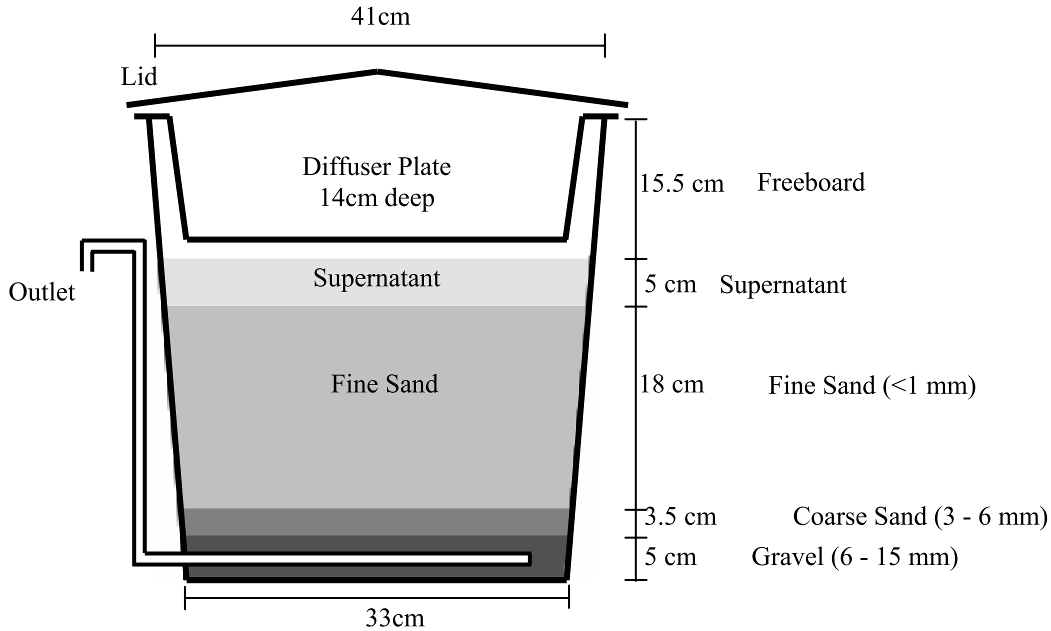


Figure E1: Control BSFs, and BSF 1 and 4

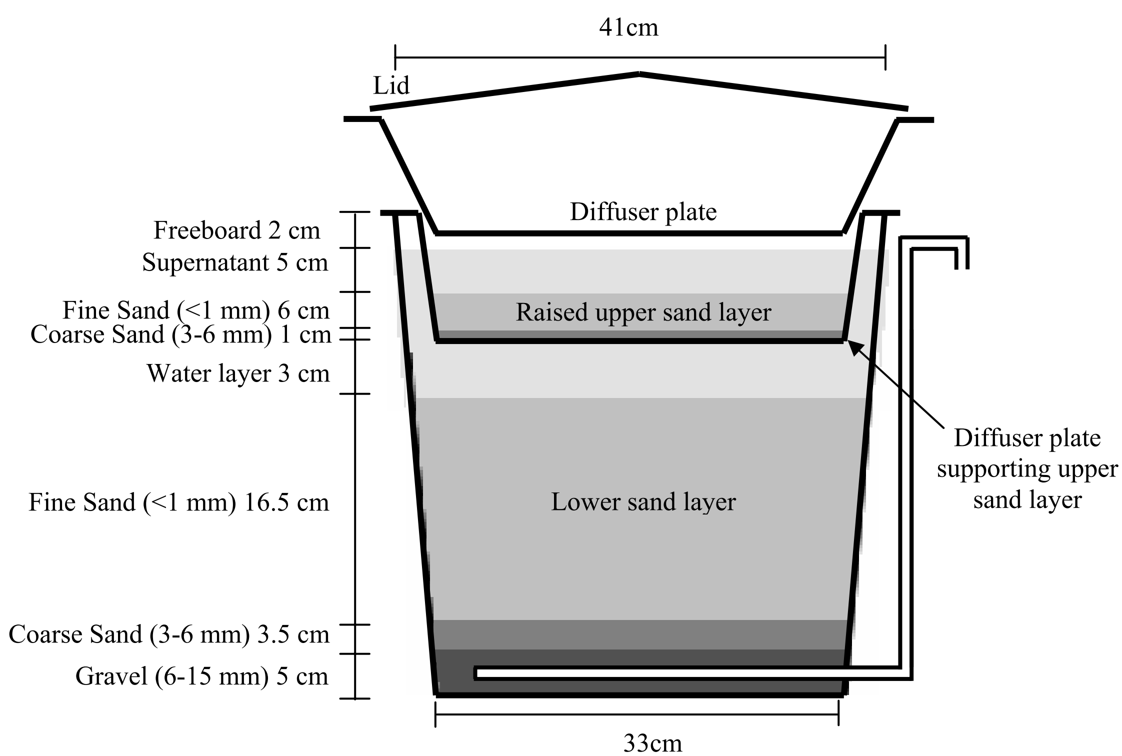


Figure E2: BSF 2

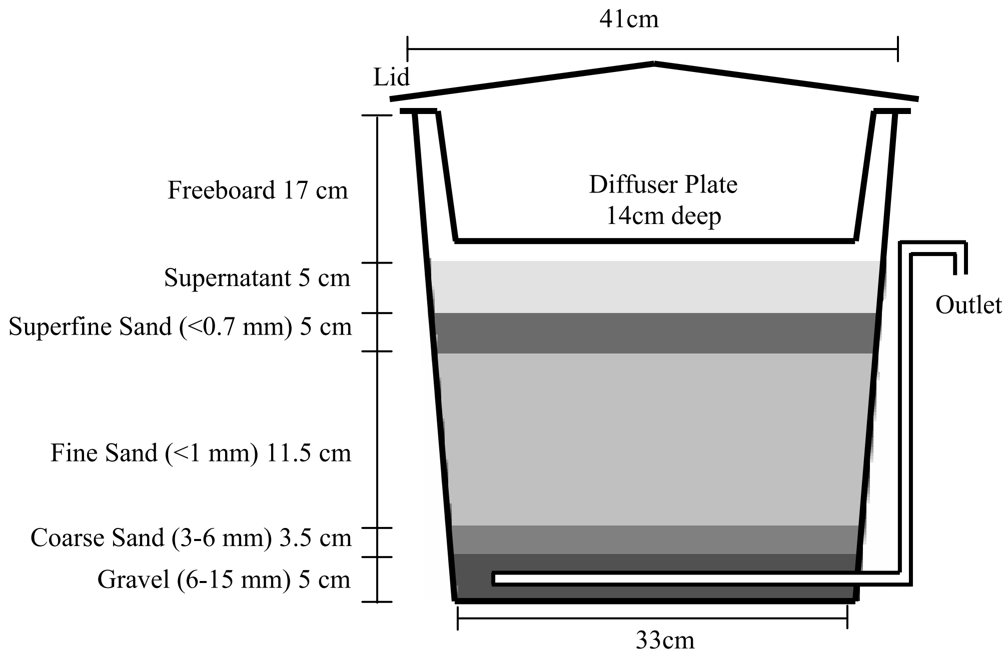


Figure E3: BSF 3

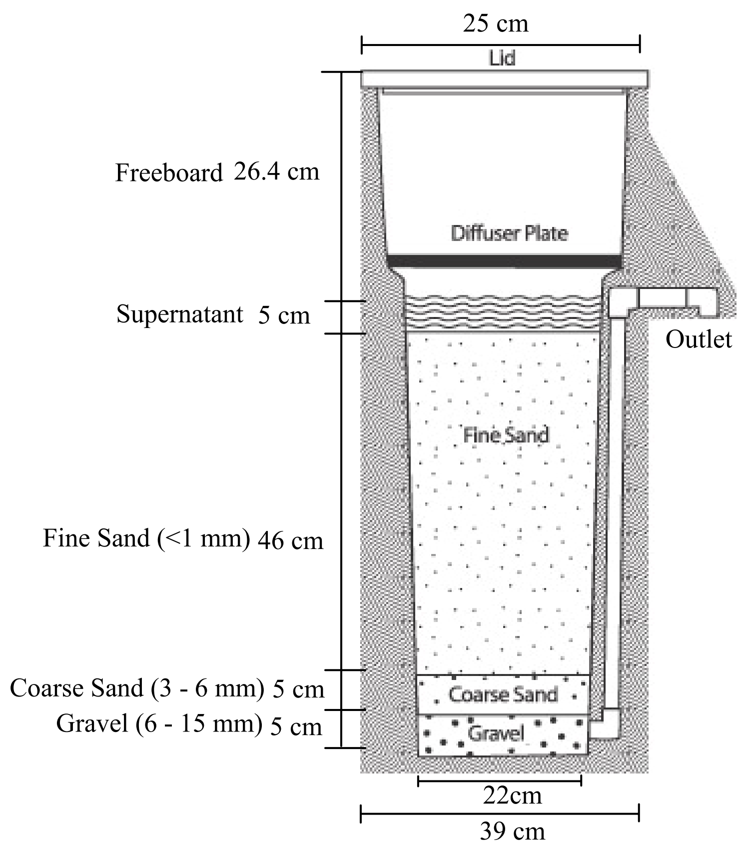


Figure E4: BSF C

Biosand Filters Tested at MIT

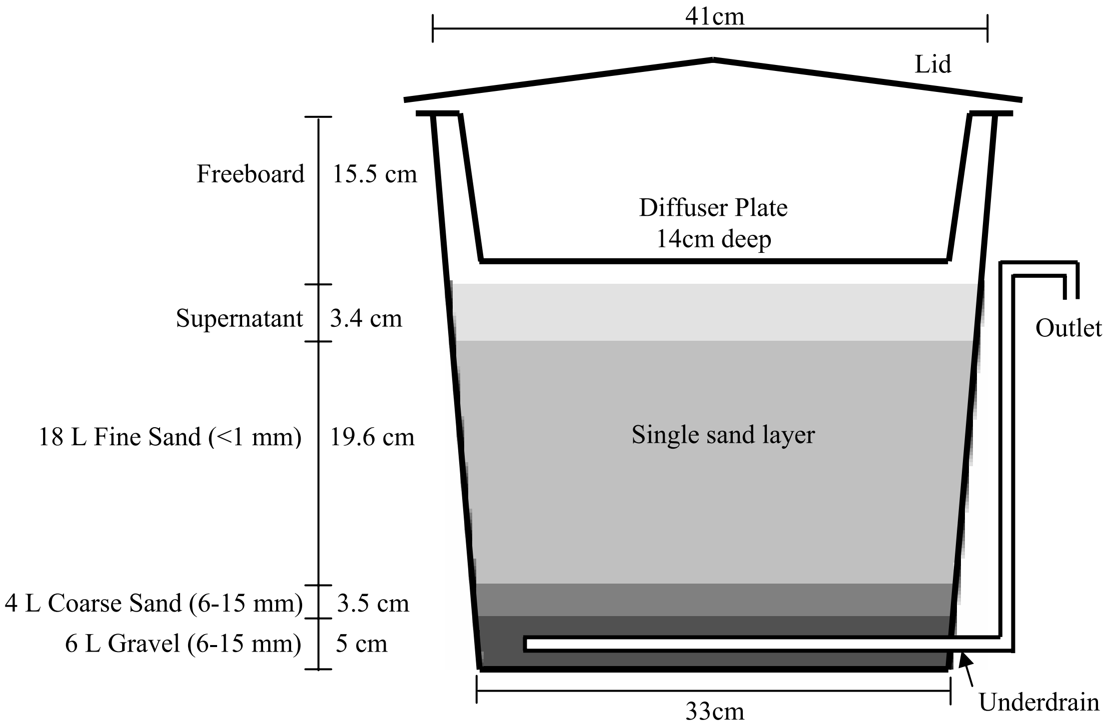


Figure E4: BSF A – Single Sand Layer BSF

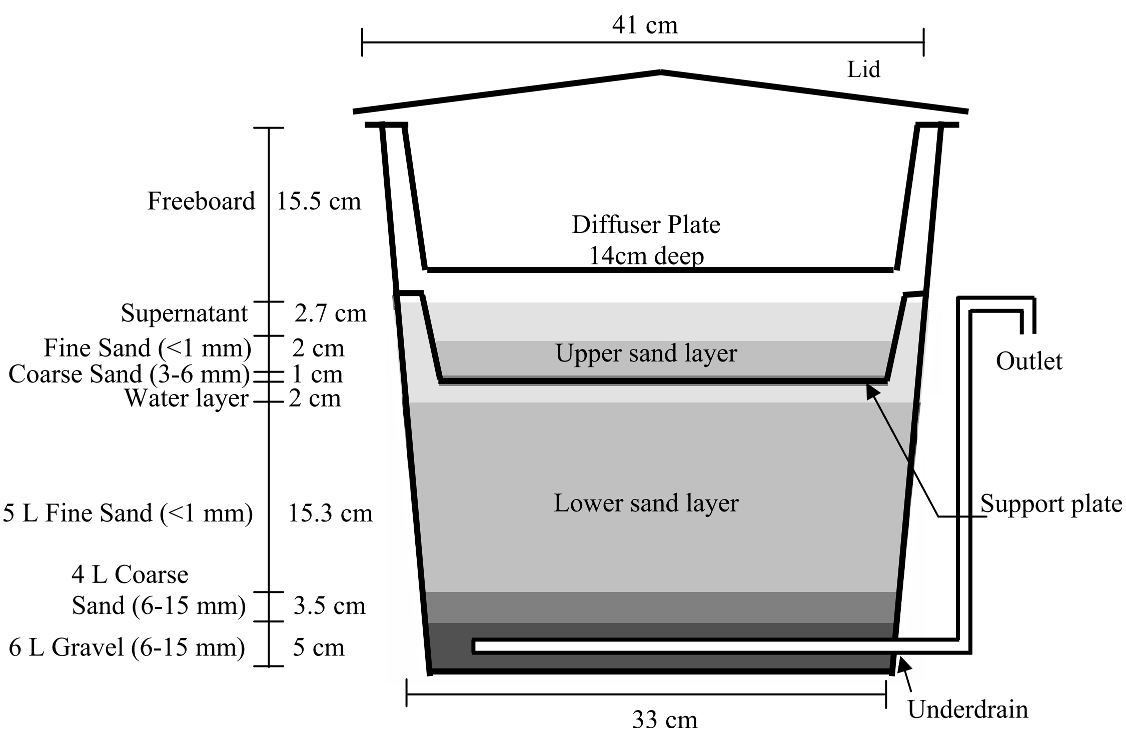


Figure E4: BSF B – Dual Sand Layer BSF

Appendix F: Water Quality Results

From Barnes (2009)

Table F1: Community Water Quality Results

Location	Tot Col CFU/100ml	*E. coli* CFU/100ml
Pong Tamale Vocational School Tank #2	99	9
Pong Tamale Vocational School Tank #2	9	9
Pong Tamale Underground Storage	2100	99
Pong Tamale Vocational School Dam	8900	1900
Savelugu Hospital	2000	99
Veterinary Laboratory Rainwater Tank #2	200	9
Veterinary Laboratory Rainwater Tank #2	99	9
Veterinary Laboratory Treatment Plant Settling Basin Pretreatment	900	99
Veterinary Laboratory Treatment Plant Post Treatment Tower	100	9

Table F2: Community Survey Summary

Tank Name	# of Users	Rooftop Area (m^2)	Storage Capacity (m^3)	Demand (L/day)	Reliability %	Cost ($)
World Vision	n/a	1129	50	1639	68	8333
Pong Tamale Health Clinic	n/a	46	0.5	16	75	unknown
Pong Tamale Vocational School (1)	200	57	1	992	5	unknown
Pong Tamale Vocational School (2)	200	69	1	992	6	unknown
Pong Tamale Health Center	55-115	70	75	189	91	3500
Savelugu Hospital	50-100	76	75	992	11	3500
Veterinary College #1	2000	174	92	n/a	n/a	unknown
Veterinary College #2	2000	184	81	n/a	n/a	unknown
Veterinary College#3	2000	102	96	n/a	n/a	unknown

Table F3: Household Survey Summary

Tank#	# Users	Roof Area (m^2)	Storage Capacity m^3	Cost ($)
21	20	19	10	708
27	10	38	10	708
19	20	18	10	708
4	20	59	10	708
7	8	25	10	708
3	25	53	10	708
2	7	72	10	708
22	7	59	10	708
20	n/a	35	10	708
26	10	12	10	708
14	20	21	10	708
15	9	35	10	708
Chief 1	11	23	10	708
Chief 2	11	11	10	708
PHW front	8	98	1	388
PHW rear	8	106	3	680

Table F4: Household Water Quality Summary

Location	Tot Col CFU/100ml	E. coli CFU/100ml
Kakpaille Tank #19 Yussef	99	9
Kakpaille Tank #21	9	9
Kakpaille Tank #27	9	9
Kakpaille Tank #27	9	9
Kakpaille Tank #26	99	9
Kakpaille Tank #4	99	9
Kakpaille Tank #7 (tap water/rainwater)	9	9
Kakpaille Tank #3 (mix tap/rainwater)	99	9
Kakpaille Tank#2	9	9
Kakpaille Tank#22	9	9
Kakpaille Tank#20	9	9
Sakpalua Tank #1	99	99
Sakpalua Tank #2	200	99
Sakpalua Chief's	9	9
Duplicate	9	9
Sakpalua Road Stand	99	9
PHW First Flush Tank	9	9

Table F5: Reliability Results: Community

Tank Name	Rooftop Area (m^2)	Storage Capacity (m^3)	Demand (L/day)	Reliability %
World Vision	1129	50	1639	68
Pong Tamale Health Clinic	46	0.5	16	75
Pong Tamale Vocational School (1)	57	1	992	5
Pong Tamale Vocational School (2)	69	1	992	6
Pong Tamale Health Center	70	75	189	91
Savelugu Hospital	76	75	992	11

Table F6: Reliability Results: Household

			Demand Scenario 1	**Demand Scenario 2**
Reliability	**# of Users**	**Roof Area (ft^2)**	Reliability(5 L/day/capita)	Reliability (20 L/day/capita)
High	7	772	99.9%	77%
Average	14	369	96%	26%
Low	20	200	43%	5%

Appendix G: SRY Relationship

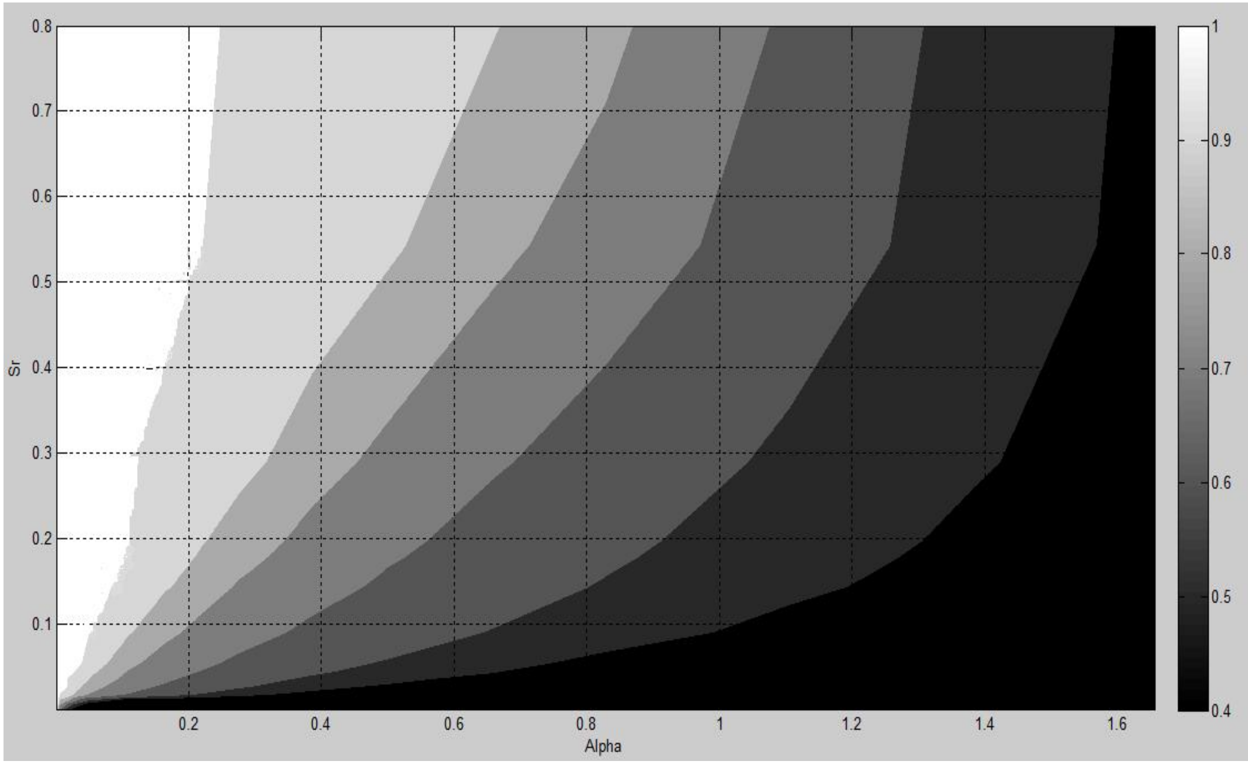


Figure G1: SRY Relationship, Northern Region, Ghana (Barnes, 2009)