A Field Assessment of BioSand Filtration

In Rural Ghana

By

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A REPORT

Submitted in partial fulfillment of the requirements for the degree of

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This report "Field Assessment of BioSand Filtration in Rural Ghana" is hereby approved in partial fulfillment of the requirements for the degree of

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Preface

This report is based on my experience as a Peace Corps Volunteer in Ghana, West Africa from September 2005 to November 2007. As part of the Health, Water and Sanitation Sector, I was assigned to work primarily in the communities of Damanko and Sibi Hilltop located eight miles apart in the Nkwanta District of the Volta Region. My primary project involved working with endemic and at-risk communities in the sub-district as part of the Guinea Worm Eradication Program but other projects included the design and construction of a prototype rainwater harvesting system, a local dam expansion, latrine projects, and health education programs.

This report was completed in partial fulfillment of the requirements for a Master of Science degree in Environmental Engineering as part of the Master's International Program through the Peace Corps and the Civil and Environmental Engineering Department at Michigan Technological University. The research study, which makes up the basis of this report, was planned and implemented during a four month period in Sibi Hilltop towards the end of my service. The BioSand Filter project was coordinated in collaboration with the Carter Center, International Aid, my advisor at Michigan Tech, and the participating households within the community.

Acknowledgements

I would like to thank my advisor, Kurt Paterson, for his insight, friendship, willingness to endure the bush taxis and rutted roads in Ghana to visit his student, and for a warm bed back in Houghton. Cheers!

I would like to thank Professors Dave Watkins, Veronica Griffis, and Mary Durfee for giving their time to serve on my committee and for all of their thoughtful comments on my report.

I would like to thank Raymond Stewart from the Carter Center, who was there during the trials of those first filters and organized so much in the way of materials and resources through the Guinea Worm Eradication Program for the installation of many more.

I would like to thank Osman Mumuni and International Aid for providing us with the HydrAid™ BioSand Water Filters, filter media, and paying for the water quality testing and transportation costs.

Thanks to all of the folks from the GWEP-Nkwanta Core Team who helped us with the installation during Phase Two and Three.

I would like to thank my APCD John Addipa for his support and eternal optimism. You are "something good" my friend.

Thanks to my community, Sibi Hilltop! Whatever people may say about the Konkombas, my two years have proved them an intelligent, loving, peaceful and joyful people – especially Abraham, Kingsley, Grace, Dora, Waja, Naomi, Stephen and Obori.

Thanks to the Nkwanta PCVs, who always had many project ideas and laughs to share.

Finally – and most importantly – I would like to thank Sayward, who agreed to spend the first two years of our marriage living in a developing country without electricity, running water, or privacy. You kept me well-fed, brightened my day, helped me through the countless projects and community meetings, challenged me, were my constant travel companion, and I think we're stronger because of it. …Let's do it again when we retire!

Table of Contents

List of Figures

List of Tables

Abstract

It is estimated that over one billion people worldwide still lack access to safe drinking water, and that far more drink water that is grossly contaminated. Approximately one-third of this is accounted for in sub-Saharan Africa, of which the Republic of Ghana is part. The WHO estimates that 36% of rural Ghanaians, or eight million, are without access to an improved drinking water supply. Some communities like Sibi Hilltop – located in a remote area of the country between the northern end of Lake Volta and Togo – have one or more boreholes that pump water some of the time; however, these sources cannot yield enough clean water for the demand of the entire community. Even if they could, some households would continue to fetch from the streams and dam for various reasons. Contaminated drinking water is part of the reason for approximately 1.8 million deaths each year in the world caused from diarrhea-related disease, the majority being children under five years of age. A recent policy shift in public health, supported by field studies and literature, has moved toward household point-of-use water treatment as an effective intervention to combat this problem.

As an adaptation of slow sand filtration, the intermittent BioSand Filter was invented by Dr. David Manz in 1995 specifically with household use in mind. Since then over 200,000 concrete BioSand Filters have been constructed and installed in over 70 countries, and numerous field tests have shown it to be an attractive point-of-use treatment option. However, its limitations of being very heavy and having a slow construction time remain a barrier to wider implementation. Overcoming these specific obstacles, the HydrAid™ BioSand Water Filter has been developed as a light weight alternative made from injection-molded plastic for efficient production.

For this study twelve HydrAid™ BioSand Water Filters were installed in Sibi Hilltop and monitored over the course of two months by the author, a Peace Corps Volunteer living in the community. A field assessment of the best methods of installation, flow rates, water quality, user acceptability and comprehension, health impacts, and comparison between the HydrAid™ and concrete model was completed. An additional forty-one filters were installed during the last two weeks of the study. The results of the study show that the filter is an effective point-of-use water treatment technology for Sibi Hilltop, Ghana, and suggests that it would be an attractive option for similar communities in West Africa. The installation guidelines – developed to provide specific information about media preparation, assembling of the filter, and installation processes – can be used by implementing agencies to efficiently install large numbers of filters in the field. At installation the filters had an average flow rate of 0.96 L/min that decreased over the two month period to roughly 0.61 L/min. With a mature biolayer, the average removal efficiencies for Total and Fecal Coliforms were 84% and 86%, respectively. However, one-third of the filters tested showed removal efficiencies of 100% for both. Surveys conducted with the twelve households in October 2007 indicate a high user acceptance and a moderate to high user comprehension of the filter. The HydrAid™ BioSand Water Filter has improved in terms of production, distribution and user-preference but remains limited by cost, durability and project sustainability, when comparing it with the traditional concrete BioSand Filter.

Chapter 1: Background

This chapter provides an introduction to the research site, Sibi Hilltop, within the broader context of the Volta Region in Ghana, West Africa. The predominant tribal group and certain other aspects of the community form the backdrop for this chapter. The motivation for performing this study in conjunction with the Ghana Guinea Worm Eradication Program as well as project stakeholders are all discussed in this chapter. Chapter 1 concludes with the goal and research objectives of this study.

1.1 Background on Ghana

The Republic of Ghana – known as the Gold Coast prior to 1957 – takes its name from the medieval Ghana Empire in West Africa located approximately 500 miles north of its present location. Some inhabitants of present-day Ghana have ancestral links with the kingdom of old and these roots can be traced to many tribal groups today in the northern part of the country. It is bordered on the west by Cote d'Ivoire, while Togo and Burkina Faso share its borders on the east and north, respectively (See Figure 1). The Portuguese were the first European colonial power to establish a foothold in the country to trade in gold, ivory, and pepper. However, with the opening of myriad European plantations in the New World in the 16th century the demand for slaves exploded and opened up trade in the export of human beings. The west coast of Africa soon became the principal source for slaves to the Americas, as other European powers and African kingdoms fought to control the lucrative trade. Over the following centuries the Dutch, British, Danes and Swedes took turns gaining and ceding control of parts of Ghana; however, in 1874 the British, as the last remaining European power in the country, made the "Gold Coast" a protectorate. Then in 1957, Ghana became the first sub-Saharan country to gain independence (www.ghanaweb.com).

Today, Ghana is a country of hope, development and contrast. Well endowed with natural resources, Ghana has roughly twice the per capita output of the poorer West African countries. The average GDP per capita in 2007 was $635 USD – approximately $1,829 USD when adjusted for purchasing power parity (CIA, IMF and World Bank figures averaged from www.wikipedia.org/). However, it remains heavily dependent on international aid agencies. Although recent economic growth looks promising, the domestic economy continues to rely on subsistence agriculture, which accounts for 50% of the GDP and employs 85% of the work force. Northern rural areas feel especially marginalized as their counterparts in the south are developing better infrastructure, education, and access to health care (www.ghanaweb.com).

Ghana is divided into ten regions, which are further subdivided into 138 districts. The Volta Region is located in the eastern most part of the country and is bordered by the Lake Volta on the west, River Volta and the Bay of Guinea to the south, Togo on the east and the River Oti in the north. It is predominantly settled by the Ewe tribal group, and tends to be forested and mountainous. The northern-most district in the region, composing approximately 27% of the area is Nkwanta district. It is known as an extremely deprived district due to its location, mix of predominantly non-Ewe tribal groups and lack of resources. The district is further broken down into six sub-districts, the northern-most being Damanko. Sibi Hilltop – the location where this study was conducted – is located near the southern boundary of Damanko sub-district (See Figure 2).

Figure 1: Political Map of West Africa focused on Ghana and its neighboring countries (www.geology.com)

1.2 Site Introduction – Sibi Hilltop

The community of Sibi Hilltop lies approximately eight miles south of the town of Damanko (pop. 12,000), and nine miles north of the city of Kpassa (pop. 25,000) on the main road running north/south through Nkwanta District. The general settlement pattern is along the road. However, larger clans in the community extend further back into the bush. Houses are constructed out of mud, covered with thatch or metal roofing sheets, and are usually built around a compound that is open in the middle for drying vegetables. There are thirteen distinct clans in the community. In each clan the compounds are built relatively close to one another, and since the clan represents the immediate and extended family unit, it is typical for one's neighbor to be his brother or cousin's household. Immediately outside of the densely populated clan areas lay the farms of community members.

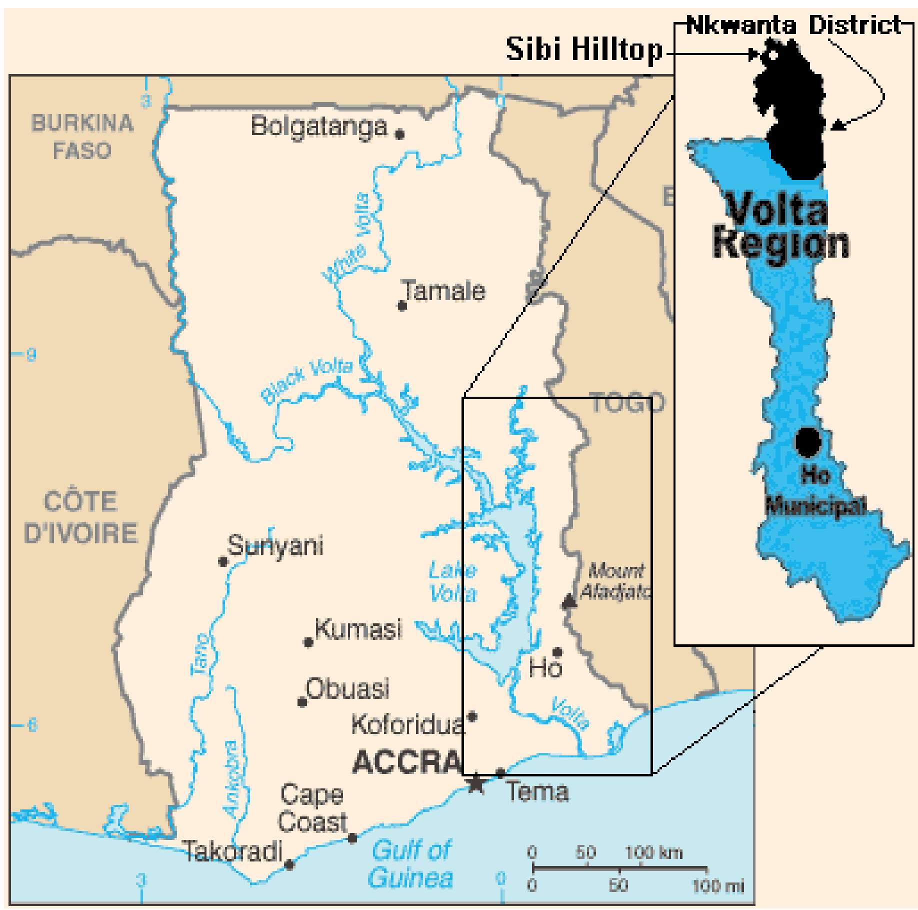

Figure 2: Political Map of Ghana indicating the location of Sibi Hilltop in Nkwanta District of the Volta Region (Adapted from CIA World Factbook)

Landmarks

As the name implies the community was established on a hill that looks north down a small valley to its sister community, Sibi Central. At the base of the hill flows the Sibi Stream and just east of where it crosses the road lies a catchment reservoir that the locals refer to as "the Dam".

Two smaller seasonal streams called Kabunbuk East and West flow on the east and west sides of the community north into the Sibi Stream at points above the reservoir and downstream of the community, respectively. There are also two boreholes in the community, one at the bottom of the hill near the Sibi Stream and one near the clinic. Sibi Hilltop has two primary schools (grades K-6), the Local Authority (L/A) on the west side and the Evangelical Presbyterian on the east side. The latter has a rainwater harvesting system that fills two 50,000 L tanks during the rainy season. Although most people practice traditional beliefs (animistic and ancestor worship) there are four basic church buildings that also serve as meeting places in the community. The most recent addition to the community has been the opening of the Sibi Hilltop Community-based Health Programs and Services (CHPS) Zone clinic, complete with two nurses.

1.1.1 Demographics

According to the 2007 census performed by the Guinea Worm Eradication Program, Sibi Hilltop has a population of 5,278 people. Like many societies in West Africa, it is polygamous, so a typical compound might include a man with two or three wives and eight or nine children. Ethnic tribal groups represented in the community include Konkombas, Basares, Chakosis, and Kotokolis. However, the vast majority of community members are tribal Konkombas; 11 of the 13 clans are Konkomba. This group of people, numbering over a half million in northern Ghana, are considered by many to be difficult, warring and uneducated farmers. They have long been neglected by the government, being denied property rights and Paramount Chieftaincy recognition. Due to their negative reputation Konkomba communities have had a hard time attracting teachers, health workers and other civil servants. Many Konkomba communities including Sibi Hilltop are still recovering from these setbacks. It is estimated that only 15-20% of the children attend primary school, and teachers are notorious for taking long unauthorized leaves of absence. Although English is the official language of Ghana, less than 1% of community members speak it adequately. Most people from the community have never attended school and those who have rarely come back to settle. Although there is some dialectic variation from clan to clan, everyone native to the community speaks Likpalkpaln, the Konkomba language. Twi, an Akan language widely spoken throughout Ghana (and the language PCVs in the district were taught), is also spoken in Sibi Hilltop. Although, generally speaking, the majority and most marginalized members of the community do not speak Twi, only Likpalkpaln.

1.1.2 Livelihood

The Konkomba people are predominantly an agricultural society. They raise a variety of crops for subsistence and any surplus is sold for profit. Assorted beans, hot peppers, groundnuts (peanuts), tomatoes, maize, guinea corn (sorghum), cassava, sweet potatoes and yams are grown by most households (See Figure 3). Palm nuts and papaya are also harvested from trees cultivated on the farm. The major cash crop is the yam, which is quite unlike the sweet potato. African yams are large white tubers with thick brown skin that are raised in mounds of dirt. Konkomba men raise immense yam farms. When harvested they are sold by the hundreds and sent to the capital Accra for sale in the larger markets, or sometimes international trade. Men can typically make from $500-$1,000 on the sale of yams each year, provided the rains cooperate. However, women tend to make less from the local sale of beans, pepper, tomatoes and groundnuts. Due to the Konkomba cultural norm calling for the separation of men's and women's finances, the women often find it difficult to support their domestic budgetary responsibilities of caring for the house and children on limited resources. As most families cannot afford improved farming techniques like tractors or herbicides, back-breaking manual labor is used in conjunction with fetish rituals. A Yam Festival is held every December to honor the gods that ensured a good harvest. Domesticated animals are also raised to a lesser degree to help supplement diets, and to use for ritualistic sacrifices. The average household will have a few chickens, goats and guinea fowls free-ranging about.

Figure 3: Typical household in Sibi Hilltop drying harvested agricultural products in their compound.

1.2.3 Land & Climate

Sibi Hilltop is located in a transition zone between the forested mountains to the south and the dryer savanna to the north. It is vegetated by grasses, scrub brush and scattered trees. Rolling hills, thin topsoil, sandstone geology and a deep ground water table characterize the area. The tropical climate is typified by two seasons – a hot, dry season from November to April and a wet, rainy season from May to October. Temperatures range from 22 deg C to 37 deg C in the dry season and 22 deg C to 33 deg C in the rainy season, with an average relative humidity around 65 percent (varies from 20-95). An informal season, the Harmattan, occurs from December to

February when continental air moves southward with the northeast trade winds from December to February bringing sand from the Sahara, hot hazy days, and cool nights. District rainfall averages 1,398 mm of rainfall per year, with a low of 922 mm and a high of 1,874 mm (Encyclopedia Britannica Online).

1.2.4 Politics

The unpaved main road divides the community into east and west factions. The original founding family in Sibi Hilltop is located on the east side. Traditionally, the chief of the community is to come from that particular family. However, when it came time to choose the chief in Sibi Hilltop they did not have any young men that were qualified so another family was given the chieftaincy rights on the west side of the community. Recent years have seen a power struggle of sorts within the community, as the west side supports the selected Chief and east side supports the community Land Owner, who also holds the title of Youth Leader, and is from the founding family. The community therefore being politically divided finds it difficult to make decisions for the benefit of everyone. To throw another variable into the equation, the chief of Sibi Central is considered the Paramount Chief of the Konkombas in the area, which includes Sibi Hilltop. However, the Sibi Hilltop Chief will not submit to the authority of the Paramount Chief, who has an alliance with the Sibi Hilltop Land Owner. Historically, the valley between Sibi Hilltop and Sibi Central was the dividing line between the Volta Region and the Northern Region. The Sibi Hilltop Chief was empowered by the Adele tribal group to the south, whereas the Sibi Central Paramount Chief was empowered by the Nanumbas in the north. Hence, each of the men's claims is somewhat legitimate. However, in Ghana status means everything and whatever development projects come to the area are used as political tools by the three men to gain more support for their claims. More often than not, projects are lost because of societal in-fighting and the status-quo remains the same.

1.2.5 Assessment of Community Needs

Sibi Hilltop continues to face many development challenges. These range from basic needs like water and health issues to improvements in education and agricultural production. Explained below are some of the greater concerns as identified by community members.

Basic Needs:

Each dry season the community faces a severe water shortage (See Figure 4). All available surface water sources in the area are fetched until exhausted and community members are forced to travel from 8-16 miles (round trip) to bring water back for everyday household activities. The small Kabunbuk Streams dry in November and the larger Sibi Stream is fetched to exhaustion in February. At this point the Chief declares the reservoir open for the women to fetch but it only lasts until the end of March before finishing. Then the community prays for the rain, which can start as early as April but typically doesn't fall enough for the streams to flow until May or as late as June. In the mean time people live in a delicate balance. Water becomes a precious commodity, and much time is dedicated to finding it. The two boreholes in the community yield very poorly during the dry season, as the groundwater table has dropped. Some households will pay to fetch their drinking water from it, but with the hand pump taking about twenty minutes to fill a thirty liter head pan (1.5 L/min) it quickly becomes apparent that there is not enough water to go around.

Figure 4: Finding water during the dry season becomes a difficult task as shown by this girl fetching from a very small pool under an outcropping in the streambed (Photo courtesy of K.G. Paterson).

Another set of community problems involve the lack of access to clean drinking water and basic sanitation facilities. As most people solely use surface water sources for their drinking and cooking throughout the year, there is a need to improve the quality of drinking water to decrease the risk of waterborne disease. The only previously taught point-of-use treatment option was to boil the water. The safe disposal of human excrement is also a huge problem, and potential source of fecal-oral illnesses in the community. Commonly called “free-ranging,” most people openly defecate just outside of the settlement areas behind trees and bushes. Children usually perform this behind houses and in ditches alongside the road.

Malaria and diarrheal-related illnesses continue to affect a large percentage of the population. The high incidence of malaria is due to the already large number of untreated cases in the area, numerous breeding grounds for mosquitoes, and lack of insecticide treated bed nets. The latter is a combination of poor hygiene, clean drinking water and unsafe disposal of excrement. Nutrition is another health problem which tends to affect children between the ages of two and twelve years old. Unbalanced diets are due primarily to a lack in variety of food crops, and traditional meals that are part of the culture.

Secondary Needs:

Sibi Hilltop is part of a corridor along the road from Damanko to Nkwanta that still lacks electricity. The district capital, Nkwanta is the last wired town in the south and to the north the electrical lines end at the border of the Northern Region. Plans to bring electricity to this corridor of communities are currently in the works, with visible signs of poles and lines erected along the main road and within the community. Although, most people would consider electricity to be a luxury item, community development remains limited in many regards without it.. As of now, it is impossible to refrigerate vaccinations at the clinic, or power water pumps. Also businesses that could provide employment opportunities for the area are not attracted here due to the lack of electricity.

The dirt road running through the town is the main line of transit from Nkwanta District to anywhere in the country. Because Sibi Hilltop lacks a transport station, community members usually walk or ride a bicycle to a larger town before boarding a vehicle onto the next leg of their journey. During the rainy season the road becomes so muddy and rutted that it can take 4 hours to travel a distance of 31 miles. In 2007 the road was practically cut off due to particularly intense flows of run-off. Overall the situation discourages many people from traveling through the district, whenever possible. The poor road conditions damage transport vehicles, which cause the transport union to charge exorbitant rates. This affects residents of the community that need to travel, for example, to the district hospital or bank in Nkwanta.

The education system in Ghana is considered better than many other countries in West Africa. However, disparity remains between schools in the north and south. Sibi Hilltop has two primary schools but they lack proper facilities, resources, teachers and overall capacity to effectively enroll and teach all of the community's children. The L/A school, for example, is composed of two pavilion-like structures and a thatched stick shelter. Walls constructed around the outside and between the classrooms would provide shelter during the rainy season and privacy conducive to a better learning environment. Since education is the key to success for any lesser developed country, improving the schools in rural areas would benefit the community and country at large in the future. Figure 5 shows the conditions of the two primary schools.


Figure 5: The two primary schools in Sibi Hilltop have a need for improvement: The L/A Primary School (left) consists of two open pavilions without walls between the classrooms, while the EP Primary School (right) has make-shift chalkboards and a deteriorating structure (Photos courtesy of K.G. Paterson).

1.3 Motivation for Research

According to the World Health Organization (WHO) 1.1 billion people lack access to an improved drinking water supply, and many more drink water that is grossly contaminated (See Figure 6). Four billion cases of diarrhea occur annually, of which 88% is attributed to unsafe water, and inadequate sanitation and hygiene. Every year, 1.8 million people die from diarrhea-related diseases with the vast majority being under 5 years of age. The lack of safe water perpetuates the cycle of poverty in which populations become further disadvantaged and entrenched within the system. WHO estimates that 94% of diarrheal cases are preventable through modifications to the environment including interventions to increase the availability of clean water, and improve sanitation and hygiene. Recent evidence suggests that point-of-use water quality improvements alone result in a one-third or greater reduction in diarrheal disease morbidity. Approaches such as these target the most affected, enhance health, contribute to development and productivity, and deserve far greater priority for implementation. The International Network to Promote Household Water Treatment and Safe Storage goes as far to suggest that, "a policy shift towards household water management and safe storage appears to be the most attractive short-term water-related health intervention in many developing countries" (the Network, WHO 2007).

According to a WHO study in sub-Saharan Africa, 44% of the population or approximately 322 million people still lack access to improved drinking water. Ghana is cited as having a higher coverage rate than the regional average in both urban and rural categories as 88% of urban dwellers and 64% of rural dwellers can claim access to clean drinking water (Table 1). Ghana also performs well compared to its neighboring countries. When looking at total water access, only Cote d'Ivoire has a higher percentage of safe water users than Ghana (WHO Joint Monitoring Program 2006).

National averages can be deceiving though. Due to disparity within the country, marginalized areas often fall far below the statistical averages. For example, in Nkwanta District it is estimated that only 24% of the population has access to improved drinking water. This percentage further erodes at the sub-district level. Damanko Sub-District where Sibi Hilltop lies has a safe water coverage rate of approximately 16% (see Appendix D, Figure 94 for a map of Nkwanta District).

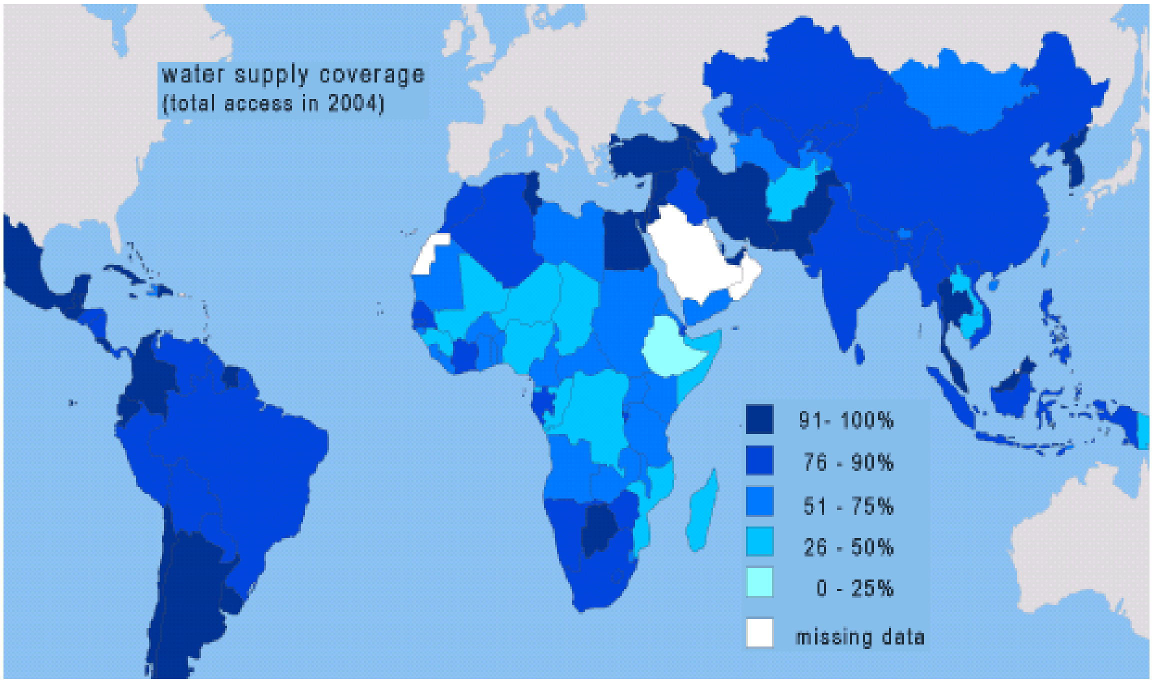

Figure 6: World Map showing developing countries' total access to an improved drinking water supply (Adapted from WHO Joint Monitoring Program 2006).

Table 1: Statistics showing Access to an Improved Drinking Water Supply in Ghana and Neighboring Countries (WHO Joint Monitoring Program 2006)

Country	Year	Urban Pop (%)	Rural Pop (%)	Urban Water Access (%)	Rural Water Access (%)	Total Avg Water Access (%)
Togo	2000	33	67	80	36	51
Togo	2004	36	64	80	36	52
Burkina Faso	2000	17	83	84	48	54
Burkina Faso	2004	18	82	94	54	61
Ghana	2000	44	56	87	57	70
Ghana	2004	46	54	88	64	75
Cote d'Ivoire	2000	44	56	95	73	83
Cote d'Ivoire	2004	45	55	97	74	84

1.3.1 Local Access to Improved Drinking Water

Two boreholes located in Sibi Hilltop provide the community with access to a source of improved drinking water. The boreholes are fixed with India Mark II and Afridev hand pumps, which are designed to deliver water for the needs of up to 300 people. A report on the drilling of one borehole (halfway up the slope of the hill) found that it was drilled in 1986 to the depth of thirty-six meters with a screened section for groundwater to permeate the last twelve meters of the well and the depth of the pipe reaching twenty-four meters. The other borehole drilled in 1999 is located at the bottom of the community near the Sibi Stream and its depth is not known. With a population over 5,000, even if the pumps could operate at the design rate, they would only be able to provide water for roughly 11% of the community. However, due to a dropping water table the flow rates significantly diminish during the dry season and can only supply drinking water for a much smaller percentage of the population – approximately 1.4%. So it can be assumed that accessibility to an improved source of drinking water is from 1.4–11%, much lower than the national average of 75%. These numbers are for total water needs, assuming an average of 30 L/p/d. Theoretically, with a drinking water average of roughly 3 L/p/d (10% of total water needs) the boreholes could provide 100% of the community with improved drinking water during the rainy season and 11.4% during the dry season. Accessibility to strictly an improved supply of drinking water varies then from 11.4-100% during the year.

Another thing to take into account is that just because people have access to a seemingly vital resource does not mean that they will take advantage of it. In other words, availability does not equal use. Although the two hand pumps yield well during the rainy season only a small percentage of the population uses them. Many households collect rainwater that they strictly use for drinking. Others who do not have a suitable roofing material to collect rainwater (like thatch) or simply prefer surface water fetch from the streams. Traditionally, the women in the household fetch the water. Their reasons vary for choosing an unsafe source over that of a safe one. However, cost, taste and convenience tend to be the top reasons. The boreholes utilize a pay-as-you fetch system, determined by the community Water and Sanitation (WatSan) Committee, which recycles the money back to the maintenance of the pumps. It costs roughly two cents per head pan (approximately 30-L) during the rainy season and five cents per head pan during the dry season. Although not an extraordinary sum, this amount would come out of a woman's pocket, and she would prefer not to spend the little money that she earns. Waiting time at the pump appears to be an issue only during the dry season. At the peak of the season women will place extra head pans at the borehole to save their place in line and there can be three or four lines with up to fifty head pans in each line spiraling out from the center of the borehole. The taste preference is a mystery, probably related to lifetime conditioning not unlike those in the U.S. who prefer the taste of well water to that of city water. However, there is a slight sulfuric odor and taste to the lower borehole. The issue of convenience relates to a woman's workload. It takes more work to fetch and manage water from multiple sources than to fetch - and instruct the children to fetch – from one source.

It is not until the dry season – when all the surface water has dried up – that community members will crowd the boreholes, offering to pay for a scarce resource that can no longer provide enough drinking water for the community.

1.3.2 Waterborne Diseases

With decreased access to an improved drinking water source the risk increases for contracting a wide variety of waterborne diseases. Bacteria such as *Escherichia Coli*, *Salmonella typhi*, *Shigella spp*, and *Vibrio cholerae* can be present in surface water, causing diarrhea, leptospirosis, typhoid, shigellosis and cholera, respectively. The nurses at the community clinic report a high number of diarrhea-related illnesses each month in the community, which can be partially attributed to drinking untreated drinking water. Protozoa like amoebas and cysts can also bring illnesses like amoebiasis and giardiasis. Helminths are parasite eggs that are usually found within a host inside surface water. When ingested they adapt to a human host and grow into worms.

1.3.3 Guinea Worm Life Cycle

Dracunculiasis, or Guinea Worm, has long plagued the community. In 2003 Sibi Hilltop was a contender for the highest number of Guinea Worm cases in the world. The parasite has a fairly simple transmission cycle (Figure 7). Dracunculiasis larvae survive in stagnant pools of fresh water inside macroscopic host arthropods known as copepods (water fleas usually of the genus Cyclops). Within 10-14 days the larvae develop into the infective stage inside the copepods. Humans become infected by drinking water containing infected copepods. Once inside the body, stomach acid digests the copepods but not the Guinea Worm larvae, which pass into the small intestine and then the body cavity. The larvae mature into male and female worms and copulate. The male worm dies off and is absorbed by the female worm. The female(s) meanwhile continue to grow to lengths of 60-100 cm and migrate to an outer extremity – 90% of all cases are in the lower limbs. After 10-13 months the female worm exits by releasing a toxin to form a blister on the skin that swells and burns. After twenty-four to seventy-two hours the blister will rupture and partially expose one end of the worm, which looks like a long cooked spaghetti noodle as shown in Figure 8. To cool the burning sensation the victim will often soak their wound in water and the female worm has the opportunity to release hundreds of thousands of eggs into the water source. The eggs are ingested by copepods and the lifecycle of the disease continues.

Sibi Hilltop has a natural environment conducive to the Guinea Worm life cycle. First, the surface water that is primarily fetched is seasonal, and during the dry season the Sibi and Kabunbuk streams form into stagnant pools of water. These – coupled with the large Sibi reservoir – constitute perfect places for the Guinea Worm parasite to survive. Secondly, as mentioned above, there is a low rate of accessibility to an improved drinking water source in the dry season. So a majority of the population is drinking water from sources potentially infested with Guinea Worm. Lastly, because of widespread indigenous beliefs, historically the community blamed the disease on the gods, spells or juju instead of attributing it to drinking contaminated water. Therefore, the water sources were frequently re-contaminated and the disease spread without any interventions to keep it in check.

1.3.4 Guinea Worm Eradication Program

Fortunately, Guinea Worm disease is preventable. By simply filtering the water through a piece of cloth the infected copepods are removed and the transmission cycle is broken. Through the efforts of a global Dracunculias Eradication Program the outcome on the world stage has been tremendous (Figure 9). From an estimated 2.25 million cases in 1986 there has been a 99% reduction in cases to roughly 25,000 in 2006. Beginning in 1990, Ghana initiated a national campaign of its own called the Ghana Guinea Worm Eradication Program (GGWEP). Partnering with international stakeholders the Carter Center, UNICEF, World Bank and WHO, thousands of community-based surveillance volunteers have been trained and mobilized in their communities to combat the disease. They perform necessary duties like distributing free cloth filters, teaching households about the Guinea Worm life cycle, demonstrating proper filtration, guarding community water sources from recontamination, bandaging victims, and ensuring case containment.

Ghana has made strides in its eradication efforts, yet continuously falls short of attaining total eradication by target dates - the latest being Ghana's 50th Anniversary of Independence on March 6, 2007.While the sheer number of endemic regions and districts in the country have dramatically decreased (6,515 endemic communities in 1989; 179 in 2007), the cases have become more concentrated. As this trend continues it should in fact make the disease easier to combat by pouring resources into smaller target areas – as opposed to widespread coverage initiatives. For example, Nkwanta District – a former hot spot of guinea worm activity - has succeeded in its efforts to reduce cases from 1,266 in 2004 to 9 in 2007; A decrease of 99% in just 3 years. A similar situation confronts Savelugu-Nanton District in the Northern Region. In 2006, due to a seasonal water shortage, tanker trucks hauled water from outlying community dams infected with Guinea Worm and sold it to households in the city, unbeknownst to the buyers. The following year (2007), residents in Savelugu-Nanton suffered over 2,000 cases of Guinea Worm – 62% of all recorded cases in Ghana. The Northern Region as a whole recorded 96% of all cases in 2007. In response to these recent outbreaks the major stakeholders in the GGWEP, Carter Center and Ghana Health Service, have reorganized their field staff, worked with the media to raise awareness, and collaborated with other agencies to focus more resources and funding into the campaign in the north.

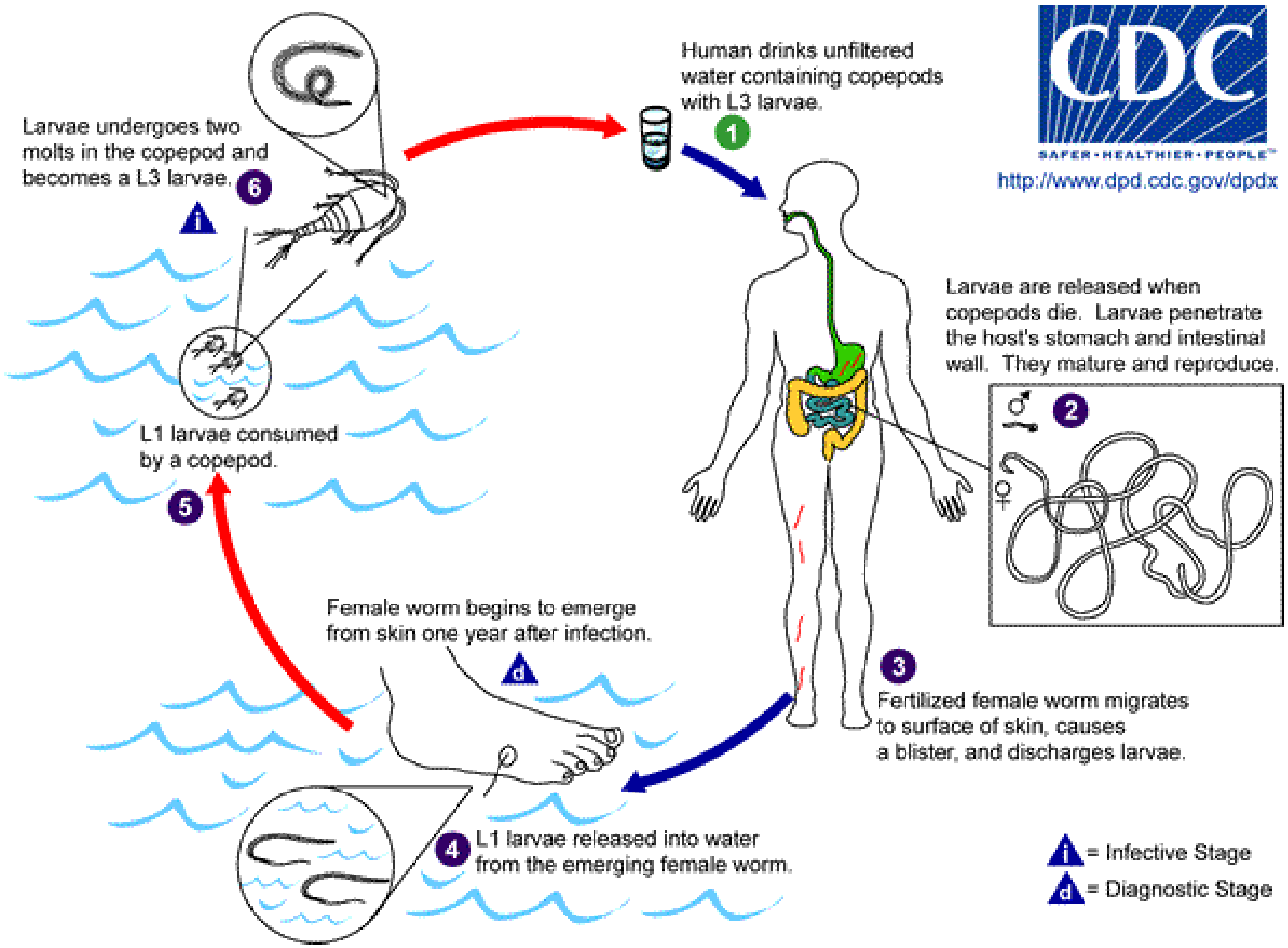

Figure 7: Life Cycle of Guinea Worm or *Dracunculiasis Medinensis* (Center for Disease Control)

Figure 8: Guinea Worm emerging from a patient's ankle (Seattle Post Intelligencer)

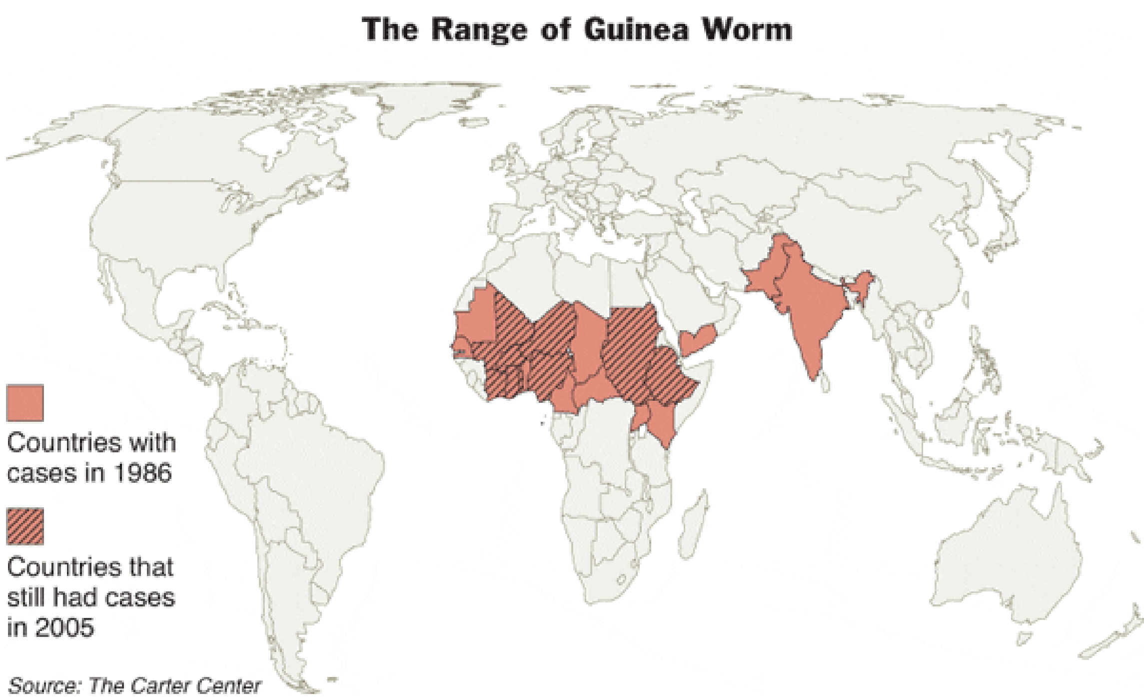

Figure 9: Countries with endemic cases of Guinea Worm in the past and today (Carter Center)

1.3.5 International Aid's BioSand Filter

International Aid – a Christian relief and development NGO from Spring Lake, Michigan – is one such agency that volunteered to collaborate with the Carter Center on their efforts in the fight against Guinea Worm. Earlier in 2007, Lamisi Mbillah (2006 Miss Ghana) attended the "Thirsting to Serve Water Conference" in Grand Rapids, Michigan where International Aid announced a major safe water initiative that focuses on the distribution and use of BioSand Filtration technology housed in a lightweight plastic container, rather than concrete. Designed by Cascade Engineering, the plastic model weighs about seven pounds (compared to about 300 pounds for the empty concrete filter), costs roughly $32 USD to produce, and is trademarked the HydrAid™ BioSand Water Filter. Figure 10 shows a profile view of the filter. Mbillah, an advocate for the GGWEP, asked International Aid to provide BioSand Filters to Ghana as an intervention for households to combat Guinea Worm. Linking the NGO with the Carter Center, the two organizations agreed to assist each other. International Aid would donate 2,000 filters to the GGWEP, and Carter Center would perform a number of tests on the filter to determine best methods of installation, water quality improvement and user acceptability.

A partnership between Carter Center and the U.S. Peace Corps enabled the HydrAid™ BioSand Water Filter to be tested in Sibi Hilltop. The Peace Corps Volunteer living in the community (the author) would select participating households for the study, facilitate filter installation in three phases, document installation procedures (best methods), educate beneficiary households on the new technology, record flow rates, identify filter problems and solutions, collect water samples for analysis, and perform household surveys. The Carter Center would provide the resources to support these tasks.

1.4 Research Objectives

The general goal of this study was to determine the capability of HydrAid BioSand Filters as a viable point-of-use water treatment option for similar communities lacking access to an improved drinking water supply. The Carter Center was mainly interested in the installation process of the filters in order to initiate it as a rapid intervention for communities at risk for Guinea Worm. International Aid was concerned about the pathogen removal capability and flow-rates of the HydrAid™ BioSand Water Filter in the field.

Four main objectives were identified for this study:

1. Determine installation guidelines for the HydrAid™ BioSand Water Filter

2. Study the performance of the HydrAid™ BioSand Water Filter in its ability to provide a household with a significantly improved quality and sufficient supply of water for all cooking and drinking needs

3. Analyze user acceptability and comprehension of HydrAid™ BioSand Water Filter technology

4. Compare the advantages and disadvantages associated with the HydrAid™ BioSand Water Filter to those of the traditional concrete BioSand Filter

Figure 10: How it Works – HydrAid™ BioSand Water Filter by International Aid (www.hydraid.org)

Chapter 2: BioSand Filtration

This chapter begins by outlining various point-of-use (POU) water treatment methods currently available in Ghana, and focuses on BioSand Filters. The development of this particular technology is discussed to reveal how it evolved from community-scale slow sand filtration to a household intermittent filter made of concrete, and then to a new design by International Aid (IA) made of light-weight plastic. More technical information forms the background for the operational processes, optimization and design parameters for the concrete-tested models. Case studies from Haiti and Cambodia demonstrate successful implementations of BioSand Filter (BSF) projects and the impacts of the technology on the communities that use them.

2.1 Point-of-Use Water Treatment

Within the last five years, POU water treatment has gained momentum within the realm of public health as an effective way to reduce diarrheal disease in developing countries. Dr. Tom Clasen summarized during a lecture at Michigan Technological University that previous in-depth studies had found water treatment alone to have a lower impact than all other interventions (Esrey et al 1991). However, the studies had only included results from point-source treatment systems, not POU technologies managed at the household level. Recent studies exclusively analyzing POU treatment technologies in the field have shown reductions in diarrheal disease of up to 48% (Crump et al 2005; Brin 2003). Due to these findings POU water treatment is noted as a viable intervention for diarrheal reduction, and many organizations and institutions are implementing projects which focus specifically on these technologies or a combination of them with another intervention.

There are many examples of POU water treatment technologies that are being promoted in lesser developed countries. These utilize three main categories of treatment methods (Sobsey 2002):

1. **Physical treatment:** using boiling, heating, sedimentation, filtration and UV radiation exposure to neutralize and/or physically remove contaminants;
2. **Chemical treatment:** using coagulation, flocculation and precipitation, adsorption, ion exchange, or chemical disinfection to neutralize and/or remove contaminants; and
3. **Combined treatment:** using a combination of the above two processes.

Each specific technology has associated advantages and disadvantages and there appears to be no outstanding recommendation among them. The ideal one would provide the best performance at the lowest cost, which is not only sustainable but also acceptable to the user. However, these variables tend to change depending on geographic location and the cultural norms and values of the people. Examined below are the POU treatment alternatives that are currently available and/or being used in Ghana to improve drinking water supplies.

2.1.1 Boiling

Bringing water to rolling boil kills most pathogens in approximately one minute at sea level , and three minutes at altitudes above one mile (epa.gov/safewater/faq/emerg.html). This method has attained widespread dissemination throughout Ghana as an effective technology that is readily available (Figure 11a). However, it is not regularly practiced simply because it is not an acceptable option to the users, i.e. – mostly women. They are the ones who fetch the firewood and water, and perform the cooking tasks in the home. For them, boiling water is time consuming and there is no visible change in the water to indicate an improvement. Plus, financial costs associated with boiling include increased burns to small children along with respiratory and environmental impacts from biomass fuel combustion.

2.1.2 Solar Disinfection (SODIS)

Invented by a Professor at the American University of Beirut, Lebanon in 1982, solar disinfection has also proven a highly effective treatment option. SODIS Researchers at the Swiss Federal Institute of Environmental Science and Technology (ETH-EAWAG/SANDEC) took up extensive studies of SODIS in 1991 and have demonstrated a high removal rate of a wide range of microbial contaminants. A simple technology, SODIS involves filling clear plastic bottles with contaminated water and exposing them to full sunlight for six hours (Figure 11b). Sunlight treats the water through two synergetic mechanisms: 1) Radiation in the spectrum of UV-A (320-400nm); and 2) increased water temperature. If the water temperature rises above 50 ^{0}C the process is three times faster (www.sodis.ch 2008).

SODIS remains a low-cost treatment – PET bottles are widely available for reuse – that does not pollute the environment. Ghana is also within the range of latitudes considered “most favorable” for solar disinfection. However, there have not been any substantial studies nor wide dissemination of information performed in Ghana concerning the technology and most people in rural areas remain unaware of its potential. Some noted drawbacks to this method include user acceptance issues such as the length of time to treat the water, the consumer’s preference of drinking water temperature, and sustained behavior over an extended period of time. Also, if the turbidity of the source water is higher than 30 NTU, another process must be employed prior to SODIS to remove sediment or color.

2.1.3 Chlorination

Highly promoted by the Center for Disease Control, chlorination is an inexpensive method of water treatment that is very effective at neutralizing bacteria and viruses. Cited advantages include ease of use, cost effectiveness ($0.40-0.80/family/month), and the ability to treat large amounts of water at once (CAWST 2006). Usually utilized in the disinfection stage of treatment and probably employed in certain areas of Ghana as a guarantee for safe storage, it is unknown to what extent chlorination is used alone as a POU option. Overall, it faces serious challenges when considering user acceptance. To be adopted chlorination needs sustained behavior change that requires an immense amount of educational and promotional support. The simplicity of the treatment is also questionable; a specific dose of chlorine (usually found as a percentage in bleach) is required for a specific amount of water. This can be a difficult process for lesser educated people to perform. Not only do the physical characteristics of the treated water offer no apparent change but the water has an unusual smell and taste that users typically dislike. Furthermore, bleach or chlorine solution (Figure 11c) is not readily available in many local markets around the country, especially in rural areas. This makes it harder when introducing a product that is unfamiliar to the user. Other limitations to chlorination include the long contact time required for treatment, need for low-turbid water to be most effective, non-effectiveness at killing protozoan cysts, and unknown carcinogenic effects caused from consuming complex chlorine-organic compounds over long periods of time (CAWST 2006).

2.1.4 CT Filtron Ceramic Filter

In 2003, collaborating with U.S. NGO Potters for Peace and Dutch Practica Foundation, private company Ceramica Tamakloe (CT) began producing a simple water filter known as the CT Filtron in Accra, Ghana. The filter looks like a planter and is fitted into a clear, plastic forty liter container with a spigot, which allows for safe storage of the treated water (Figure 11d). The ceramic pot is made from a precise ratio of red clay and fine-sieved saw dust, the latter of which burns out during the firing process to leave tiny pores for water to pass through the filter. Each pot is then immersed in a solution of colloidal silver, which acts as a disinfectant and inhibits bacterial growth within the pore spaces. It has an estimated life span of two years for the ceramic filter and ten years for the plastic container. The product is fully enclosed and costs approximately $18 UDS per filter. However, some aid organizations have ordered the filter in bulk and offer it at a subsidized price (http://www.bidnetwork.org/artefact-67547-en.html). The main problems identified with the filter include the high initial price, fragile design that is susceptible to breakage during transport, the necessity to maintain the filter on a weekly basis, and a slow filtration rate (2 L/hr quoted rate; 1.06 L/hr as tested). The National Director of Ghana Health Service remarked that the filter is "just too slow."

In 2005, MIT engineering and business students partnered with two Ghanaian entrepreneurs to start a social business called Pure Home Water (PHW). Begun as an organization to promote and sell a variety of POU technologies, the CT Filtron quickly became their best seller and main water treatment product. So much so, that it became locally known as the Kosim Filter – *Kosim* meaning "best water" in the northern tribal language, Dagbani. Working exclusively within three districts in the Northern Region, PHW has marketed and sold the Kosim Filter to thousands of households that previously lacked access to an improved drinking water supply. To the most marginalized groups in rural areas they offered a micro-finance scheme that allowed households to pay the money over several months instead of in as an upfront lump payment. During 2005-06 PHW set the filter price at $19 USD when bought in cash, and $20 USD when bought on credit. The price of the ceramic pot was $6.10 USD. During 2006-07 PHW changed their marketing scheme to create a higher level of awareness and make the filters more affordable for consumers. New prices included a $1 USD profit margin for distributors at the community level, who would both advertise and sell the product for $7 USD and $13 USD for rural customers and institutional/urban customers, respectively. Part of PHW's strategy was to also manufacture its own ceramic filters in the Northern Region by December 2007 in order to scale-up operations and bring down costs (Okioga 2007). A study performed by PHW in 2006 showed a 69% reduction in diarrheal disease in rural areas among filter users. Field tests on the treated water indicated reductions of 99.4% and 99.7% for total coliforms and E. coli. In a forty-one household survey, 100% of the users reported that the filter was "easy to use," they used it daily, and they would recommend it to others (Johnson 2007).

2.1.5 Nnsupa Ceramic Candle Filter

The Nnsupa is another locally produced filter (Kumasi, Ghana) using ceramic candle technology. The project came about through collaboration between Michael Commeh from the Technology Consultancy Centre and Kwame Nkrumah University of Science and Technology (KNUST) in Kumasi. The filters cost roughly $1.50-$2.00 USD for the candle and $20 USD for the system. Funded by the Swiss Embassy, the goal was to open up a local filter production market and to produce cost effective ceramic candles for household filters. In 2003, the first filters were produced that, according to Commeh, reduce bacteria, cysts and heavy metals by 100%. PHW found the total coliform reduction rate to be 92% during microbiological indicator tests in 2005. The filter system is composed of two clear, plastic containers – one on the top housing the filter and one on the bottom collecting and storing the water that percolates through the candle. A tap on the bottom container provides water to the user in a safe manner (Figure 11e). The candle is made out of white clay and produced in a similar manner to the pot in the Kusim filter, except it is not coated in colloidal silver at the end. When finished they are mounted on an aluminum base, which screws into the bottom container using rubber washers to prevent leakage of unfiltered water. PHW also tried to market this product for the cost of $25 USD per filter with only limited success (Mattelet 2006).

Like the Kusim, the biggest advantage for this filter is product sustainability. Since it is made and distributed locally it does not depend on donor support or funding. However, the cost is high and marketing is a problem; the filter is not well known throughout the country, being limited mainly to the Ashanti Region where it is produced. The flow rate when tested by PHW of 0.34 L/hr is also a barrier to user acceptance. (Mattelet 2006)

2.1.6 Everest Aquaguard Ceramic Filter

The Everest Aquaguard is produced in India and sold in Melcom department stores in major cities within Ghana. Not much information is known about the filter or the company that produces it. The filter components include top and bottom metal, cylindrical containers that fit together, and a ceramic candle between them made from white clay (Figure 11f). The candle itself is not coated with colloidal silver. The price of the filter depends on the volume capacity. At Melcom the twenty, twenty-four and twenty-seven liter systems cost roughly $15.10 USD,

$17.30 USD and $19.50 USD, respectively. The target clients for the filter are mainly middle class consumers who can afford to shop at the Melcom department stores. Since this does not include the poorest groups of society, especially from rural areas, it is not a viable solution for increasing access to improved drinking water supplies. Perhaps it could be if the Ghana Health Service or an NGO marketed it and created channels of distribution to make it available to the poor. Again, like the other two ceramic filters, the low flow rate (0.55 L/hr as tested by PHW) is an issue along with maintenance and replacement of the candles after a few years of use. Microbiological indicator tests performed by PHW in 2005 were inconclusive (Mattelet 2006).

2.1.7 BioSand Filters (BSF)

In 2006 the Centre for Affordable Water and Sanitation Technology (CAWST) conducted training with a local NGO, Afram Plains Development Organization (APDO), in the Volta Region of Ghana (Figure 12). The purpose of the training was to provide APDO with all the tools, resources, and educational materials needed to implement BioSand Filter entrepreneurial projects throughout their coverage area. This approach seeks to sustainably increase POU coverage by training artisans to construct the filters, providing training and start-up materials, and supporting them to develop micro-enterprises to sell the filters within their communities.

In laboratory and field tests the BSF consistently reduces bacteria, on average by 81-100% (Kaiser et al, 2002) and protozoa by 99.8-100% (Palamateer et al, 1999). However, initial research shows that BSFs remove less than 90% of indicator viruses. Since it does not provide complete removal of pathogens, recontamination of drinking water can occur in the storage phase. The technology has high user acceptability due to its ease of use, and provision of a physically improved and better tasting drinking water. Other benefits include sustainability since it can be produced locally from available materials, the convenience of a one-time installation with little maintenance required, a fast flow rate of up to 1.0 L/min, and a long product lifetime with no parts to replace. Some challenges to the technology involve the difficulty of transport – each concrete filter can weigh over 300 lbs empty – and a high initial cost.

(a)

(b)

(c)

(d)

(e)

(f)

Figure 11: POU water treatment options available in Ghana: (a) Boiling is commonly known but unacceptable to the user, (b) SODIS inactivates microorganisms by UV-A and thermal treatment, (c) Chlorine is cost-effective but not available in small market towns, (d) the CT Filtron (Kosim) is currently being marketed by PHW in the Northern Region, (e) Nnuspa ceramic filters are made in Kumasi, and (f) Everest ceramic filters are sold in Melcom department stores in large cities (Pictures from CAWST 2006, CT Limited 2008, Mattelet 2006, and Mattelet, Peletz and VanCalcar 2005).

2.2 Biological Sand Filtration

Conventional slow sand filtration (Figure 13) has been used for several centuries throughout Europe and in developing countries for the effective treatment of drinking water. It is different from rapid sand filtration mainly because it contains biological activity. For this reason it is also referred to as biological sand (BioSand) filtration. The technology is a combination of four biological and mechanical processes to remove pathogens and other contaminants (CAWST 2006):

1. **Mechanical Trapping:** The primary process for removal of pathogens, mechanical trapping is the physical filtration of particles and organic material as they pass through the filter. Sand grain sizes are usually 0.1 – 1.0 mm and the pore spaces are usually less than this. Large materials such as grass, leaves, silt, or clay particles, along with large pathogens like parasites, helminthes and worms are trapped in the pore spaces. Smaller pathogens such as bacteria and viruses are trapped by the same process when they are attached to the larger particles. The filter removes 60-90% of all pathogens (over 99.9% of large pathogens) during this process.

2. **Predation**: Organic material is trapped at the surface of the fine sand and forms a complex biological layer, much like a pond or wetland ecosystem, where microorganisms grow and thrive. Referred to as the *schmutzdecke*– a German word for "dirty layer" – the composition of the top 1-3 cm varies depending on the source water. However, it will typically consist of a gelatinous biofilm of bacteria, fungi, protozoa, rotifera, and a range of aquatic insect larvae. These microorganisms gain nitrogen and carbon by consuming nutrients from the organics and other pathogens in the source water. Larger microorganisms consume smaller ones. Stronger ones consume weaker ones. Living ones consume dying ones. The series of predation is an active food chain within the *schmutzdecke*. Oxygen is necessary for these aerobic organisms to survive. This is provided by dissolved oxygen in the source water. (Intermittently operated sand filters differ from conventional designs in that additional oxygen is diffused through the static layer of water above the sand. If the water is too deep (>8cm) the oxygen cannot diffuse enough to get to the organisms.)

3. **Adsorption:** Pathogens and particles, attracted due to electrical and cohesive forces, attach themselves to one another and are thus trapped in pore spaces. Bacteria and viruses can also attach directly to the sand particles that compose the filter media. Once attached they are metabolized by the cells or inactivated by antiviral chemicals produced by organisms in the filter. As the biofilm starts to grow it tends to attract an increasing amount of particles to it. This takes place in the biological zone (or biolayer) of the filter, roughly 5-10 cm from the surface. After this depth biological activity curtails due to lack of nutrients and oxygen.

4. **Natural Death:** Different from predation, this refers to the "natural" die off rate or life expectancy of the microorganisms. If they are trapped long enough within the filter the pathogens will die from food scarcity or less than optimal temperatures before exiting the filter. This can also occur if the pause period is long enough – some organisms have life-spans of only a few hours – or if aerobic organisms are trapped deep within the filter where oxygen is not available.

2.3 Intermittent BioSand Filters

Due to the need for a continuous supply of food and oxygen from the source water, it was previously considered impractical to operate a slow sand filter intermittently. The biological organisms would start to die even after a few hours of halting the continuous flow of water. However, in 1995 Dr. David Manz from the University of Calgary redesigned the traditional sand filter to be able to operate with significant pause periods. His simple innovations downsized the filtration bed into a small vertical unit and extended the outlet pipe from the bottom under-drain up to approximately 5 cm above the sand layer. The latter adaption allowed for adequate diffusion of oxygen through the supernatant to the biolayer during the resting periods. Suddenly, the community-sized technology of slow sand filtration was able to operate just as effectively as a smaller unit at the household level (biosandfilter.org 2004).

Manz's design, illustrated in Figure 14, utilizes a container made of concrete and stands approximately 95 cm in height and 36 cm in width. Weighing 150 kg empty, the filter can surpass 225 kg when filled with filter media and water. Due to their high flow rates of 30-40 L/hr the filters can easily provide enough clean drinking water for an entire family each day. The cost varies depending on the country – ranging from $10 to $40 USD – and averages around $25 USD per filter (Duke et al 2006). The BioSand Filter (henceforth referred to as BSF) is particularly suitable for use in low-income countries where populations still rely on untreated, contaminated surface water.

Figure 12: BSF training facilitated by CAWST in the Volta Region (CAWST 2006)

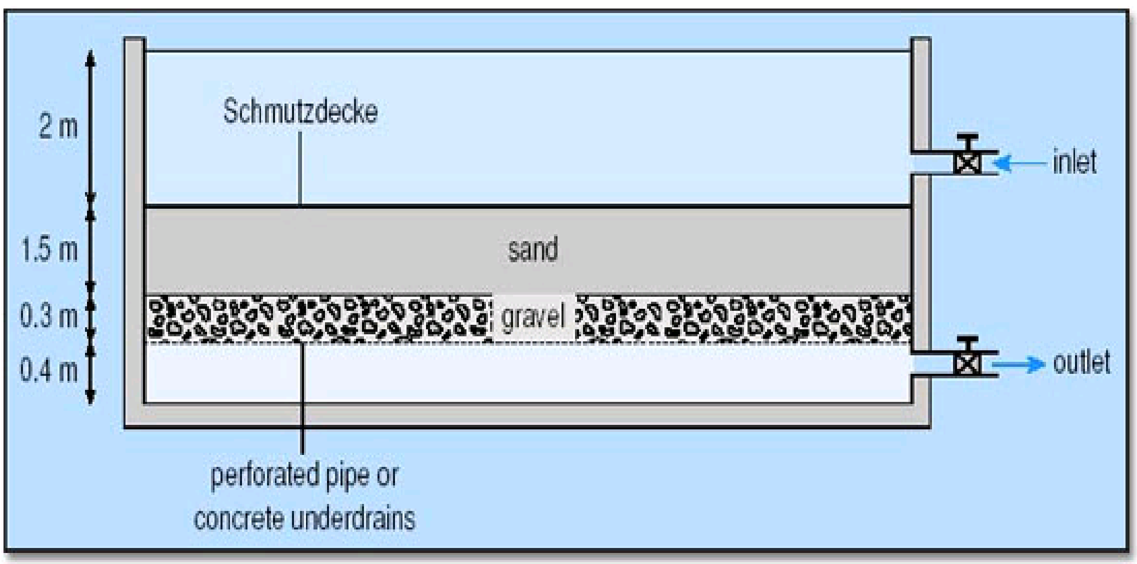

Figure 13: Conventional slow sand filters operate continuously to provide enough dissolved oxygen from the source water to the microorganisms in the Schmutzdecke and biological zone (Adapted from www.openlearn.com).

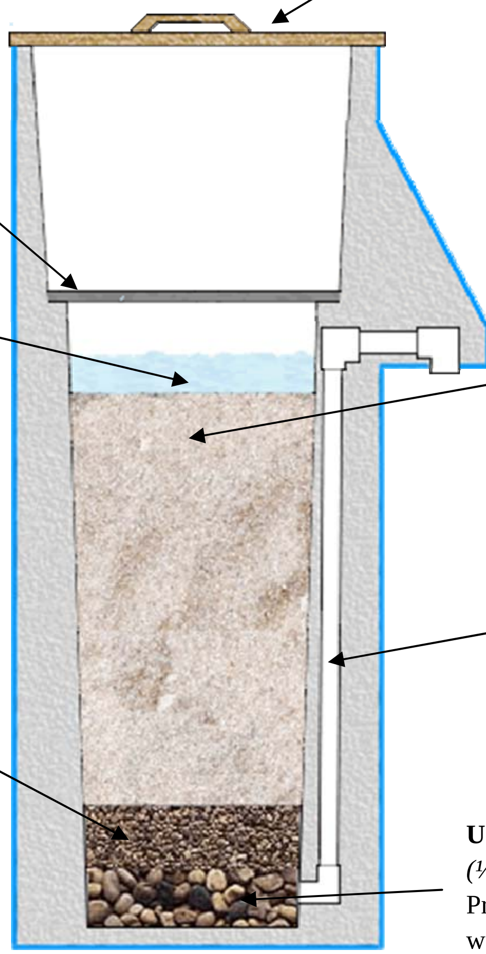

Figure 14: The BioSand Filter is a technology modified from the conventional slow sand filter that can operate intermittently at the household level (Adapted from CAWST 2006).

2.3.1 Operation

The BSF is especially noted by users for its high ease of operation. The technology is without any valves, moving parts or electrical requirements. The lid is removed and a bucket or head pan of contaminated water can be poured into the top reservoir of the filter as necessary. The water then enters the diffuser pan which causes the water to spread out into many smaller openings to ensure the initial force of water does not overly disturb the *schmutzdecke*. The water filters through the biolayer, sand and gravel media and exits through the outlet pipe as the pressure increases to match the inside of the filter reservoir. After all added water has been displaced through the filter, the head falls to the height of the horizontal outlet, approximately 5 cm above the sand. Equilibrium of pressures in the filter and outlet pipe forces the effluent to stop.

2.3.2 Flow Rate

The microorganisms in the BSF are more closely confined to the surface than that of a continuously operated slow sand filter and are limited by the diffusion of oxygen across the supernatant. Due to a shallow biological zone there is an overall shorter contact time between the source water and biofilm, which decreases removal rates and water quality. In order to provide comparable treatment, slower flow rates are needed when operating the BSF. The percentage removal of pathogens has been found to be inversely proportional to the flow rate, which is controlled by the size and cleanliness of the sand layer during the installation process. Although BSF literature states a maximum flow rate of 1.0 L/min, CAWST recently recommended 0.6 L/min as the ideal flow rate for optimizing treatment effectiveness with adequate supply (www.cawst.org). Pause periods have also proven effective when operating the filter as they allow time for predation to occur within the biological layer. As the pathogens and substrate are consumed the flow rate is restored and hydraulic conductivity increases exponentially. This further improves reduction of pathogens. However, if the pause period is too long the microorganisms will consume everything and die off – thus decreasing reduction rates when the filter is used again. The BSF is most effective and efficient when operated intermittently and consistently. The optimal pause period is 6-12 hours, with a minimum of 1 hour and a maximum of 24 hours (CAWST 2006).

2.3.3 Influent Water Quality

The water supplied to the BSF can come from a variety of sources including rain water, groundwater (shallow wells or bore holes) and surface water (rivers, lakes, springs, reservoirs). For optimal performance the turbidity in the source water should be below 100 NTU to avoid premature clogging of the filter. If higher than this the water should undergo a pre-filtration, sedimentation or coagulation process. It is generally recommended that the water come from the cleanest water source available. However, it should be consistently taken from the same source since the biolayer in the BSF will become adapted to conditions where a certain amount of food is available. If the influent water is changed to a more contaminated source the microorganisms will not be able to consume the increased amount of nutrients and pathogens.

This type of spike event may result in a reduction in water quality for several days afterward until the biolayer adjusts to the new substrate levels (CAWST 2006).

2.3.4 Effluent Water Quality

It normally takes a period of two to three weeks for the biological zone to mature in a new filter. During that time the removal efficiency and oxygen demand continue to increase until leveling out and reaching maximum rates. After maintenance of the filter the removal efficiency also declines somewhat but has a quicker rebound period as demonstrated in Figure 15.

Many water quality analyses have been performed over the last fifteen years by various government, research, and health institutions as well as NGOs with regard to the removal efficiency of BSFs. Statistics vary by country and program, and depend largely on the quality of installation, education, filter media, source water, and household use patterns. Overall, these studies have shown that the BioSand Filter removes (CAWST 2008):

- 90-99% of fecal coliforms
- 100% of protozoa and helminthes
- 50-90% of organic and inorganic toxicants
- 95-99% of Zn, Cu, Cd, and Pb
- <67% of Fe and Mn
- <47% of arsenic with filter adaptation (called a Kanchan filter)
- ~80-90% of viruses with a mature biolayer

Although average removal efficiencies are not 100% for bacteria or viruses, in many cases the remaining level of pathogens in the effluent water is below the infectious dosing rate. Therefore, the filter remains effective at preventing illness and disease.

2.3.5 Safe Storage

Although the filtered water is collected in a container of the user's choice, it is recommended for safety reasons that the collection be a closed system to prevent recontamination (Figure 16). The outlet pipe should flow directly into a clean durable container with a small opening – preferably raised and with a spigot on the bottom for easy access. An additional step of disinfection by chlorination or SODIS would further protect the stored water from recontamination.

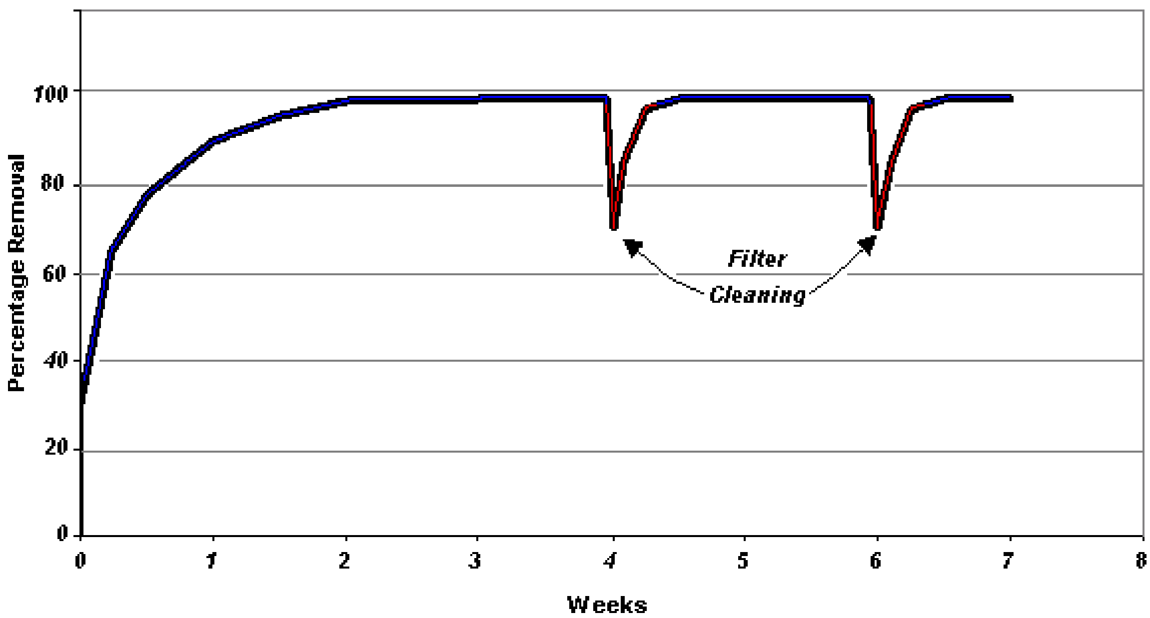

Figure 15: BSF removal efficiency graphed over time (Adapted from CAWST 2006)

Figure 16: Examples of safe storage containers (CAWST Learning Aids 2006)

2.3.6 Maintenance

Over time the pore spaces within the *schmutzdecke* will become clogged and the flow rate will reduce significantly (Figure 17). Although this will increase contact time and result in greater reduction of pathogens, the user will at some point desire a greater flow rate. Maintenance is simple and requires only a few minutes of time to perform what CAWST terms the "swirl-and-dump" method. The reservoir is filled with additional water and the diffuser plate removed. The surface of the sand is agitated by hand or with a stick to suspend the captured material in the water (*swirl*). However, the surface layer should not be worked deeper than 5 cm. The dirty water is then bailed out with a small container (*dump*) and the process is repeated until the desired flow rate is reached. The biolayer tends to re-grow quickly and removal efficiency returns to the previous level (CASWT 2006). The spout and receiving container also need to be disinfected with chlorine solution or cleaned with soap and water on a regular basis to reduce the risk of recontamination.

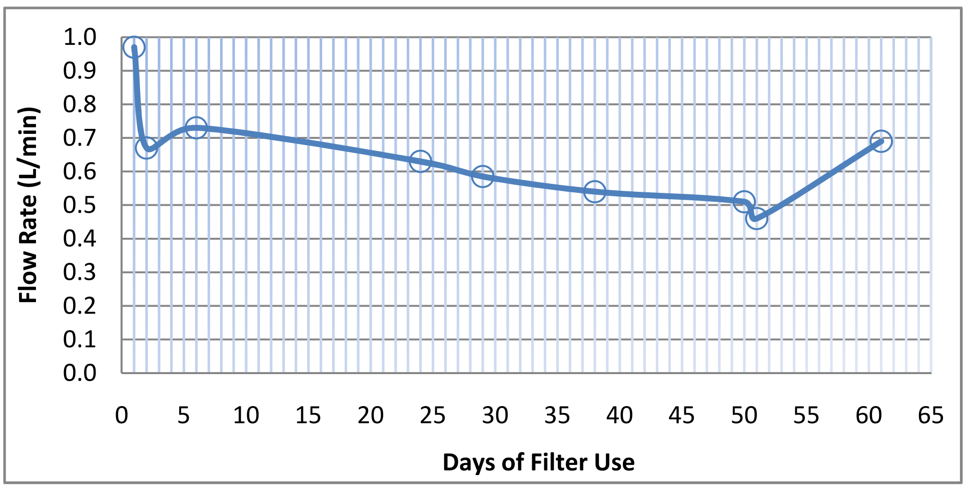

Figure 17: The graph above demonstrates how flow rates decrease with time as sediment and pathogens block pore spaces within the filter media. Once the flow rate becomes too slow, maintenance is performed and the flow rate increases.

2.3.7 BioSand Filtration Summary

BioSand Filters currently provide safe drinking water to over 200,000 households in over 70 countries around the globe (www.manzwaterinfo.ca). As discussed above, BSFs are not the only treatment option available to the developing world and must be evaluated based on a framework of criteria in the context of site-specific information. Once they are compared to other POU water treatment methods, the most appropriate technology can be selected. However, using only general parameters as in Table 2, intermittent BSFs appear to be a remarkably attractive household water treatment option. Other issues such as Local Demand for the Technology, Opportunity for Community Participation, Ease of Technology Transfer, and Economic Sustainability will vary with the participatory group (Lukacs 2002).

Table 2: Design parameters including advantages and limitations for the concrete BioSand Filter (costs from CAWST 2006, parameters form Lukacs 2002)

Parameter:	Advantages:	Limitations:	Comments:
Water Quality	Lab Removal: 100% Protozoa 99.9% Viruses 99.5% Bacteria	Field Tests: 80-90% Viruses 90-99% Fecal coliform bacteria	60-99% bacterial removal while biolayer is maturing; Overall less reduction than ceramic filters
Water Quantity / Flow Rate	≤ 1.0 L/min, ~30L/hr	Flow rate decreases as biolayer is clogged	CAWST currently recommends flow rates of 0.6 L/min for the most effective water treatment
Robustness of Design	Very Durable: Concrete container w/ internal piping	Concrete Filter is heavy - Typically >300 lbs	Only component that may need to be replaced is the diffuser plate, depending on material
Technological Sustainability	All BSF materials local: Cement, wood, stones, sand, PVC piping	Start-up materials for production are costly (steel mold, screens, various tools)	Many implementing agencies provide training and materials to local BSF artisans to help them start a micro-enterprise
Obvious Importance to Users	Physical change in water appearance as filter reduces color and turbidity; Improved taste	Physical change varies based on source water & BSF performance	Education needed to explain how BSF removal mechanisms work, especially predation and function of non-visible biofilm
Maintenance	"Swirl-and-dump" method is free, easy and effective	Breaks up biolayer and removal rates decrease temporarily	Performed when flow rate is too slow for the user, by the user
Costs	One time initial cost: $10.75 – $39.50 USD No maintenance costs	Many people cannot afford to pay the high initial cost upfront	Most implementing agencies offer the technology at a reduced/subsidized rate

2.4 BioSand Filter Case Studies

The BioSand Filter appears not only as a viable solution on paper but has been evaluated in the field through several studies and determined to be a successful POU treatment and appropriate technology. Discussed below are case studies from Haiti and Cambodia performed by two different research teams that show high user acceptance, reduction efficiencies, and in Cambodia, positive implications for BSF technology as an effective intervention against diarrheal disease.

2.4.1 Artibonite Valley, Haiti

Located in central Haiti, the Artibonite Valley is a productive agricultural area that has been described as "one of the worlds' most densely populated and impoverished areas" (schweitzerhospitalfund.org). As demonstrated by vast irrigation on the valley floor, water resources are close at hand. People mostly access shallow hand dug wells near their homes (61%). Some also have access to piped bore-hole water or developed springs with distribution systems to shared standpipes (26%). A few access both (13%). Due to contaminated source water and unhygienic practices there proved a need for a method of providing safer drinking water to the residents. In 1999 Dr. Manz visited the Albert Schweitzer Hospital, located in Deschappelle within the valley. The staff of the Community Development Division was instructed on the construction, installation and maintenance of the concrete BSF. Through the program households were required to contribute $12 USD or roughly one-third to one-half of the cost of the BSF. Between 1999 and 2004, the staff installed approximately 2,000 BSFs around Artibonite Valley (Figure 18). In 2005 a field study of 107 households was conducted by CAWST and the University of Victoria, B.C. to determine the use and performance of the BSFs. By this time the installed filters were one to five years old with an average of two and a half years in use. Interviews, observations and water samples were carried out by two teams of trained Haitians, each consisting of a nurse and filter technician. Water quality analyses were performed by Haitian lab technicians on various influent (source, transfer bucket, supernatant) and effluent (filter spout and storage container) water samples (Duke, et al 2006).

The surveys indicated that the participants were generally satisfied by their filter's performance: 100% liked their filters and said they were easy to use; 99% preferred the appearance, taste and smell of the filtered water over the source water and felt the BSF could produce enough water for their entire household; 95% felt their family's health had improved since using the filter; and 92% of the BSFs appeared to be well maintained by the users. None of the households treated their water after filtering and no problems related to BSF construction were found. The water quality testing revealed an average of 234 E. coli cfu/100 mL of source water from the shallow, hand-dug wells. Piped sources averaged 195 E. coli cfu/100 mL. Overall bacterial removal efficiency for the BSFs was calculated to be 98.5% with 97% of the effluent water samples containing 0-10 E. coli cfu/100 mL. Turbidity decreased 85%, from an average of 6.2 NTU in the source water to 0.9 NTU in the filtered water. However, recontamination was found to be a problem with 22% of the samples taken from stored filtered water containing 0-10 E. coli cfu/100 mL. The study concluded that BSFs are "an attractive option for supplying water treatment to family units in rural areas of poorly developed countries" but safe filtered water storage and/or disinfection should be a part of the education given to users to prevent recontamination (Duke, et al 2006).

Figure 18: BSF in a Haitian home (Duke, et al 2006)

2.4.2 Independent Assessment in Cambodia

As early as 1999 BioSand Filters were introduced to certain areas of Cambodia through pilot projects. Due to encouraging results the NGO Samaritan's Purse and the Canadian International Development Agency supported two local NGOs, Hagar and Cambodia Global Action (CGA), to scale up project initiatives. Since 2001, over 22,000 filters have been installed in Cambodia making it the largest number and concentration of BSFs in the world, and therefore a good location to perform an assessment of the technology. Dr. Mark Sobsey, a renowned epidemiologist from the University of North Carolina – Chapel Hill, put together a team of researchers to do just that. The team sought to: 1) Survey hundreds of households in five provinces of Cambodia to gather information on user acceptability; 2) Collect water samples from source and filtered water to measure E. Coli counts; and 3) perform a health impact study to determine reduction rates of diarrheal disease incidence through BSF use. The last objective is especially useful from the perspective of public health. Many studies have quantified filter performance in laboratory and field settings, showing high reductions of total/fecal coliforms, E.coli, parasites, helminths, and viruses. However, very few have examined to what extent BSFs as a POU water treatment intervention can reduce rates of diarrheal disease in the households of users versus non-users (Lang et al 2008).

The research team initially visited 336 randomly selected households with BSFs from December 2006 – January 2007 to collect data on water handling practices and use, filter use and maintenance, and sanitation and hygiene methods. At this point the filters had been in use from zero to eight years. From the total pool 104 households with BSFs were again randomly chosen – fifty-three filters installed by Hagar, fifty-one by CGA – and 104 households without BSFs for a matched control. The 208 households were visited on a monthly basis over a five month period. During the visits to BSF households samples were collected from the source water, filtered water, and POU storage container and measured for E.coli cfu/100 mL. Also, data on diarrheal rates in user and control households was gathered with the number of cases per person per week counted and stratified by group, age, and province (Lang et al 2008).

The results showed that 87.5% of the households were still using their BSFs on a regular basis demonstrating high sustained usage, a long technology lifespan and low breakage rate. The water quality tests revealed that the BSFs reduced E.coli concentrations on average by 95%. Effluent samples had < 10 cfu/100 mL 55% of the time (low risk) and turbidity decreased on average by 82%. The health impact study revealed that BSF users had 44% less incidence of diarrheal cases than non-users (Figure 19), with 46% reductions for the vulnerable age bracket of two to four year olds. These results build upon previous data and continue to support BSF technology as a leading POU water treatment intervention in the developing world (Lang et al 2008).

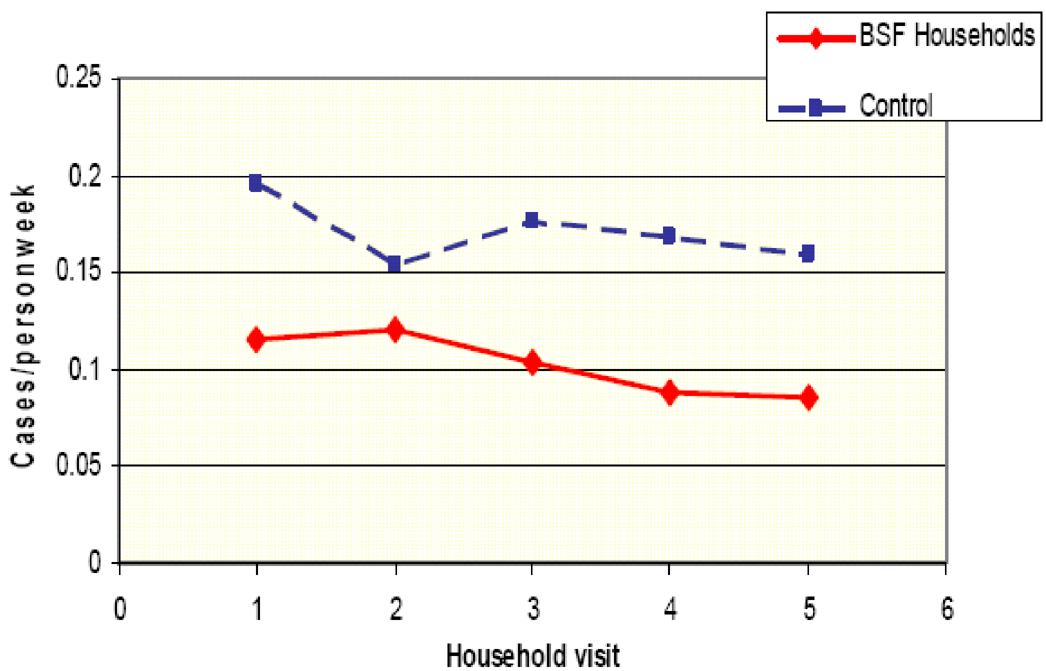

Figure 19: Diarrheal cases decreased in households using BioSand Filters with a 44% average reduction (Adapted from Lang et al, 2008).

2.5 HydrAid™ Bio-Sand Water Filter

Two distinct disadvantages of the BSF that have led to limited use and production in many countries are the amount of time and effort required to produce a single concrete unit and the weight of the filter, which can exceed 150 kg when empty. Although an effective intervention and POU treatment technology, these constraints do not lend themselves to rapid diffusion of the filter in its current shape and form. Shortly after inventing the BSF and co-founding CAWST, Dr. David Manz (with his wife Nora) formed a company known as Davnor Water Treatment Technologies Ltd to promote the commercial opportunities available with the use of the BSF. This included developing a plastic model of the BSF that is lightweight, can be manufactured quickly using modern machinery, and sold at a low-cost. Such an example that was implemented by Manz and partner Fred Richards on the Indian sub-continent was called the Canada Bangladesh Filter. Partnered with a Bangladesh NGO called Proshika a processing plant was established in-country and the company sold different models, the lowest costing $28.85 USD and filtering 20 L/hr (www.purefilteredwater.com).

The NGO International Aid (IA) later bought a patent for the plastic BSF from one of Manz's companies and is now the "exclusive holder of the worldwide humanitarian license" for their BSF model called the HydrAid™ BioSand Water Filter. Introduced at the 2007 "Thirsting to Serve" Water Conference, the HydrAid™ BSF is the brainchild of a collaboration between IA and Cascade Engineering, which developed and manufactures the injection-molded, seven pound plastic model. It is designed to be easily transported – when disassembled one filter fits inside another – in the difficult terrain typical of rural areas in the developing world without risk of breakage.

The filter itself is 30.5" tall and has a 16" diameter on the top that tapers down to 10" on the bottom. The height from the base to the spout is 24". The flow rate is advertised as 0.75 L/min with up to 47 L/hr maximum. The filter media consists of four layers and uses the same proven technology as the concrete model discussed in the case studies.

Starting from the bottom, the four layers are:

1. 2.25" – Large Gravel
2. 2.00" – Support Layer Gravel
3. 14.75" – Well-Sorted Sand
4. 2.00" – Fine Sand

The filter includes a plastic diffuser plate and lid that can be tied to the container with a zip-tie or string. Unlike the concrete model, the HydrAid™ BSF has ½" PVC piping exposed and joined to the container with PVC connector pieces and runs up the side to slide into an opening in the container at the top. Newer 2008 models also have a support piece to stabilize the outlet at the base. A 'T' connector joint with adjoining pipe serves as the exit point for the filtered water approximately 23" from the base (Figure 20).

The HydrAid™ BSF costs roughly $32.00 USD to produce – that price includes the molded container, diffuser plate, lid, and PCV outlet assemblage pieces (www.hydraid.org). The cost of shipping depends on the destination but is minimized using harbor shipping containers which hold approximately 2,000 filters per container. However, transportation costs from Spring Lake, MI to port and from port within the destined country to the implementation site will bring additional costs. Not to mention, filter media processing and household installation could potentially be performed by the user but most likely will cost something even if the tab is picked up by an implementing agency. After taking all of these factors into consideration a rough cost estimate puts the HydrAid™ BSF around $50.00 USD.

Figure 20: Cross-section of the International Aid HydrAid™ BioSand Filter (Adapted from www.hydraid.org)

Chapter Three: Research Plan & Methodology

Using the four main research objectives as guidelines, a research plan and experimental methods were determined and implemented from July – October 2007. These namely included the:

1.) Installation of fifty-three HydrAid™ BioSand Filters in three phases;
2.) Completion of surveys for twelve households using the HydrAid™ BSF; and
3.) Collection of flow-rate measurements and water samples for laboratory testing.

3.1 HydrAid™ BSF Workshop

In July 2007, International Aid (IA) and the Carter Center held a joint workshop in Tamale to debut the HydrAid™ BSF in Ghana. IA representative, Osman Mumuni, discussed the collaboration in Ghana to test the performance of the BSF and how it could be used as an effective treatment intervention in the Guinea Worm Eradication Program (GWEP). Carter Center planned to install approximately 1,000 BSFs in the Northern Region for this purpose and 200 filters in the Volta Region to determine the usefulness of the technology as a POU treatment option against waterborne diseases. At the conclusion of the workshop Mumuni demonstrated to the audience how to install the filter media in an assembled container. Using dirty dam water from a typical "dug-out" in the Northern Region; the BSF significantly reduced the turbidity and showed a high flow rate. The following day Mumuni released the components and filter media for three complete HydrAid™ BSFs to the Carter Center for installation in Sibi Hilltop as part of a pilot project for the study.

3.2 Phase 1 – Pilot Project

The objective behind the pilot project was to determine how to correctly install a few of the HydrAid™ BSFs and to work on any problems that may develop (i.e. "getting the bugs out") before installing a larger number of the filters in the community. This included adjusting the flow rate to 0.8 L/min as suggested by IA (and previously recommended by CAWST). The three BSF containers were assembled at a central location before transporting them to the participating households and installing the filter media (Figure 21). No PVC cement or Teflon tape was included with the assembly components so all the pieces were tightened by hand. However, one of the plastic container's threaded outlet-piece tore when tightening and the filter had to be discarded from the study. Therefore, the pilot project was left with two BSFs.

3.2.1 Installation

Two households were selected for the pilot project based on their location and familiarity with the Peace Corps Volunteer (PCV). The household heads were approached and shown the HydrAid™ BSF, educated about the technology, and asked whether they would want their households to participate in the project. Both candidates agreed to the terms of the project, which included a contribution from the household of GHC 2.00 ($2.17 USD) to "buy" the BSF.

The first two BSFs – henceforth known as Sibi 01 and Sibi 02 – were initially installed on July 14, 2007. The households were given the choice on where they desired their BSF to be installed with general recommendations given to place it in a location that would protect it from rough weather or direct exposure to the sun since UV radiation degrades plastic over time. Care was taken to consult the women in the household of Sibi 01 since they are the primary stewards of water and in many cases the ultimate decision makers of whether a particular technology will be used or not. Since Sibi 02's household did not include a woman, the man chose the installation location.

The BSFs were installed per the directions given by Mumuni at the workshop demonstration. This was a simple enough operation since the filter media layers were pre-sorted by volume in separate plastic bags. These were provided through a contract that IA had with a filter media processing plant near Accra. All sand and gravel were processed from crushed and sieved granite. A bucket of water was dumped into the BSF to check for leaks. In this case both of the BSFs leaked at the lower connection and needed to be tightened with a wrench until the leakage stopped. The first layer (2.25" of large gravel) was poured into the filter and leveled, followed by the second layer (2.00" of smaller gravel). Then more water was added to the container with the diffuser plate in place until almost half full. This layer of water prevents air pockets from forming within the sand layer. The diffuser plate was removed and the third layer (14.75" of well-sorted sand) was placed into the filter. The remaining water at the top turned a dark gray color from fine sediments in the sand that became suspended in the water. This was bailed out to prevent the filter from prematurely clogging. (At this point in the pilot project, three layers of filter media were being used as instructed by International Aid, instead of the four layers discussed in the previous chapter (Figure 20). This was later modified to include a fourth layer of fine sand.)

Figure 21: Assembled BioSand Filter ready for installation during Phase 1

3.2.2 Health Education

Complementary to the introduction of BSF technology, household education is vital to teach everyone in the household how to use and maintain the filter. This was performed shortly after the installation of Sibi 01 and 02 and included information about safe drinking water practices as well. The participants were asked about the water sources available in the community, which were safe and unsafe sources, what treatment methods were available to make the unsafe sources safe for consumption, and why women in the community chose not to treat their water with more than a Guinea Worm cloth filter. Education was then given on BSF treatment processes, how to use the filter, maintenance issues and storage of the effluent water. The entire health education lasted approximately one hour.

3.2.3 Monitoring

Following the installation of Sibi 01 and 02 the households started using their BSFs to treat their drinking water even though the biolayer had not sufficiently matured. Because July is one of the wettest months of the rainy season, when not using rainwater the households fetched water from the Sibi stream for all their drinking, cooking and washing needs. Although the BSFs were not at maximum removal capacity the filters were still achieving some bacterial and viral removal, an improvement in any case over the contaminated source water (Chapter 5, Table 5). By allowing the households to use the water they filtered it also guaranteed the filters would be intermittently dosed as was needed, contributing to normal amounts of substrate (food) in the biolayer for the microorganisms. This would allow their population to grow to the appropriate size to achieve maximum efficiency in the ripened biolayer within two to three weeks .

The BSFs were monitored on a weekly basis and the visits depended largely on the schedule of the household and whether there was water readily available to perform a flow rate test. The flow rates were measured by filling the BSF reservoir to the top with water (twenty liters) and collecting the filtered water with a 500-mL bottle (Figure 22). The flow rate was calculated in L/min by recording the amount of time it would take to fill the 500-mL bottle. All flow rate measurements were taken two to three times to verify the validity of the first measurement. During the monitoring visits the BSF was also inspected to confirm that there was an adequate depth of supernatant above the sand layer and none of the PVC pieces were leaking water. A wet diffuser pan was also a good indication that the BSF had been used recently. Any questions or problems noted by the households were fielded at this time.

3.2.4 Problems

Just after the installation process the flow rates for both filters were much lower than the target 0.80 L/min: Sibi 01 = 0.22 L/min; and Sibi 02 = 0.12 L/min. This indicated that either the filter was clogged and maintenance was required or the filter media was too dirty and would need to be washed in order to increase the flow rate. The following day maintenance (“swirl-and-dump” method) was performed on Sibi 01 and yielded a higher flow rate of 0.50 L/min. Since the flow rate for Sibi 02 had decreased to 0.08 L/min the filter media was removed and washed (not using any particular technique) and replaced to yield an improved flow rate of 0.44 L/min. These flow rates were still lower than the desired rates recommended by CAWST and IA (0.6 to 0.8 L/min) but much better than the previous day (Chapter 5, Figure 36).

By July 19 both of the BSFs had developed a crack at the bottom outlet on the same PVC connector piece, which was leaking. Cans were placed under the leak to gage how much water was being released from the filter, and the households were told to put this water back into the reservoir so the static head would not drop to the sand layer.

On July 22 a twelve hour flow rate test was performed on Sibi 01 and Sibi 02 to determine the extent of which the flows decrease with each subsequent load of source water. Every hour the reservoir was filled to the top and a flow rate measurement was recorded. The flow rates were still very slow especially in Sibi 02, which recorded 0.03 L/min at the start of the test. Unsatisfied with the slow flow rate, the homeowner had pounded the side of the BSF with his fist in order to increase the flow of the water. However, this action caused the filter media to compact and ultimately decreased the flow rate of the filter with time. Even after several “swirl-and-dump” rounds of maintenance the flow rate did not increase significantly.

Figure 22: Flow rate measurement test of HydrAid™ BioSand Water Filter (Photo courtesy of Carl Allen, 2007)

3.2.5 Household Surveys

The households of Sibi 01 and 02 were surveyed on July 21, 2007. Eighteen questions were asked to the household heads mainly to determine the use patterns of the filter, preference of taste, information about the participating households, source of the influent water, and document any problems with the filters. Their answers confirmed that the BSFs were not supplying an adequate supply of clean drinking water to the household due to the low flow rates, and the leaks would need to be addressed by replacing the cracked pieces. The survey results and flow rate measurements were presented to the Carter Center and International Aid representatives at the GWEP National Review Meeting in Tamale on July 25 for evaluation. See Appendix D for the complete results of the Phase 1 survey.

3.2.6 Modifications

A Carter Center Technical Advisor, Raymond Stewart, visited Sibi Hilltop on August 12 to assist with modifications to Sibi 02. The filter media layers were carefully removed from the container and placed in separate head pans. The outlet pipe on the container was removed and the cracked piece replaced with a new one. All threaded PVC pieces were wrapped with Teflon tape prior to re-assembling (provided by Stewart). The filter media was washed in small batches according to the CAWST Manual – the gravel layers four to five times, and the sand layer twice – before placing them back in the container (Figure 23). This took place at the household using stream water available. The washing was done in small shallow pans, adding roughly one to two liters of filter media to the pan and twice the amount of water, swirling the media by hand and quickly decanting the dirty water. A jar test was performed (CAWST Manual Appendix F) on the sand layer in order to determine if the sand was clean enough. This was performed by adding one part sand to one part of water in a jar and swirling rapidly to suspend the solids from the sand in the water (Figure 24). From the moment the swirling stopped the number of seconds was counted. Looking from the side of the jar three to four seconds after counting, the surface of the sand should be visible. In this case, washing the sand twice seemed to provide the right results as described by the jar test. However, after the installation the flow increased to 0.39 L/min but was still below the CAWST-IA suggested flow rates (0.6 to 0.8 L/min), indicating a need for further washing of the filter media.

The next day similar modifications were made to Sibi 01. However, all layers of the filter media were washed four times in small batches as described above instead of twice. The flow rate increased dramatically to 1.71 L/min but when monitored four hours later had fallen to 0.29 L/min. After performing maintenance on the top layer of sand (“swirl-and-dump”) the flow rate increased again to roughly 1.5 L/min. On August 18 the sand from Sibi 02 was removed and washed an additional two times (four total), which yielded similar results to Sibi 01’s flow rate.

The Phase 1 BSFs were further modified on August 22, 2007 with the addition of a fourth layer of fine sand provided by IA and delivered by the Carter Center. The fine sand was washed four times in the same fashion as described above and installed to replace two inches of the third layer (well-sorted sand) that was removed so that there was no change to the supernatant depth. At this point the flow rates decreased to 1.09 L/min (Sibi 01) and 1.11 L/min (Sibi 02).

Figure 23: Washing of the filter media in small batches

Figure 24: Jar test performed to determine if the sand has been washed thoroughly

3.3 Phase 2 – Determining Best Methods

The Carter Center delivered an additional ten HydrAid™ BSFs on August 17, 2007 for installation in the community. These were, as before, unassembled shells and PVC pieces, and bags of unwashed but separated filter media. PVC cement was also included to seal the joints in the outlet pieces. Using the lessons learned from Phase 1, the ten additional BSFs were installed over the course of four days, and involved training other individuals from the GWEP on the installation process.

3.3.1 Selection of Households

As discussed within the background of Chapter 1, Sibi Hilltop has approximately thirteen clans of varying size and is divided politically by the road into east and west factions. In order to implement the project in a way that would not bias certain clans, it took much planning to select households from both sides of the community and from as many clans as possible. Given their leadership roles in the community, political figures, elders, and opinion leaders were given preference since they would be essential in convincing others to treat their drinking water in the future. However, it was also essential to utilize people who were both familiar with the PCV and more progressive individuals since early adopters are key to the diffusion of technologies. Gender balance was also considered noting the role that women play in managing household water. During Phase 2 of the installation process four women, six men, and their households were chosen to participate. Five households were on the east side of community, five were on the west side, and nine clans were represented. The Chief, Landowner and Assembly Man's households all participated in this phase.

As in Phase 1, all ten households paid GHC 2.00 ($2.17 USD) to "buy" their BSF. Although, this does not seem like a substantial amount of money and does not nearly cover the total price of the HydrAid™ BSF, the price was significantly high for some households. This particular season was a few months before the yam crops were harvested, and was termed by the Konkomba people as "Likpasi" – a time of "no money." Purchases were made only on necessities and the BSF would therefore be an investment item that would be well cared for by the household.

3.3.2 Installation

The ten HydrAid™ BSFs – Sibi 03 through 12 – were installed from August 22-25, 2007 with the assistance from a team of individuals from the GWEP. One BSF was installed the first day, followed by three BSFs on each of the following three days. Several changes were made in the installation procedures noted during Phase 1 in order to improve efficiency. Since washing the filter media was the most time consuming and water intensive part, it was transported to the Sibi Stream and washed with help from the participating households (Figure 25a). Each household provided at least one helper to assist with the washing plus enough head pans and containers to carry water up from the stream bed to the washing area and for the storage of the clean filter media (Figure 25b). Proper methods for washing the filter media were demonstrated to those who helped. Once all of the filter media had been washed (Figure 26), the Carter Center truck would deposit it at the BSF households targeted for installation that day (Figure 27).

The BSF containers were pre-assembled by the PCV and deposited at the ten households prior to installation. Teflon tape and PVC cement were used on all threaded and joint pieces, respectively (Figure 28a). Many of the places that the households chose for their filters were on uneven ground so an added step in the installation process involved leveling sand as a base for the BSF (Figure 28b). A level BSF keeps the depth of the supernatant constant across the filter area and thus the biolayer growth at an equal depth in the third and fourth layers.

Placing the filter media inside the BSFs followed the same procedures as described for Phase 1; however, the third layer was dumped into the filter as much in one fluid motion as possible (Figure 28c). This required two people to hold up the head pan of sand and one person to guide the sand into the filter as the water splashed everywhere. The reasoning behind placing the sand like this was to prevent the stratification of multiple layers of fine sand within the third layer that would occur naturally if placed within the filter a batch at a time. This occurs because the third layer is composed of well-sorted sand – meaning of various grain sizes. As the sand is dumped into the layer of water smaller sand particles stay suspended longer than larger sand particles. If done in batches the top layer of each section will have a fine layer at the top, which is then sandwiched between the next batch of third layer dumped into the filter and so on. These layers of fine sand are thought to decrease the flow rate and were therefore avoided. (It was later learned that during the installation process there should be four inches of water above the previous filter media layer to prevent air bubbles from forming in the sand layer, and no more than eight inches to prevent stratification of the sand layer(s). Dr. Manz recommends batch placement of the third layer when using these water depths [Manz 2007].)

After the installation and leveling of each individual layer inside the BSF, the team would verify the depth with a tape measure (Figure 28d). Although the media was prepackaged according to its appropriate volume or weight at the processing operation near Accra, the second and third layer bags held consistently less than the appropriate amounts. This was not discovered until the second day when placed inside the filters. As a safeguard against this on subsequent days, extra filter media was washed and transported to the site in case it was needed.

In all ten of the BSFs the turbidity of the water did not appear to be reduced upon installation of the BSF. The GWEP team learned the installation procedures quickly. Average installation time was approximately forty-five minutes, not including the time taken to wash the filter media.

3.3.3 Health Education

The health education component was performed in a similar manner to that of Phase 1. The biggest problem was in coordinating a time when all of the family members were available. In a few cases, the entire household was not present during the talk and had to be taught later by other family members.

(a)

(b)

Figure 25: (a) Streamside washing of the filter media by beneficiary household members, and (b) fetching a continuous supply of water for washing (Photos courtesy of Carl Allen, 2007)

Figure 26: The BioSand filter media after it has been washed and separated (Photos courtesy of Carl Allen, 2007)

Figure 27: Guinea Worm support vehicle transporting the filter media to improve installation efficiency (Photos courtesy of Carl Allen, 2007

(a) (b)

(c) (d)

Figure 28: Phase 2 Installation Practices: (a) Leveling BSFs using a layer of sand at the base, (b) wrapping threaded PVC outlet pieces with Teflon tape to prevent leaks, (c) fluidly pouring the third layer into the filter, and (d) the measuring and leveling of each layer by hand

3.3.4 Monitoring

As with Phase 1, the households were encouraged to begin using their BSFs right away so the biolayer could mature quickly and adapt to the source water conditions. Weekly visits were conducted to monitor the performance of the filters, record flow rate measurements (per the method described in Phase 1), check supernatant level and for leaks, and field questions by the households. If the flow rate for a particular filter was too slow, the "swirl-and-dump" maintenance was demonstrated to a member of the household and subsequent measurements taken to ensure an adequate flow rate (Figure 29). Since twelve BSFs were now spread out over the entire community, the monitoring was performed by the PCV via bicycle. Again, difficulties were found in meeting household members in the home (since August is a prime farming season) or in finding enough water in the house to perform the flow rate tests.

3.3.5 Modifications

During the period of installation, the fourth layer of filter media was used up before completing the last four filters (Sibi 09 through 12). This was brought by Mumuni on a visit to the community on August 28 and installed in the remaining filters on August 30 and 31. Maintenance was first performed on the BSFs to remove any sediment that had collected on the surface of the sand while previously in use by the households. Then the sand for the fourth layer was washed four times and placed in the filters.

In the case of Sibi 09 the flow rate was less than adequate (0.45 L/min) before the fourth layer was installed in the filter. Approximately half of the third layer was removed and washed two more times prior to installing the fourth layer. This proved to increase the flow rate initially (0.77 L/min) but later showed a decrease in flow as time passed (Appendix A, Figure 80, Table 19).

Sibi 03 also needed additional modification. The BSF had the fourth layer at the time of installation but the flow rate dropped to 0.4 L/min three weeks later, and did not significantly improve with maintenance. The problem was resolved by washing half of the third layer and the entire fourth layer twice more. After reinstallation the sand the flow rates improved dramatically to 1.22 L/min, which later decreased over the next five weeks with frequent use to 0.88 L/min (Appendix A, Figure 62, Table 13).

3.3.6 Household Surveys

During the last monitoring visit each household was asked to participate in a comprehensive survey. The surveys included 45 questions and – after agreeing to participate – were administered to all the households of the twelve BSFs from both phases from October 22-25, 2007. At this point all of the filters had been in use for at least two months. The purpose of the survey was to evaluate the user acceptance and comprehension of BSF technology in the community by asking the participating households various questions. Although the households had never seen an example of a concrete BSF, questions were asked to draw a comparison between the traditional and HydrAid™ BSFs and study the likelihood of user acceptance of the former. To gage the impact of the BSF technology on health, the households were asked to recall the number of incidences of diarrheal cases in the home prior to and following BSF installation.

Whenever possible the surveys were administered to a member of the household most familiar with the BSF (Figure 30). In four cases this was a woman and in eight cases a man. For the questions regarding diarrhea the women were asked since they would be more inclined than the father to know whether their children had been sick. Along with the surveys, a picture of the household member was taken with their BSF. Final flow rate measurements, depth of supernatant, and turbidity indicators were also recorded and pictures taken of influent and effluent water samples. See Appendix A for profiles of each participating household and BSF (Sibi 01 through 12) and Appendix D for the compiled survey results.

3.3.7 Identification of Fetching Points

During the interviews, the households indicated the place where they were currently fetching the source water for their BSFs. Since most households in the community use a limited number of access locations at the various streams these points were visited, photographed (Figure 31) and identified on a community map. Drawn with the assistance of the Zonal Coordinator for the GWEP, the community map shows cross-hatched areas of population along the road, delineates clan areas, and shows the distribution of the BSFs throughout the community (Figure 32).

Figure 29: Swirl-and-dump maintenance performed to increase flow rate (Photo courtesy of Carl Allen, 2007)

Figure 30: Interviews conducted with Phase 1 and 2 households

Figure 31: Popular fetching and washing point on Kabunbuk Stream on the east side of the community behind the E.P. Primary School

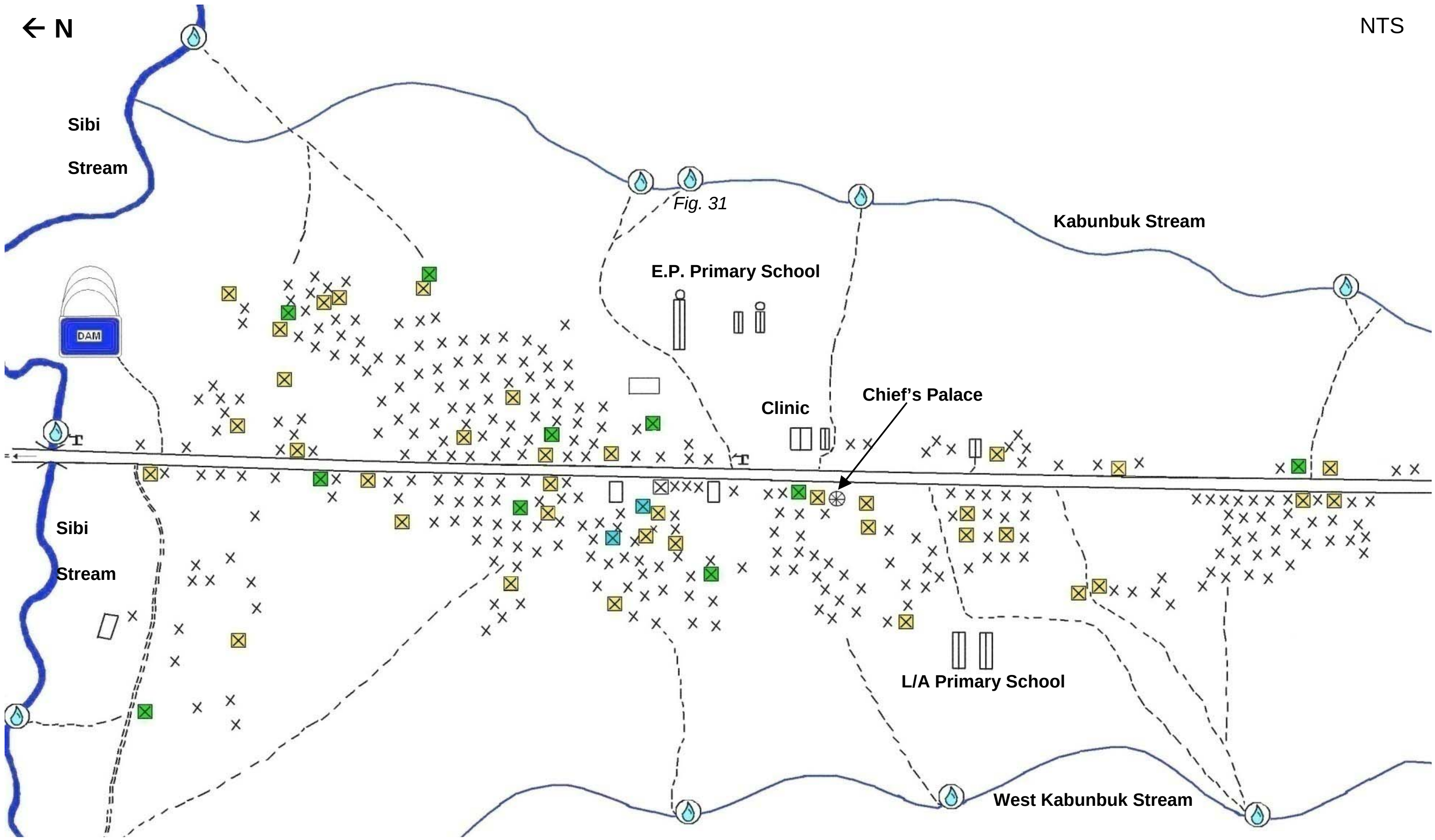

Figure 32: Map of Sibi Hilltop community showing the distribution of BioSand Filter households, represented by a box with an "X" inside

3.4 Phase 3 – Project Expansion

In the beginning of October the Carter Center made arrangements to bring another fifty BSFs to Sibi Hilltop for installation in the third phase of the project. With only a limited number of filters available, the project could not be opened up to the entire community. However, with an average of twelve people per household noted from the surveys in Phase 2, bringing an additional fifty BSFs could mean giving 600 additional community members the access to safe drinking water.

3.4.1 Selection of Households

Since the delivery of the BSFs would occur roughly two weeks before the PCV would be concluding his service, it was essential to coordinate the installation process as quickly as possible to allow time for monitoring and adequate education of the receiving households. The GWEP core team from Nkwanta District that helped with the installation of Phase 2 also assisted in Phase 3. Even though they were not from the community each individual was offered a HydrAid™ BSF for their participation and to demonstrate it as a POU treatment option within their own community in the district. All nine individuals agreed, which left forty-one BSFs for installation in Sibi Hilltop.

Instead of hand selecting the households as was done in Phase 1 and 2, the community volunteers from the GWEP were called to a meeting, educated about the technology and asked whether they wanted to participate in the project. All the volunteers (seventeen households) were eager to receive a BSF and agreed to the conditions of the project including the payment of GHC 2.00 ($2.17 USD) to "buy" the BSF, and lending head pans/containers and someone from their household to assist with the washing of the filter media. The remaining twenty-four BSFs were divided among the various clans in the community based on size and prior participation. The community volunteers – who already cover specific clan areas in the community for their surveillance work with the GWEP – were then assigned to educate and register a set number of households for the remaining filters.

3.4.2 Installation

The installation of the forty-one BSFs took place over a three-day period from October 10-12, 2007. The nine GWEP district core team members were divided into three teams with each team held responsible for the installation of four or five filters each day. The installation methods used in Phase 2 were determined to be the best practical procedures, and were reviewed by the team prior to starting. Each team was given a measuring stick that had the filter media levels pre-marked so that after each layer was poured and leveled, the depth could be easily checked and adjusted until correct (Figure 33). They were also given 500 mL jars and taught how to take flow rate measurements following the installation of a filter. As in Phase 2, the filter media was washed on the side of the road next to the Sibi Stream due to easy access to a large volume of water. The household members sent to assist were taught proper washing techniques and helped to fetch a continuous supply of water. When the delivery of the filter media arrived the day before it was noticed that the second and third layers of filter media were packaged in thin, black plastic bags within a larger woven grain sack. Unfortunately, some of the bags ripped open during transportation and needed to be laboriously separated during the washing period. This seemed to be the biggest problem during the three days of installation.

While monitoring Sibi 03 through 12, it was noticed that the BSFs were shifting off their sand bases and were no longer level. Therefore, the installation teams were encouraged to look for alternative materials for leveling. These included pieces of wood, metal, plastic, rubber, and stones. Without three horizontal levels available, the teams took advantage of the natural "water-level" of the filter itself. When filled with water – the cover and diffuser plate are removed – the levelness is determined by judging the depth of water against the sides of the BSF and adjusting until equal.

The teams installed thirteen BSFs on the first day, thirteen on the second day, and fifteen on the third day. On the last day the fine sand ran out, and seven of the BSFs were installed without or containing less than two inches of the filter media layer. This was later added when more of the fine sand was obtained, and after maintenance was performed in order to prevent the trapping of any solids between the third and fourth layers. All of the newly installed filters were labeled with identification numbers, Sibi 13 through 53.

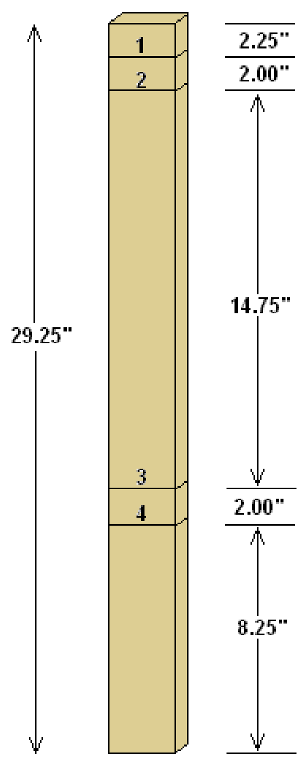

Figure 33: Measuring stick constructed by a local carpenter to check layer depth in HydrAid™ BSF during the installation process

3.4.3 Health Education

Due to time constraints individual health talks could not be conducted by the PCV with each of the households that received a BSF in Phase 3. Therefore, the GWEP community volunteers were utilized for this task as well. A second meeting was called with the volunteers, where they were trained about safe water issues, and the use and maintenance of the HydrAid™ BSF. They were then charged with the task of holding health talks with the households in their clan area that received a filter – the very same households they originally signed up to receive a BSF.

3.4.4 Monitoring

The households were encouraged to begin using their BSFs directly following installation. Efforts were made to finish installing the seven BSFs that lacked a full fourth layer of filter media as a first priority. This was successfully completed by October 17, 2007. Then the weekly monitoring activities began on the other thirty-four BSFs. However, due to the increased number of filters and time constraints the weekly monitoring was staggered over several days with more comprehensive checks to ensure the long term functionality of the filters. The depth of the supernatant, levelness of the filter, and flow rate measurements were checked on all but two of the forty-one filters. Notes on the reduction of turbidity in the filtered water were recorded for twenty-four of the filters as well. See Appendix C for the monitoring notes and flow rate measurements for Phase 3.

Part of the motivation behind utilizing the GWEP volunteers stemmed from the work they currently do in the community with safe drinking water and health. As such, they should have no problem monitoring their neighbors' BSFs as they also replace cloth filters or perform case searches within their clan area. So ultimately, the responsibility of the monitoring is transferred over to them as a PCV is no longer living and working in the community.

3.5 Water Quality Analysis

One of IA's main objectives of the study was to gage how well the HydrAid™ BSFs were performing in the field with regard to water treatment. In order to determine the bacterial reduction rates of the filters, water quality testing would be needed. However, without electricity or adequate materials and resources, this could not be performed in Sibi Hilltop. It was agreed that the best option available would entail collecting water samples in the community and transporting them to a qualified laboratory to perform the tests. The number of test samples was limited by the budget of IA, and in this case did not generate a large pool of results. The PCV did, however, lend some guidance as to which of the filters should be tested, and the importance of collecting an influent sample for every effluent one (since the identification of the fetching points in Phase 2 showed that households were collecting different source water).

3.5.1 First Sampling

Osman Mumuni from IA visited Sibi Hilltop on August 28, 2007 to inspect the HydrAid^{TM} BSFs from Phases 1 and 2. He checked the flow rates, questioned the households on their filter's performance, and discussed installation methods with the PCV. He also brought extra bags of fourth layer sand since at the time of Mumuni's visit only Sibi 01 through 06 had all four layers. Half of these were chosen for the first round of water quality testing, based on frequency of use by the household and whether the flow rate was close to the IA target of 0.8 L/min. Previously-used 1.5 liter water bottles were washed with soap and hot water and set out to cool. Six samples were collected in all – one from the influent and effluent of Sibi 02, 05 and 06. For the influent source water, a standard flow rate test was performed and the water sample collected from the reservoir at the top of the filter. The effluent sample was collected straight from the outlet pipe after it had been flowing for a few minutes (Figure 34). After the samples were taken from the three filters, the water bottles were labeled, placed in a cooler without ice, and transported to Nkwanta (approximately thirty-one miles away) where they were placed in a refrigerator. On the following day, the water samples were transported inside a cooler with ice to the capital city, Accra.

Figure 34: Water sample collection of filtered water from BSFs by re-using 1.5 liter water bottles (Photo courtesy of Carl Allen)

The Water Research Institute (WRI), a branch of Ghana's Council for Scientific and Industrial Research, began an analysis of the water samples at their laboratory that afternoon and finished on September 6, 2007. Total coliform testing was performed by membrane filtration in accordance with the American Public Health Association (APHA) Standard Method 9222B. Fecal coliform testing was performed by membrane filtration using APHA Standard Method 9222D. Total heterotrophic bacteria were tested using the Pour Plate Method in accordance with APHA Standard Method 9215B. An analysis of twenty-six physico-chemical constituents of the raw and filtered water was also performed by WRI. See Appendix B for the full analysis results.

3.5.2 Second Sampling

Raymond Stewart from the Carter Center visited the community during the last day of Phase 3 filter installations on October 12. Water samples were collected from six BSFs: the three filters that were tested during the previous round (Sibi 02, 05 and 06); and three new filters from Phase 2 (Sibi 08, 09 and 12). The purpose of testing the first three again was to determine if the reduction efficiency had improved with a mature biolayer. The second set of three BSFs was selected based on how often the households were using their filter and whether the flow rates were close to the target rate. Twelve samples were collected – six from the influent source water and six from the effluent. The method for collection involved opening sealed 500 mL Voltic brand water bottles, emptying the water, and filling it with the sample water (Figure 35). The influent sample was collected directly from the top reservoir during a standard flow rate test and the effluent from the outlet pipe after waiting several minutes. The samples were labeled, placed in a cooler with ice, and transported to Tamale in the Northern Region.

The water samples were analyzed at the Tamale office of the Water Research Institute using the same Standard Methods as outlined in the first set of sampling. Due to budget limitations of IA the physico-chemical characteristics were not measured in the second sampling; only the total and fecal coliforms were measured as indicators of the water quality, which cost $326 USD for the twelve samples, or roughly half of what a school teacher makes per month in Ghana.

Figure 35: Water sample collection using sealed 500-mL Voltic bottles

3.6 Results and Discussion Outline

The next four chapters present and discuss the data and results gathered from executing the research plan and methodology. These chapters form the results section and directly link with the four research objectives as stated at the end of Chapter One:

- Chapter Four – Installation Guidelines
- Chapter Five – Filter Performance
- Chapter Six – User Assessment
- Chapter Seven – BioSand Filter Comparison

The idea behind presenting the results section in this manner is to clearly and concisely address each of the research objectives before moving on to next. Note that although some of the figures and tables from the results are referred to within this chapter to assist the reader with understanding the methodology; these graphics are meant to be examined more closely in the following chapters in the context of the results and discussion section.

Chapter Four: Installation Guidelines

To address the first research objective outlined in Chapter One, the best methods of installation for the HydrAid™ BSF were determined through the installation of fifty-three filters in Sibi Hilltop during three phases from July – October 2007. This chapter highlights the methods as they relate to the physical installation process that can be replicated in Ghana by the Carter Center (or other agencies) to efficiently implement additional BSF programs within the country. If using filter media prepared industrially at a processing plant and installing a large quantity of BSFs, Dr. David Manz's guidelines for a four layer system provide thorough instructions for flow rate quality control (See References, Manz 2007). The installation guidelines outlined below were adapted from the 2006 CAWST manual for concrete BSFs, and followed some recommendations in Manz's publication. However, the vast majority of the recommended procedures are the results of first-hand experience installing the HydrAid™ BSF in the field. As such, these guidelines are meant to add to the base of BSF installation knowledge specifically for the plastic HydrAid™ model within rural Ghana.

4.1 Filter Media Preparation

A source of filter media must first be selected, and is accomplished by examining all available sources of sand and aggregate. These include locally available media found in or nearby the site of installation, and processed media made from crushed rock processed out of site. The CAWST manual includes guidelines for sieving and washing locally available filter media. Since this project used processed filter media, the following guidelines for preparation will address this specific type of media:

- Prior to installation the bags of media should be checked to ensure that different layers have not mixed together. If mixing has occurred between the second and third layers, the materials can be separated during the washing by using the diffuser plate to wet-sieve the combined materials – the sand layer will pass through with the water and can be collected, while the gravel is retained.

- One support vehicle is needed for every three BSF installation teams, as long they are within the same community. The vehicle is utilized for transporting the filter media from the storage area to the source of water used for washing and then to the installation site.

- It is more efficient to wash all the filter media at one time in a single location. Preferably, this is done in the morning and the BSF installation in the afternoon. The installation teams should coordinate the washing of the filter media for the specific households that they are installing that day. This means that household members receiving the filter should assist with this work.

- Each participating household needs to provide three small head pans and two large head pans for the batch washing and collection of the filter media, respectively. They should also provide two or three people to help with the filter media washing and carrying a continuous supply of water from the source to the washing site.

- Wash each layer of the filter media approximately four times in small batches. This is done by adding one to two liters of filter media to a small head pan and two or three times as much water. Swirl the material and water in a clockwise or counter-clockwise motion for ten to fifteen seconds and quickly decant the fluid with the suspended solids from the material. (The correct number of times was determined by the pilot phase of two BSFs in the beginning of the project. If the filter media changes, it is recommended to also monitor pilot filters to determine the correct number of washings that are needed so that the BSF operates within the CAWST-IA range of flow rates, 0.6 to 0.8 L/min.)

- Wash extra filter media and transport it to the installation site in case more is needed to reach the appropriate level in the filter.

4.2 Assembling the HydrAid™ BSF

Prior to the day of installation the BSFs should already be assembled. This takes approximately ten minutes per filter but is more efficient if using many people in an assembly line fashion. Guidelines for assembling the container and outlet pipe system include:

- Wrap Teflon tape two or three times around the ends of the three threaded PVC pieces and tighten the main (inner) couplet to the base of the filter by hand until it can no longer be turned. The threaded end of the 90-degree elbow should also be tightened into the outer gasket piece with the outer couplet around it. A rubber glove can be used on the tightening hand to minimize soreness. The outer couplet and coordinating gasket piece should not be screwed onto the inner couplet (attached to the blue container) until it has been attached to the vertical pipe and spigot.

- Roughen the long vertical and short horizontal PVC pipes on both ends with sandpaper or a file. Add a generous amount of PVC cement around the circumference of the pipes ½” from each end and slide the pipes into the “T” and 90-degree elbow joints. Tap them firmly so that they fit in all the way.

- Once the external outlet pipe has been fully assembled, slide it vertically into the blue HydrAid™ container and screw the outer couplet onto the inner couplet, which has already been tightened to the container outlet. Again this should only be tightened by hand to avoid over-tightening and cracking the PVC pieces. The Teflon tape prevents leaks.

4.3 Installation

Once the filter media and pre-assembled BSF container are at the site, an experienced installation team can set up the HydrAid^{TM} BSF in 30-45 minutes. The BSF is installed *in situ* and is not meant to be moved afterward. Guidelines include:

- The assembled container is checked for leaks prior to installation of the filter media by filling the container with water and observing the connection pieces. If leaks are found the couplets and/or elbow may need to be tightened, in which case the old Teflon tape may need to removed and new tape added.

- Installation teams should consist of at least two trained persons in order to carry the third layer of filter media and provide a way to double-check the installation. The teams explain the process of installation to the households in order to provide additional education. Each team should carry a toolkit consisting of a stopwatch, notebook, pen, 500/1000 milliliter bottle for measuring the flow rate, horizontal (bubble) level, and measuring stick (as shown in Chapter 3, Figure 33). The BSF measuring stick (field-conceived tool), with pre-marked depths of the filter media layers from the top of each layer to the lip of filter container, is used to easily check and adjust the layer depths as necessary.

- The location for BSF installation is to be selected by the household with recommendations from the installation team to place it in a protected area of the home that is not in direct sunlight (Figure 36). If the location is on uneven ground, the BSF is leveled with pieces of wood, metal, plastic, rubber, stones or whatever may be available in the house. The horizontal (bubble) level is used to check for levelness. (Sand is not recommended as a leveling material.)

- For the physical installation of the filter media, start by adding at least four inches and no more than eight inches of water to the bottom of the HydrAid^{TM} container. Pour the first layer of under drain gravel into the filter, level with the palm of a hand, and check the depth with the measuring stick. Adjust if necessary, and add more water so that at least four inches and no more than eight inches is above the first layer. Pour the second layer of support gravel into the filter, level with the palm of a hand, and check the depth with the measuring stick. Adjust if necessary, and add more water so that at least four inches and no more than eight inches is above the second layer. The third layer of well-sorted sand can either be poured into the filter in one fluid motion or placed one container at a time until the level and depth is correct (as instructed in Manz's guidelines). The benefit of using a specific-volume container would be that once the correct height is reached the number of containers needed is known for future installations using similar filter media. At this point, if the water appears to have a lot of suspended solids the water should be bailed out and replaced. After measuring, the water depth is checked and adjusted to be at least four and no more than eight inches above the third layer. Lastly, the fourth layer of fine sand is poured into the filter, leveled and measured. Again, the water is bailed out if it appears turbid with suspended solids. Adjustments are made until the correct depth is reached.

- Flow rate tests are performed directly after installation by recording the time it takes to fill a 500 or 1000 milliliter bottle with effluent water from the filter, and dividing the volume by time. From field observations concerning the behavior of the crushed granite filter media, the HydrAid™ BSFs need to be installed with a flow rate approximately 50% greater than the desired rate to account for the decrease in flow after installation with the settling of the particles within the filter. For example, if the IA suggested flow rate of 0.8 L/min is the desired flow rate, the installation flow rate should measure roughly 1.2 L/min. However, if the CAWST suggested flow rate of 0.6 L/min is the desired flow rate, the installation flow rate should measure roughly 0.9 L/min. Calculating this in reverse, the overall, average operational flow rate can be estimated as two-thirds or 66.6% of the installation flow rate (See Appendix A, Figures and Tables).

- The day after installation the BSF household should be visited. The filter is examined for levelness, supernatant depth, and flow rate. Modifications are made as necessary, with small adjustments to the flow rate being possible by adding or removing up to one centimeter of the fourth layer of fine sand to decrease or increase the flow, respectively.

4.5 Caveat

These guidelines are intended to be an outline of recommended procedures that worked well for this project when installing the HydrAid™ BSF and not an exhaustive or comprehensive list applicable to every BSF project, or each phase of the development project. No two communities or implementation programs are alike and should not be treated as such. Therefore, these guidelines may need to be adjusted or scaled-up to site-specific conditions in order to achieve the goals of the project. This should be done after careful consideration of a community's resources, participatory readiness/willingness, and availability of resources and capability of the implementing agency.

4.6 *Example Scenario*

It is reasonable to assume that with the proper resources, and by taking these guidelines into consideration, a large number of HydrAid™ BioSand Filters could be installed in a single period. As an example, a resource assessment is given for the installation of 200 HydrAid™ BSFs within a community during a Monday through Friday work-week.

Resources required:

- An onsite project manager making various preparations beforehand including: scheduling the household installation dates and subsequent education; meeting with the participating households and arranging the household contributions to the project; facilitating the shipment and storage of filter media; and coordinating the assemblage of the HydrAid™ containers and outlet pipes.

- 200 HydrAid™ BSF containers, outlet pipe assemblages, diffuser plates, lids; ten pieces of sandpaper and rolls of Teflon tape; one pint of PVC cement; and enough filter media for the installation (200 bags of each layer when packaged separately)

- Two support vehicles would be needed to transport the filter media from the storage facility to the washing source water, and then to the installation sites.

- Five trained installation teams (two people per team) with each required to install eight filters per day. A total of forty BSFs would be installed each day and thus 200 total over the course of five days. The installation teams also double as the coordinators of the washing of filter media for the households that they are installing that day, and could be utilized to perform the household education the following week after installation.

- Five toolkits consisting of a stopwatch, notebook, pen, 500/1000 milliliter bottle for measuring the flow rate, horizontal (bubble) level, and measuring stick

- Ten education kits with visual learning aids (CAWST 2006) would be needed – one for each instructor. With each instructor performing education for eight households each day, approximately ½ week would be needed.

- Two field technicians with tool kits would be needed to check the BSFs each day following installation.

Figure 36: BioSand Filter owner Stepen Agba chose to install Sibi 11 in an alcove of his house to be protected from the weather, and collect his water in a ceramic pot to keep the drinking water cool

Chapter Five: Filter Performance

To address the second research objective outlined in Chapter One, the filter performance was studied in regards to its ability to provide a household with a significantly improved quality and sufficient supply of water for all cooking and drinking needs. As for the supply issue, the flow rate of the BSF serves as an indicator to determine whether it is able to filter enough water in a timely manner. The water quality tests performed are also indicators to determine bacterial removal efficiency at a particular time in the BSF's operational history. This chapter will present the results from these tests, discuss their meaning, and compare them with the performance of other BSFs in the field.

5.1 Flow Rate Measurements

Directly following the installation and during weekly monitoring visits, flow rate measurements were recorded for the BSFs using the methods described in Chapter Three. This was done initially after installation to gage whether the filter media had been washed correctly, and later monitored to observe how the flow rate changes over time and to ensure that with proper maintenance that the filters could continue to supply water at a sufficient flow rate as suggested by BSF research. Of course, since the filters in Phase 1 (Sibi 01 and 02) and Phase 2 (Sibi 03 through 12) were operational for the longest period of time, the flow rate data is most extensive for these twelve filters. A recorded measurement simply represents the flow rate of the BSF at that particular moment. Variance is expected in the flow rate data between filters since each household uses and maintains their BSF with different frequencies, and uses different source water as influent for their filter.

5.1.1 Installation

The initial installation of the BSFs during the pilot period in Phase 1 yielded low flow rates of 0.22 L/min for Sibi 01 and 0.12 L/min for Sibi 02. This was because the filter media had not been washed and needed to be cleaned. Through a series of trials and testing over the course of five weeks, this problem was corrected. Ultimately, washing all layers four times, the flow rates improved to 1.71 L/min for Sibi 01 and 1.74 L/min for Sibi 02. At this point, the filter media had been sufficiently washed and on Day 40 the fourth layer was installed, slowing the filters to 1.09 L/min (Sibi 01) and 1.11 L/min (Sibi 02). This essentially reset the filter run-time to Day 1 and provides a starting place to compare the flow rates between the Phase 1 and 2 filters. Figure 37 shows the history of all flow measurements for Phase 1. Note the low flow rates during the first ten days of operation and the increases for Sibi 02 on Day 30, Sibi 01 on Day 31, and Sibi 02 on Day 36 with experimental washing of the filter media. In Figure 38 the background measurements from the testing period are removed for Sibi 01. A new Day 1 – with the installation of the fourth layer – corresponds to the previous Day 40 and multiple measurements from the same days are averaged. See Appendix A for individual graphs of adjusted average flow rate measurements for Sibi 01 through 12.

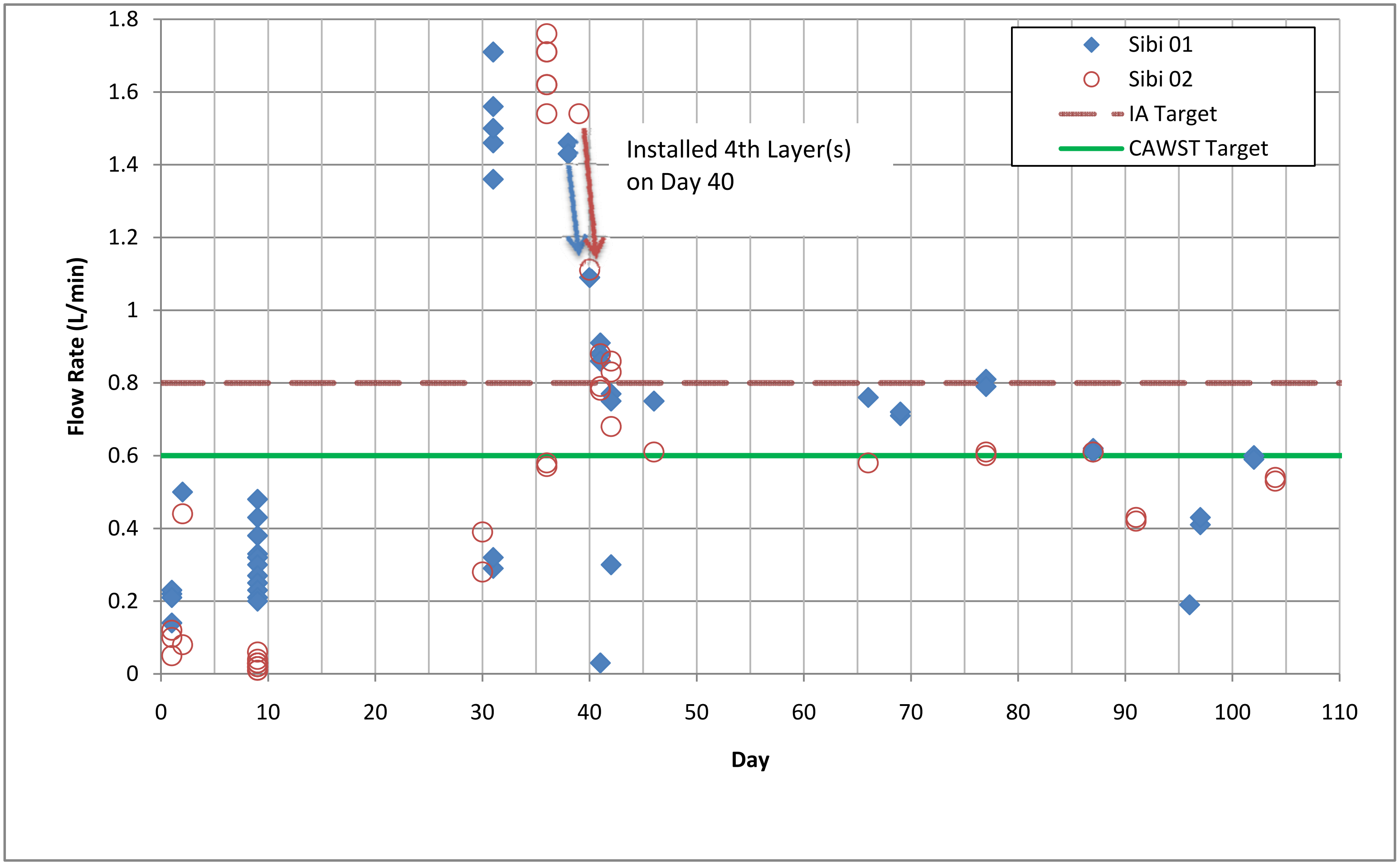

Figure 37: Phase 1 – BioSand Filter flow rate measurements for Sibi 01 and Sibi 02 from initial installation in July to October 2007. Optimal flow rates recommended by the Center for Affordable Water and Sanitation Technology (CAWST) and International Aid (IA) are also graphed at 0.6 L/min and 0.8 L/min, respectively. A general range of acceptable flow rates is from a maximum of 1 L/min to a minimum that is determined by the user to be the lowest acceptable flow rate (e.g. 0.4 L/min).

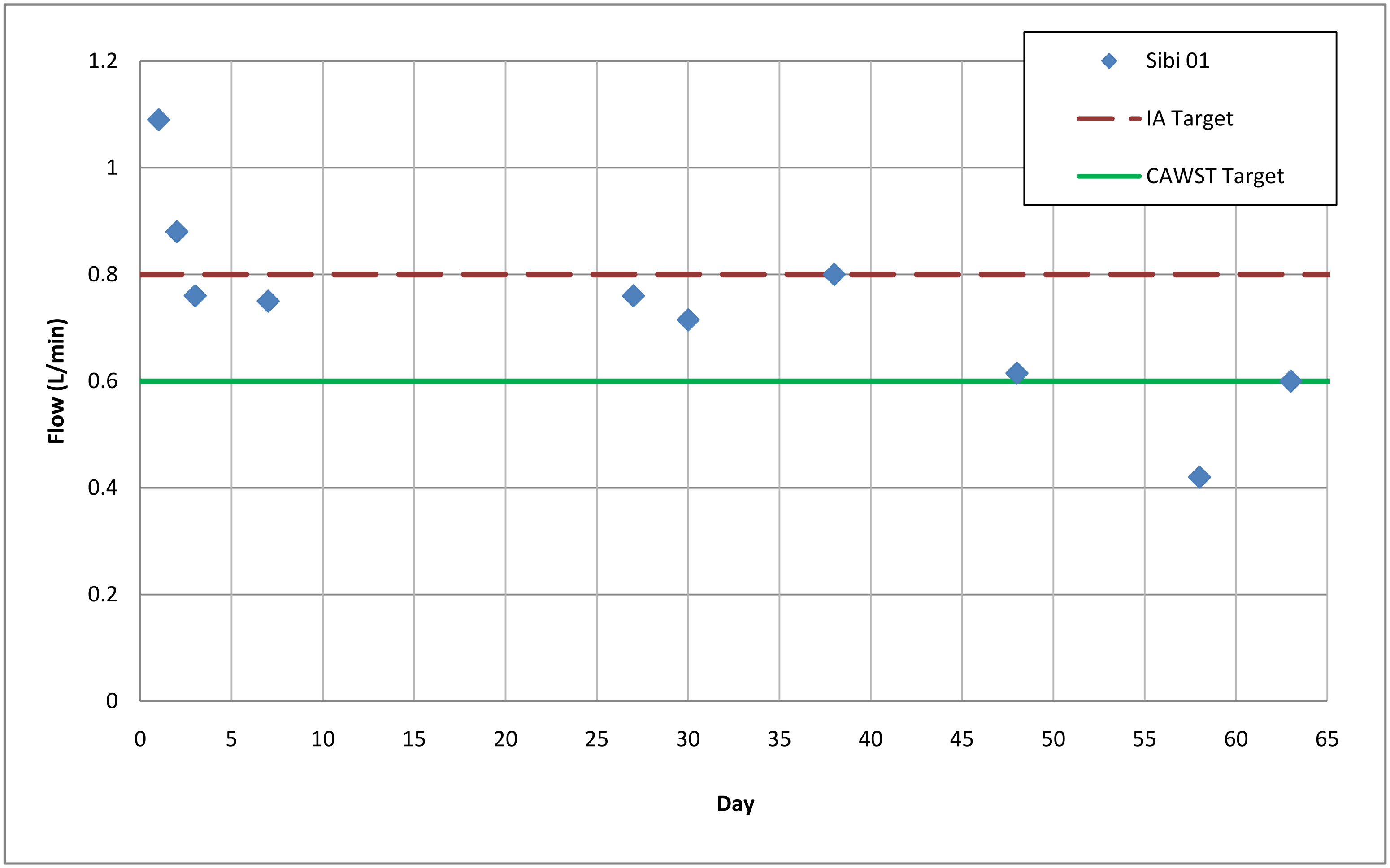

Figure 38: Adjusted-average flow rate measurements for BioSand Filter Sibi 01 with the installation of the fourth layer reset as Day 1. Recommended flow rates by the Center for Affordable Water and Sanitation Technology (CAWST) and International Aid (IA) are also graphed at 0.6 L/min and 0.8 L/min, respectively. A general range of acceptable flow rates is from a maximum of 1 L/min to a minimum that is determined by the user to be the lowest acceptable flow rate (e.g. 0.4 L/min).

Utilizing the same methods for washing the filter media that were determined during Phase 1, the next ten filters were installed to initiate Phase 2. For Sibi 03 to 06, the fourth layer was installed on the same day as the other layers. This was not the case for Sibi 07 to 12, which had to wait until more of the fourth layer media was transported to the site. Approximately one week later the fourth layer was placed into these filters, and the effective filter run-time was reset to Day 1 to provide comparative data between all filters. The average flow rate upon installation was 0.93 L/min with a range between 0.74 and 1.24 L/min. For Phase 3 BSFs, Sibi 13 to 53 ranged from 0.61 – 1.50 L/min, with an average of 0.93 L/min. A comparison between the three Phases is presented in Table 3, displaying the sample size, mean, range, and standard deviation. Since the pilot period for Phase 1, best methods of installation were determined and implemented in Phase 2 and 3. Therefore, it is not surprising that the initial flow rates are similar, especially in Phases 2 and 3. However, as the sample size increases, so does the range and standard deviation. This could be due to the nature of the filter media, inconsistency in installing the third layer, or mean the filter media needs to be washed in a more uniform manner – especially the third and fourth layers.

Table 3: BioSand filter installation flow rate data for Phase 1 through 3

Phase:	Sample Size:	Avg Q (L/min):	Q (L/min) Range:	Std Dev:
1	2	1.1	1.09 -- 1.11	0.0141
2	10	0.93	0.74 -- 1.24	0.167
3	41	0.93	0.61 -- 1.50	0.211

5.1.2 Weekly Monitoring

The data collected from the BSFs during the weekly monitoring period (roughly nine weeks) demonstrates how the flow rate changes through use. The households containing Sibi 01 and 02 were geographically close to one another, so the weekly monitoring was usually performed for both BSFs on the same day. As expected the flow rate decreases over time with usage of the filter as sediment is physically trapped in the pore space and the biolayer matures in the top of the third and fourth layers. However, due to differing source water, filter use, and maintenance, the flow rate measurements vary between the two. Figure 39 displays the general decreasing trend in the flow rates during Phase 1 as shown by a line that was plotted using averaged data points from Sibi 01 and 02 collected on the same days. The graph also includes averaged raw data for each filter and the range of suggested values by CAWST (0.6 L/min) and IA (0.8 L/min). Note that during the majority of the filter run time the Phase 1 average operates between the range of suggested flow rates, meaning the filters should be providing households with a sufficient supply of water and operating at a level that provides adequate treatment removal of pathogens from the source water.

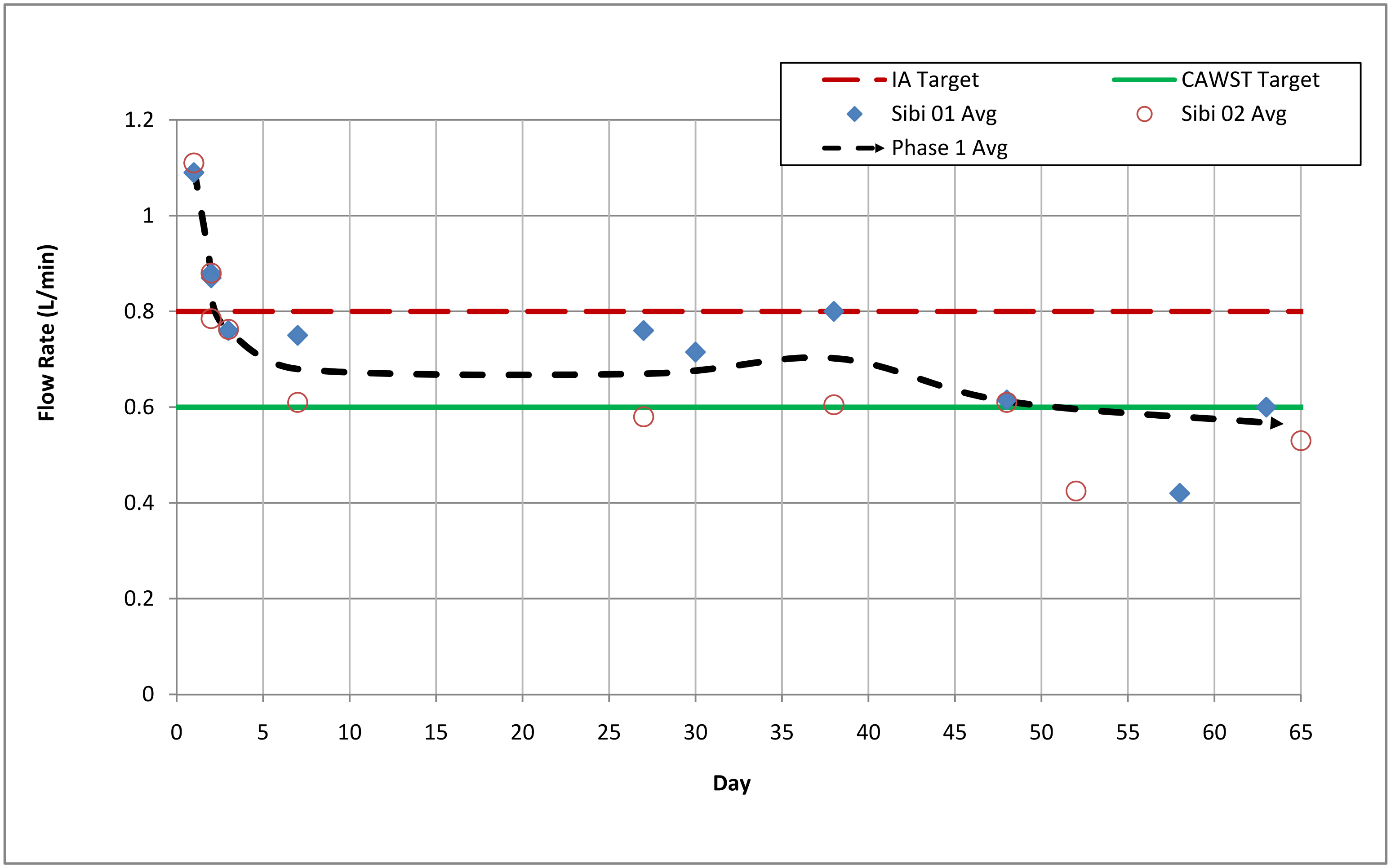

Figure 39: Adjusted-average flow rate measurements for Phase 1. The trend line demonstrates the general decrease in flow rates over time. Recommended flow rates by the Center for Affordable Water and Sanitation Technology (CAWST) and International Aid (IA) are also graphed at 0.6 L/min and 0.8 L/min, respectively. A general range of acceptable flow rates is from a maximum of 1 L/min to a minimum that is determined by the user to be the lowest acceptable flow rate (e.g. 0.4 L/min).

This exercise can also be done for the BSFs in Phase 2 (Sibi 03 to 12) to display a trend line of decreasing flow rates over time. However, since these filters are in households spread out over the entire community, the weekly monitoring was not always performed on the same day for each filter. In other words, although flow rate measurements were taken roughly once a week for each filter they do not exactly correspond in time to the other filters in Phase 2. Therefore, averaging the data points for all ten filters would require interpolation between actual measurements to create corresponding data. Plus, the sheer number of data points makes this graph rather confusing to interpret (Appendix C, Figure 93.)

5.1.3 Flow Rate Modeling Equation

In order to better understand the relationship of how the flow rates behave over time a modeling equation was calculated based on the adjusted-average flow rate data for the HydrAid™ BSFs in Phase 1 and 2. To clarify, the adjusted-average data has been manipulated from the raw data by *adjusting* Day One of the filter so that it was reset when the fourth layer sand was installed or modified (the case for nine of the filters), and by *averaging* multiple data points from the same day (the case for all filters). By fitting an exponential trend line to the adjusted-average flow rate graphs for each filter an equation of the form in Equation 1 was realized.

$$y = Ae^{-kx} \quad (1)$$

For use in this study, the variables are defined as: *y* representing the resultant flow rate, *A* – the starting flow rate, *e* – the base of the natural logarithm (Euler's number), *k* – the rate of exponential change, and *x* being time. Therefore, each of the twelve BSFs have an *A* and *k* value from which the mean value and standard deviation are calculated from the set of filters. The average values for A and k are used to determine the flow rate modeling equation (Equation 2) and as such can be used to anticipate the expected behavior of a HydrAid™ BSF in the community.

$$Q = 0.8709e^{-0.007967t} \quad (2)$$

where t is time [days] and Q is BioSand filter flow rate [L/min].

Figure 40 presents the modeling equation as a plotted average flow rate curve. Due to time-variable limitations in the source data, the run-time is set at sixty days. Also displayed are two average flow rate curves, plus and minus the standard deviation, respectively. These represent the range of values from which the average curve was estimated from Equation 2. As with the previous figures from this chapter the CAWST and IA recommended flow rates are plotted as a range from which to compare the flow rates from the modeled curve. As expected the flow rate begins above 0.8 L/min; it then proceeds to decrease with operating time. The curve remains above 0.8 L/min for ten days, spends roughly thirty-six days (sixty percent of the time) within the CAWST-IA range of 0.6 to 0.8 L/min, and then dips below the CAWST flow rate for the last fourteen days of the model period. Specifically, the model represents the behavior of Sibi 01-12 and although some of the households were maintaining their filters during the two month period, most were not. So, as seen by the curve there is a general decrease in the flow rate of the filters throughout the sixty day period. What this represents, especially after Day 51, is that the filters are simply dirty and need to be maintained to increase the flow rate again. The model provides guidance on the maintenance cycle in this community, suggesting filters should be cleaned approximately every thirty-six days if users wish to have flow rates within the operational range of CAWST and IA values.

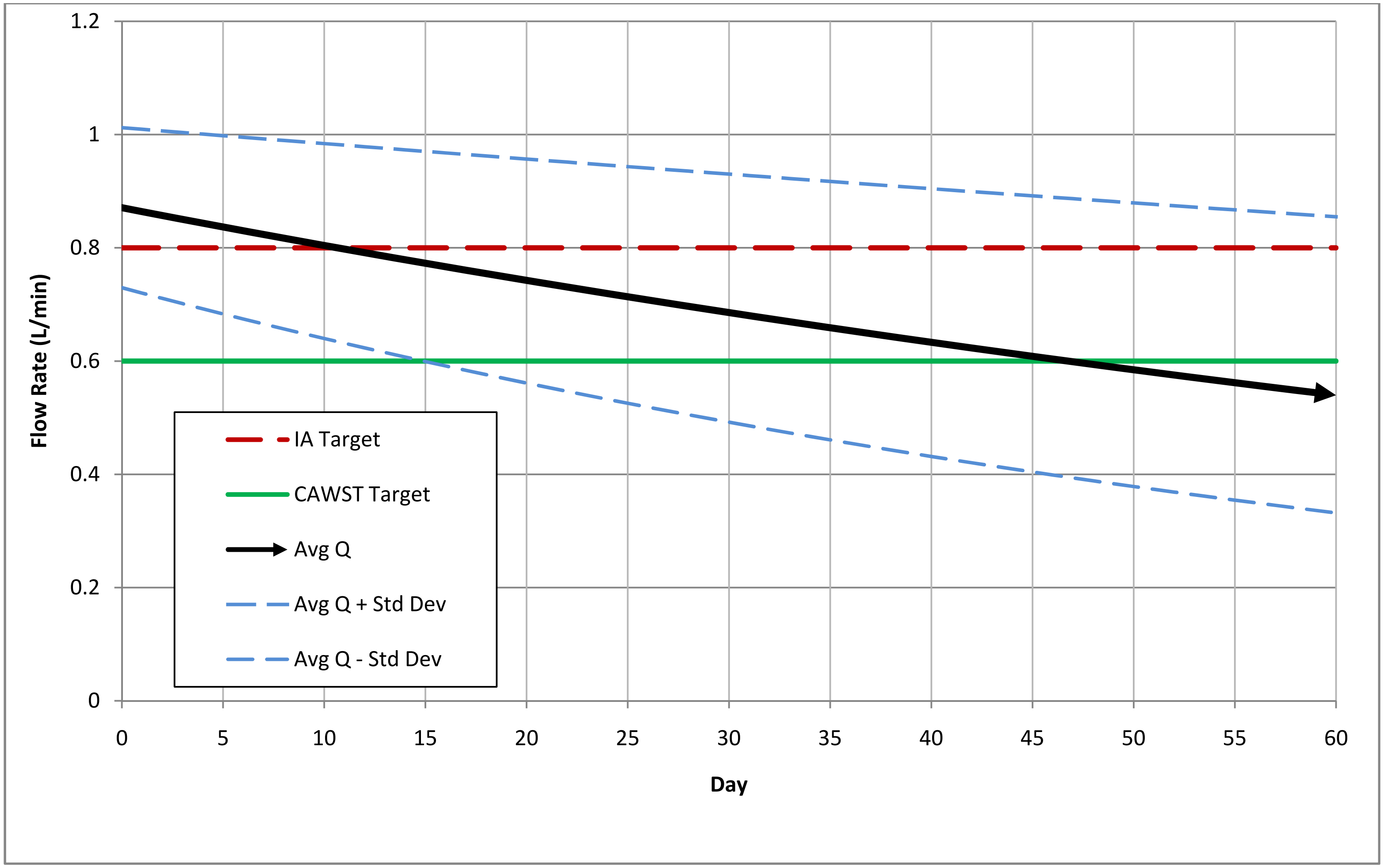

Figure 40: Flow rate modeling curve based on adjusted-average data for Sibi 01-12. Recommended flow rates by the Center for Affordable Water and Sanitation Technology (CAWST) and International Aid (IA) are also graphed at 0.6 L/min and 0.8 L/min, respectively. A general range of acceptable flow rates is from a maximum of 1 L/min to a minimum that is determined by the user to be the lowest acceptable flow rate (e.g. 0.4 L/min).

5.1.4 Examining Flow Rate Ranges

As noted in the previous section the flow rate modeling equation curve (Figure 40) spends approximately 60% of the time in between the CAWST-IA range of 0.6-0.8 L/min. In order to gain a better understanding of how the real data behaves in regards to this range of suggested flow rates the adjusted-average flow rate data for Sibi 01 through Sibi 12 is examined and represented in Table 4. As stated in the last section, the adjusted-average flow rate data has been manipulated from the raw data by *adjusting* Day One of the filter so that it is reset at the time the fourth layer sand was installed or modified, and by *averaging* multiple data points from the same day.

Table 4: Percentage of actual flow rate measurements above, within, and below the CAWST-IA range for BSF two month run-time

BSF #:	Q > 0.8 L/min	Q = 0.6 to 0.8 L/min:	Q < 0.6 L/min
1	27.3%	63.6%	9.1%
2	20.0%	50.0%	30.0%
3	100.0%	0.0%	0.0%
4	62.5%	37.5%	0.0%
5	11.1%	44.4%	44.4%
6	44.4%	55.6%	0.0%
7	57.1%	42.9%	0.0%
8	12.5%	75.0%	12.5%
9	0.0%	14.3%	85.7%
10	33.3%	66.7%	0.0%
11	0.0%	28.6%	71.4%
12	0.0%	25.0%	75.0%
Average:	***30.7%***	***42.0%***	***27.3%***

As shown in Table 4, the category with the highest percentage of flow rate measurements at 42% was within the CAWST-IA range of 0.6 to 0.8 L/min. This range represents the suggested operating flow rates to receive both adequate treatment and supply. As such, the households should be getting the best possible performance from the BSF when operating at this level. The flow rate measurements were above 0.8 L/min 30.7% of the time. As the flow rate on the BSF increases, the capability of the filter to produce a larger volume of treated water also increases – a function that pleases the user. However, since the water is passing faster through the filter, the bacterial removal efficiency should decrease – something the user usually cannot see (apart from turbidity removal). Slightly lower is the average percentage of the measurements recorded below 0.6 L/min, 27.3%. This has the opposite effect of being above the CAWST-IA range; with a decreasing flow rate the bacterial removal efficiency increases as the source water has more contact with the biolayer. However, users do not like the flow rate to be too slow, as it inhibits their ability to produce a sufficient supply of water. Remember that the BSF is meant to be used intermittently with the optimal resting periods of 6-12 hours as discussed in Chapter Two. If a BSF has an undesirably low flow rate, the household will be forced to obtain an adequate supply of treated water by not allowing proper resting periods in between use.

While Table 4 represents roughly a two month operation run time, the percentages for flow rate measurements above, within and below the CAWST-IA range of 0.6-0.8 L/min would change as the filter run time increases. After installation the flow rate in a filter tends to decrease relatively quickly at first but still spends some time above 0.8 L/min before entering into the 0.6 to 0.8 L/min range, and later dropping below 0.6 L/min. However, after performing swirl-and-dump maintenance on the filter the flow rate increases but not as high as the installation rate. Instead, it would most likely increase to around the 0.6-0.8 L/min range, and follow the same pattern of decreasing over time until below 0.6 L/min when the filter again needs maintenance. So ultimately, with a longer run-time and weekly monitoring of the BSFs the percentage of flow rate measurements above 0.8 L/min would be much lower and would continue to decrease with time, as more flow rate measurements are gathered. For the other two categories, the percentage would depend on how often the household is performing maintenance on their filter. If the household always performs maintenance before the flow rate drops below 0.6 L/min then the flow rate should stay within the range of 0.6-0.8 for the BSF life time. However, as seen by the modeling equation curve, the flow rate will most likely drop below 0.6 L/min to a certain point where it is unacceptable to the user, for example 0.5 or 0.4 L/min. At this point maintenance will be employed and the flow rate will rebound back into the 0.6-0.8 L/min range.

5.1.5 Flow Rate Patterns

Table 3 in Section 5.1.1 compares the installation flow rates in the filters from all three phases. Using additional flow rate measurements collected during weekly monitoring, the data sets for each phase can be analyzed and compared at certain points in time. Figures 41 and 42 display box plots of the Phase 1 and 2 data, respectively, and show how the flow rate decreases from installation (Day 1) to the next day (Day 2), one week (Day 7), four week (Day 27) and seven week (Day 48) points. Due to the observed run-time being much shorter for the Phase 3 BSFs, only the installation (Day 1), next day (Day 2) and one week (Day 7) points are displayed as box plots in Figure 43.

With all three figures there is a decrease in flow rate with time; however, the rate of decline at certain points tends to vary between the graphs. Figure 41 shows its largest decrease of 25% between Day 1 (1.10 L/min) and Day 2 (0.83 L/min). Taking the installation rate as the baseline from which to compare, by Day 7 (0.68 L/min) the average flow rate has decreased 38% from Day 1. From this point the rate of change appears to level out. By Day 27 (0.67 L/min) the flow rate decrease is at 39% and by Day 48 (0.61 L/min) the flow rate has decreased 44% from Day 1. The interpretation from Figure 41 would bring us to the conclusion that most of the flow rate decrease occurs during the first week of filter operation. Perhaps this is because the two households in Phase 1 were actively maintaining their filters using the “swirl-and-dump” method when the flow rate had become too low for their needs. Taken at these specific days in the filter run-time this appears as a leveling out of the flow rate, almost as if the data is approaching the boundary of an asymptote.

This does not appear to be true for Figure 42, which shows an almost uniform decrease in flow between the box plots. Taking the installation rate (Day 1 – 0.93 L/min) as the baseline from which to compare, the percentage decrease in average flow rates on specific days for the data set of ten filters is as follows: Day 2 (0.85 L/min) – 8.4%, Day 7 (0.8 L/min) – 14%, Day 27 (0.69 L/min) – 26%, and Day 48 (0.59 L/min) – 37%. So unlike the asymptotic-type effect observed in Figure 41, the flow rate continues to decrease. This could be because only three of the ten households were maintaining their BSFs during the entire filter run time (Appendix A), which would impart an overall decline in average filter flow rates over time. Perhaps if all ten households were performing “swirl-and-dump” maintenance the flow rate pattern would mimic that of the one observed in Figure 41.

For Figure 43, it is also difficult to jump to conclusions regarding the pattern of flow decrease. This is due to the small number of flow rate measurements collected after installation and the way that data is manipulated to produce the box plots. Flow rate tests were performed upon installation, and then again eight or nine days later for 80% of the filters. No actual flow rate measurements were collected on Day 2 or Day 7. Linear interpolation between known data points – such as Day 1 and Day 8 – was used to determine these points. However, based on field observations of the BSFs (especially from those in Phase 1 and 2), the decrease in flow rate over time is not linear. Therefore, this graph does not accurately represent the decrease in flow over the first week operation. In order to gain a better picture of this trend, flow rate measurements for a set of filters should be collected each day.

The difference in flow rates between filters is thought to be caused by a number of factors. Variability during the installation process (shown by the range of installation values in Table 3) could be due to both inconsistencies in the washing of the filter media, and that the amount of water above the second layer within some filters during the installation process probably exceeded eight inches. The later point, as discussed in Chapter Four, is derived from Manz’s guidelines to prevent stratification in the sand layer, which decreases flow. Since the installation teams in Phases 2 and 3 were not given specific guidance on the water depth within the filter this could account for some of the filters experiencing low flow rates. This variability perpetuates with lower flow rates throughout the entire run-time of the filter. Added to this is the fact that different source water was being used as influent for the filters, which had different concentrations of bacteria and solids (seen in Table 5 and 8 later in this chapter).

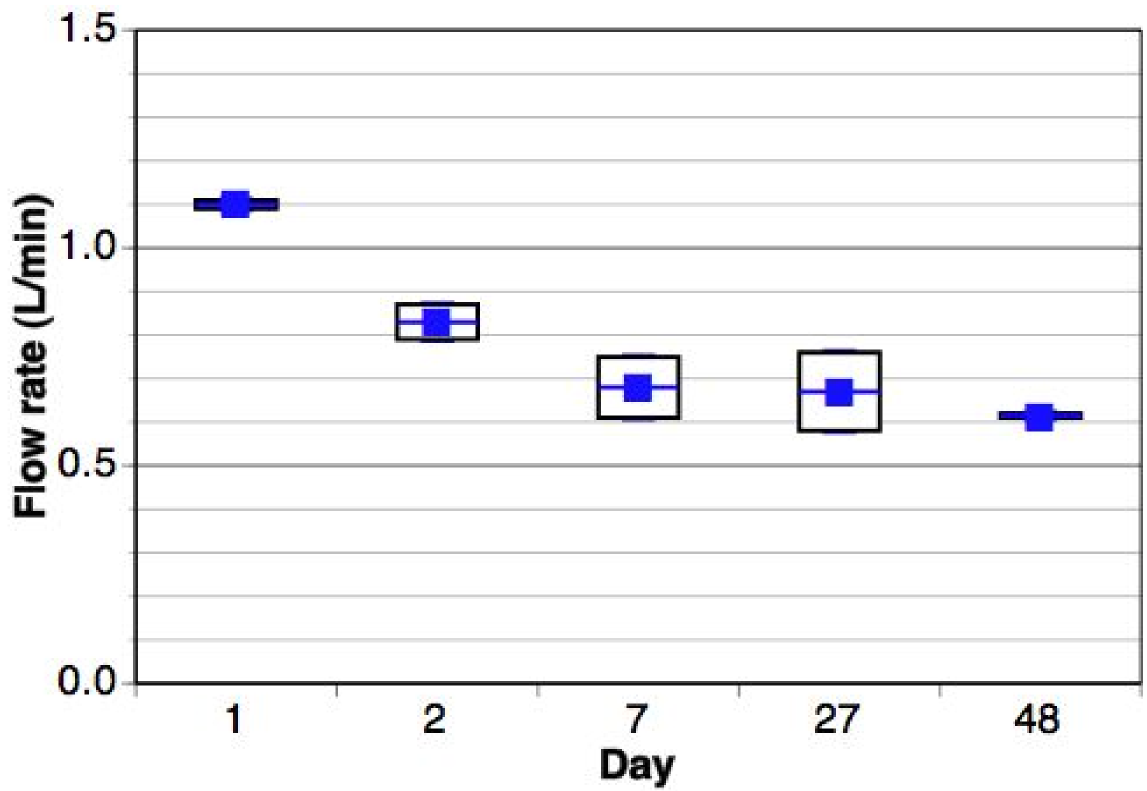

Figure 41: A boxplot comparison of Phase 1 (2 BSFs) flow rate measurements with time of use. The blue square with the box represents the mean, blue line inside the box represents the median, ends of the box are the 25 and 75 percentiles and the whiskers (in this case hidden by the quartiles) are the minimum and maximum values.

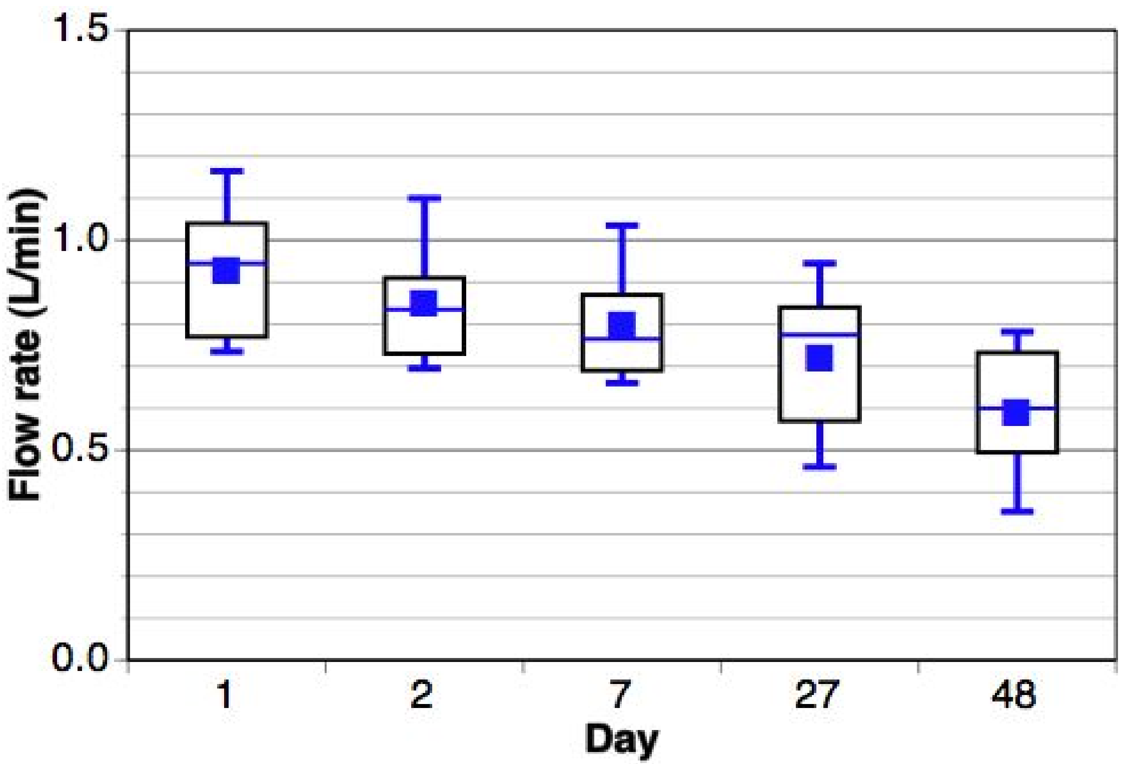

Figure 42: A boxplot comparison of Phase 2 (10 BSFs) flow rate measurements with time of use. The blue square with the box represents the mean, blue line inside the box represents the median, ends of the box are the 25 and 75 percentiles and the whiskers extended from the box are the minimum and maximum values.

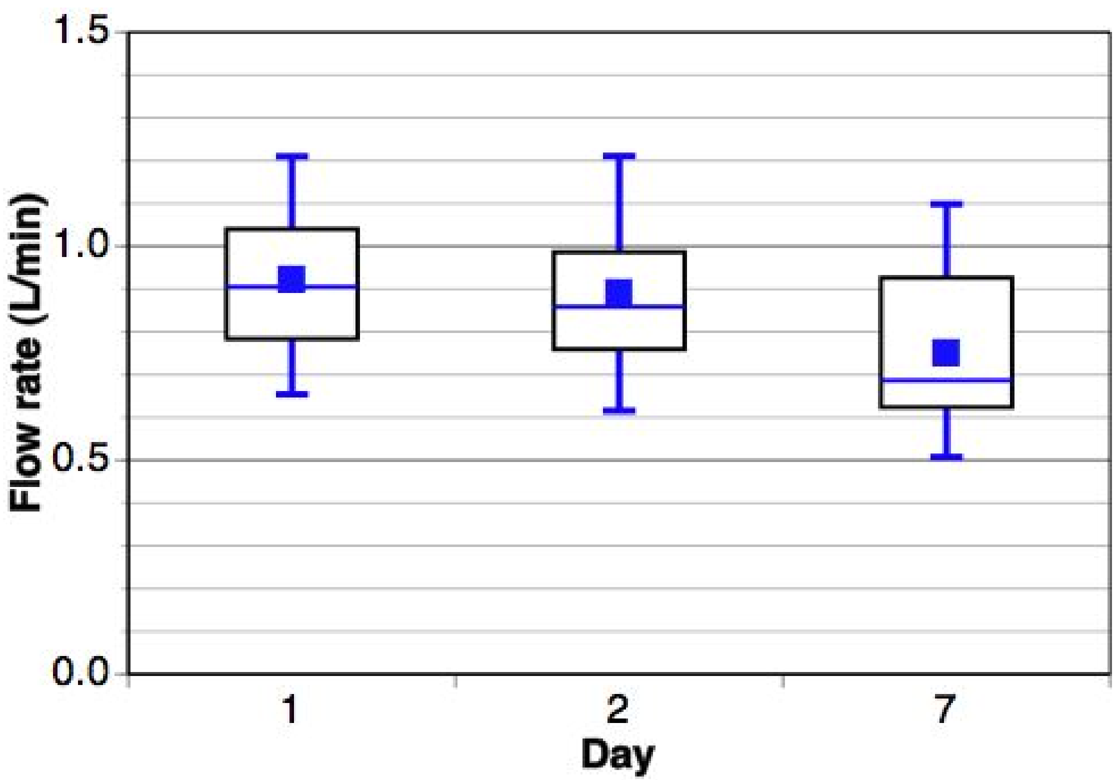

Figure 43: A boxplot comparison of Phase 3 (41 BSFs) flow rate measurements with time of use. The blue square with the box represents the mean, blue line inside the box represents the median, ends of the box are the 25 and 75 percentiles and the whiskers extended from the box are the minimum and maximum values.

5.2 *Water Quality Tests*

The water quality testing was performed in two separate samplings that were roughly seven weeks apart. As explained in Chapter Three a small number of water samples were collected and transported to a qualified laboratory where they were analyzed in accordance with APHA Standard Methods. Membrane filtration was the method used to analyze the total and fecal coliforms in the water. The reason for the small set of analyzed samples was due to the cost involved and budgetary restrictions of IA to pay for more comprehensive results. As such the results are useful as an indicator of the quality of influent (source) and effluent (filtered) water at the time of testing. These results are then used to calculate the bacterial removal efficiency for each BSF, and when taken together give a general picture of how the filters are performing in regards to their ability to provide a safer supply of drinking water for participating households in the community.

5.2.1 First Sampling

One influent and one effluent sample were collected from three BSFs – Sibi 02, 05 and 06 on August 28, 2007 (Day 5/6 of operation). Total coliforms, fecal coliforms, and total heterotrophic bacteria were measured and are presented in Table 5. Twenty-six physico-chemical constituents were measured and a subset of the data is presented in Table 6 (the raw data is available in Appendix B).

Table 5: Water quality test results for water samples collected on 8/28/2007 (Day 5/6)

SAMPLE ID:	Total Coliforms (CFU/100mL)	Fecal Coliforms (CFU/100mL)	Total Heterotrophic Bacteria (CFU/100mL)	Flow Rate (L/min)	BioLayer Growth Time (Days)
Sibi 02 Raw	3520	837	808	0.61	6
Sibi 02 Filtered	1675	208	332		
Reduction	*52%*	*75%*	*59%*		
Sibi 05 Raw	2230	651	544	0.74	5
Sibi 05 Filtered	672	12	232		
Reduction	*70%*	*98%*	*57%*		
Sibi 06 Raw	2420	232	772	0.80	5
Sibi 06 Filtered	6	0	308		
Reduction	*100%*	*100%*	*60%*		
AVERAGE:	**74%**	**91%**	**59%**	**0.71**	**5**

Table 6: Physico-chemical characteristics of water samples for first sampling collected on 8/28/2007 (Day 5/6)

	Sibi 02		Sibi 05		Sibi 06		WHO
Characteristic:	Raw	Filtered	Raw	Filtered	Raw	Filtered	Standard
Turbidity (NTU)	**119**	**124**	**118**	**85**	**25.4**	**19.4**	5
Color (apparent)	20	20	16	10	5	5	15
pH	7.3	7.8	7.32	7.88	7.14	7.8	6.5 - 8.5
Conductivity	64.3	82	53.5	99.5	34.1	97	-
Total Suspended Solids	30	24	25	12	6	4	-
Total Dissolved Solids	35.4	45.1	29.4	54.7	18.8	53.4	1000
Sodium (mg/l)	10	11.3	9.6	10.3	3.2	8.3	200
Potassium (mg/l)	1.5	2.7	0.882	1.2	0.65	2.1	30
Calcium (mg/l)	7.2	12	5.6	10.4	3.2	10.4	200
Magnesium (mg/l)	2.4	2.9	1.9	4.8	1.9	3.9	150
Total Iron (mg/l)	2.84	3.23	1.7	1.11	0.29	0.069	0.3
Ammonium (mg/l)	<0.0	<0.001	<0.0	<0.001	<0.0	<0.001	0 - 1.5
Chloride (mg/l)	2	2	2	2	2	1	250
Sulfate (mg/l)	17	22.4	11.1	8.53	1	1	400
Manganese (mg/l)	0.04	0.047	0.004	0.007	0.04	0.025	0.5
Nitrite (mg/l)	0.05	0.044	0.103	0.096	0.03	0.249	1
Nitrate (mg/l)	1.33	1.28	1.89	1.86	1.82	6.54	10
Tot Hardness as CaCO3	28	42	22	46	16	42	500
Fluoride (mg/l)	<0.0	<0.005	<0.0	<0.005	<0.0	<0.005	1.5

At this point the three BSFs had been in operation for five to six days, and had an average flow rate of 0.71 L/min. The biolayer was not yet mature so the predation removal process is limited, and the filters are therefore not at maximum removal efficiency. However, utilizing other removal processes (such as mechanical trapping, adsorption and natural death) there was an average of 74% removal of total coliforms and 91% removal of fecal coliforms. So even without a fully mature biolayer the filters on average are within the 90-95% removal range of fecal coliforms as described in the BSF literature and discussed in Chapter Two. However, it must also be noted that although improved, this is not in compliance with WHO standards, which requires that no thermotolerant coliform bacteria be present in any 100-mL sample (WHO 2006).

Of interest also is the amount and range of total and fecal coliforms in each raw water sample. The total coliforms ranged from 2,230 to 3,520 cfu/100 mL, while the fecal coliforms ranged from 232 to 837 cfu/100 mL. One explanation for the range in values is that all three households were using different fetching points, which yield different source water. Figure 44 shows the community map and the fetching points utilized by the households. The household owning BSF Sibi 02 was fetching from a smaller seasonal stream called Kabunbuk, which was also used by the women for washing clothes and the children for playing (Figure 45c). The source water from this fetching point was the highest for fecal and total coliforms. The household owning Sibi 06 fetched from the larger Sibi Stream at a point upstream from the community and from where the Kabunbuk flows into it (Figure 46a). The total coliforms were lower than those of the Sibi 02 source water, and the fecal coliforms were lower than those of the other two filters' source water. The household owning Sibi 05 fetched their source water from the Sibi Stream but downstream of the community and downstream from where the Kabunbuk Stream joins the Sibi Stream (Figure 46c). The total coliforms were similar in count to the source water fetched by Sibi 06. However, the fecal coliforms were higher than Sibi 06 and lower than Sibi 02. This could be caused by higher concentrations of fecal bacteria from the smaller-volume Kabunbuk stream mixing with lower concentrations of fecal bacteria from the larger-volume Sibi Stream.

As shown in Table 6 the BSFs do not all perform the same in regards to the physico-chemical characteristics. The parameters that do exhibit similar behavior between the three filters include: 1) increases in pH, conductivity, total dissolved solids, Na, K, Ca, Mg, and total hardness as $CaCO_3$, and 2) decreases in total suspended solids. Sibi 05 and 06 both demonstrate decreases in turbidity and total iron. However, the rest of the parameters (color, NH_{4+}, Cl, SO_3, Mn, NO_2, NO_3, and F) vary by filter. The decrease in total suspended solids aids in the bacterial removal within the BSFs during this period of operation, and adsorption probably also contributes to this as well. The increase in total dissolved solids is most likely from the newly installed filtered media itself, which would also explain why there are increases in some concentrations of chemical ions between the raw and filtered water.

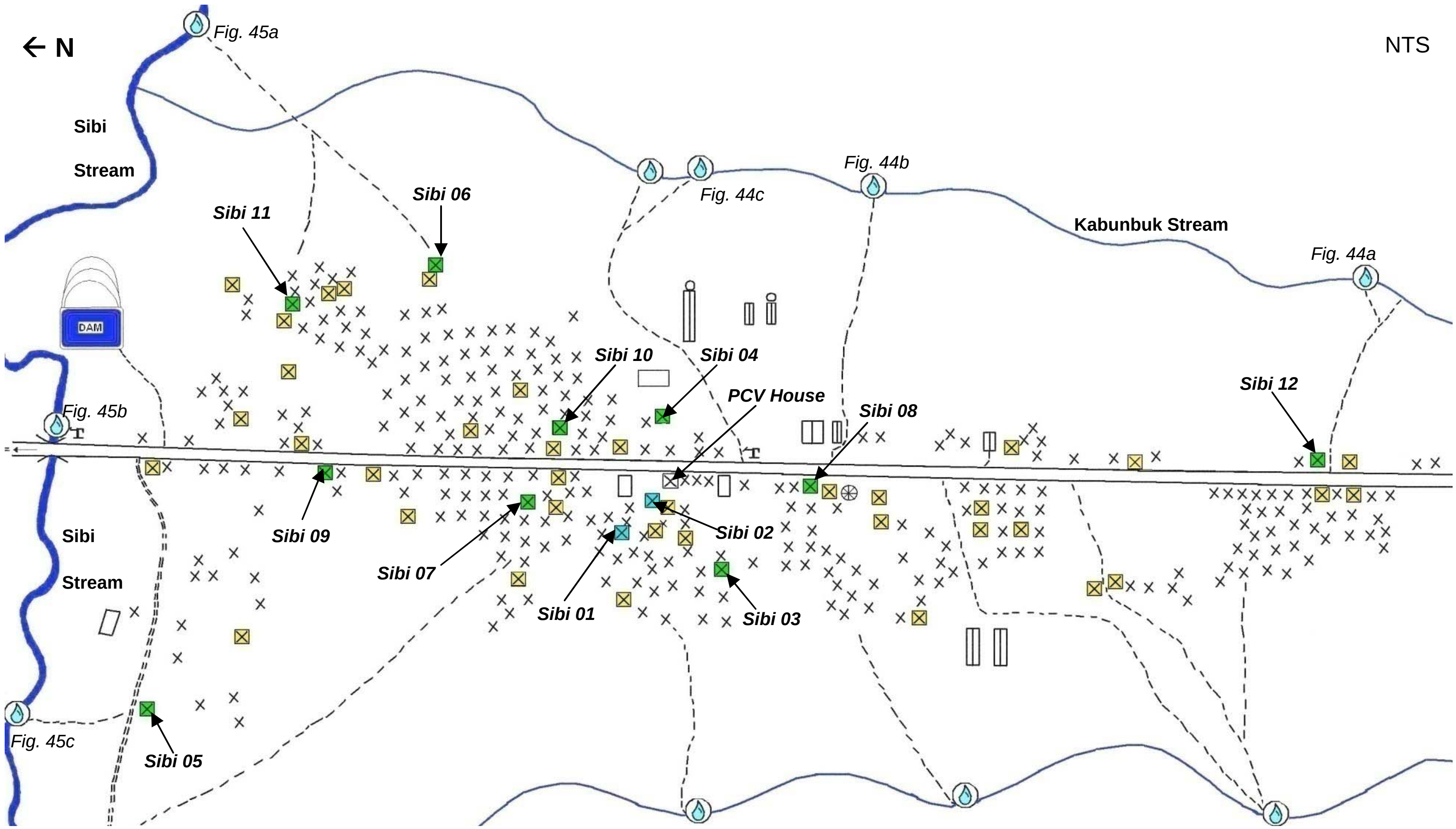

Figure 44: Community map showing fetching points and households with BioSand Filters. Each fetching point is represented by a water droplet and those labeled correspond with figures that show photographs of the locations. The BSF households are color-coded as follows: Phase 1 – light blue, Phase 2 – green, and Phase 3 – yellow.

The last column in Table 6 indicates the WHO standards for each parameter, and provides a means of comparing the filtered water to international drinking water standards. Table 7 presents the data for all of the physico-chemical characteristics measured by the Water Research Institute for BSF Sibi 06, and serves as an example for such a comparison (Appendix B includes similar tables for Sibi 02 and 05). The percent change is noted with a negative percentage indicating a decrease by that amount from the raw to filtered sample, while a positive percentage demonstrates an increase. Most of the parameters increased in value including twelve out of fourteen that more than doubled. These included conductivity, total dissolved solids, Na, K, Ca, Mg, Nitrite, Nitrate, Total Hardness as $CaCO_3$, Total Alkalinity as $CaCO_3$, Ca Hardness as $CaCO_3$, and Bicarbonate as $CaCO_3$. Only turbidity, Total Suspended Solids, Total Fe, Cl, and Mn experienced reductions in concentration. However, apart from the turbidity, all of the characteristics comply with WHO standards for drinking water, as noted in the last column. This demonstrates that, at least initially, the BSF does not contribute towards the improvement of the source water to meet WHO standards for drinking water in regards to physico-chemical characteristics. Instead, the filter is making its most significant improvement by reducing pathogens such as bacteria (shown in Table 5 and 8).

Table 7: Sibi 06 physico-chemical characteristic analysis collected on 8/28/2007 (Day 5)

Characteristic:	Raw:	Filtered:	%	WHO Std	Complies?
Turbidity (NTU)	25.4	19.4	-24%	5	No
Color (apparent)	5	5	0%	15	Yes
Odor	-	-	-	Inoffensive	-
pH	7.14	7.8	9%	6.5 - 8.5	Yes
Conductivity	34.1	97	184%	-	-
Total Suspended Solids (mg/l)	6	4	-33%	-	-
Total Dissolved Solids (mg/l)	18.8	53.4	184%	1000	Yes
Sodium (mg/l)	3.2	8.3	159%	200	Yes
Potassium (mg/l)	0.654	2.1	221%	30	Yes
Calcium (mg/l)	3.2	10.4	225%	200	Yes
Magnesium (mg/l)	1.9	3.9	105%	150	Yes
Total Iron (mg/l)	0.294	0.069	-77%	0.3	Yes
Ammonium (mg/l)	<0.001	<0.001	-	0 - 1.5	Yes
Chloride (mg/l)	2	1	-50%	250	Yes
Sulfate (mg/l)	1	1	0%	400	Yes
Phosphate (mg/l)	0.291	<0.001	-	-	-
Manganese (mg/l)	0.044	0.025	-43%	0.5	Yes
Nitrite (mg/l)	0.039	0.249	538%	1	Yes
Nitrate (mg/l)	1.82	6.54	259%	10	Yes
Tot Hardness as CaCO3 (mg/l)	16	42	163%	500	Yes
Tot Alkalinity as CaCO3 (mg/l)	18	50	178%	-	-
Ca Hardness as CaCO3 (mg/l)	8	26.1	226%	-	-
Mg Hardness as CaCO3 (mg/l)	8	15.9	99%	-	-
Fluoride (mg/l)	<0.005	<0.005	-	1.5	Yes
Bicarbonate as CaCO3 (mg/l)	22	61	177%	-	-
Carbonate (mg/l)	0	0	0%	-	-

5.2.2 Second Sampling

One influent and one effluent sample were collected from six BSFs on October 12, 2007. These included the three BSFs tested in the first sampling (Sibi 02, 05, 06) plus three additional filters (Sibi 08, 09 and 12). Total and fecal coliforms were measured and are presented in Table 8. No physico-chemical constituents were analyzed in this round.

Table 8: Water quality test results for second sampling collected on 10/12/2007 (Day 47-51)

SAMPLE ID:	Total Coliforms (CFU/100mL)	Fecal Coliforms (CFU/100mL)	Flow Rate (L/min)	BioLayer Growth (Days)
Sibi 02 Raw	760	90	0.425	51
Sibi 02 Filtered	215	0		
Reduction	*72%*	*100%*		
Sibi 05 Raw	1880	140	0.46	50
Sibi 05 Filtered	365	60		
Reduction	*81%*	*57%*		
Sibi 06 Raw	780	115	0.71	50
Sibi 06 Filtered	0	0		
Reduction	*100%*	*100%*		
Sibi 08 Raw	2500	145	0.61	43
Sibi 08 Filtered	200	10		
Reduction	*92%*	*93%*		
Sibi 09 Raw	1560	350	0.29	42
Sibi 09 Filtered	200	75		
Reduction	*87%*	*79%*		
Sibi 12 Raw	260	185	0.46	45
Sibi 12 Filtered	0	0		
Reduction	*100%*	*100%*		
AVERAGE:	***89%***	***88%***	***0.49***	***47***
AVERAGE (2,5,6):	***84%***	***86%***	***0.53***	***50***

At this point the BSFs were in operation on average for seven weeks, a greater period than the two or three weeks cited to achieve a mature biolayer. Due to increased predation the filters should hypothetically be at their maximum removal efficiency. However, average removal for total and fecal coliforms was 89% and 88%, respectively. This demonstrates an overall increase in reduction for total coliforms from the first round of sampling but a small decrease in reduction for fecal coliforms. The average flow at the time of collecting the water samples was 0.49 L/min – below the CAWST-IA range of 0.6-0.8 L/min.

Interpreting the difference in coliform counts for each raw water sample is less straight forward than in the first round of sampling. Again refer to the community map (Figure 44), which has the fetching points and BSF households marked. Overall, the total coliforms measured in the source water vary significantly from 260 to 2,500 cfu/100 mL, and the fecal coliforms range from 90 to 350 cfu/100 mL. What stands out from the first three BSFs is the similarity between the coliform counts for Sibi 02 and Sibi 06. Although these two households reported different fetching points it is possible that this particular source water was fetched from the same location in the community. Often times the children (mostly girls) in the community fetch water at certain times of the day; this could almost be described as a social activity. Therefore, it would not be uncommon for children to be fetching water from the same place (Figure 46b) so that they can see their friends, even if it is farther away than their household's normal fetching point. This could also be proposed for the similarity between Sibi 05 and 08 but unlikely, since the households are so far away from each other and users would have to go quite far out of their way to fetch at a common point.

The household owning Sibi 12 fetched water from an upstream point on the Kabunbuk Stream that was approximately 100 ft from where the water flowed out of the ground (Figure 45a). This gave the lowest concentration of total coliforms of the raw water samples, yet for unknown reasons had the second highest concentration of fecal coliforms (perhaps this was due to a storage issue). The highest concentration of total coliforms came from behind the clinic at the Kabunbuk Stream (Figure 45b) – close to the same location of source water that had the highest concentrations of both fecal and total coliforms in the first round of sampling.

Another interesting question that arises from comparing the source water from the first and second samplings involves the difference between the range of concentrations. In August the concentration of total coliforms in the raw water samples range from 2,230 to 3,520 cfu/100 mL. However, by October the concentrations were lower, measuring between 260 and 2,500 cfu/100 mL. For fecal coliforms in August the concentrations were from 232 to 837 cfu/100 mL. However, this decreased substantially by October with concentrations from 90 to 350 cfu/100 mL. The reasons for the difference in source water concentrations could be attributed to two things: the physical environment prior to collection, and/or the management of water samples after collection. The first idea takes into consideration that there may be variability in water quality over time at each fetching point. The first sampling took place in August, which is still in the main part of the rainy season, whereas October (when the second sampling occurred) is at the tail-end of the rainy season and beginning of the dry season. Since there is more rain and runoff during August than there is in October, higher concentrations of fecal bacteria are perhaps washed off the land into the streams at this time. The second notion addresses the methods from Chapter Three. After the water samples were collected in Round One, Mumuni from IA transported the samples in a cooler without ice to Nkwanta – approximately a three hour drive with a private vehicle during the rainy season– before placing them in a refrigerator. Due to the hot weather, population growth of certain thermophilic bacteria could have multiplied in the sample bottles during this period causing higher concentration ranges for the first round of sampling.

(a) (b)

(c)

Figure 45: Kabunbuk Stream fetching points: (a) Upstream of the community and close to the source of where the water comes out of the ground – a fetching point for Sibi 12, (b) Roughly 100 yards behind the clinic – a fetching point for Sibi 08, and (c) Behind the E.P. Primary school – a fetching point for 02.

(a)

(b)

(c)

Figure 46: Sibi Stream fetching points: (a) Upstream of where the Kabunbuk meets the Sibi Stream – a fetching point for Sibi 06, (b) Next to the traffic bridge – a fetching point for Sibi 09 and possibly Sibi 02 and 06, and (c) Downstream of the bridge and en route to the next village to the west – a fetching point for Sibi 05.

5.2.3 Comparing Water Quality Test Results with Operation Run-Time

The motive behind collecting the water samples from Sibi 02, 05 and 06 again in the second sampling, was to provide the basis for a comparison of the water quality as operation run-time increases. Unfortunately, the physico-chemical parameters were not re-tested. However, with total and fecal coliform test results the basis exists to examine the bacterial removal efficiency. Presented in Tables 5 and 8, the average reduction for total coliforms in the first sampling was 74%. When looking only at the retested BSFs (Sibi 02, 05, and 06) roughly six weeks later the reduction increased to 84%. However, the average fecal coliform reduction decreased from 91% in the first sampling to 86% in the second sampling. This decrease in removal efficiency for the fecal coliforms was not expected since with a mature biolayer the BSFs should be providing additional reduction, not less. However, when examining a small pool of results such as this, the data for one filter can skew the data results for the set.

Figure 47 demonstrates improvement in the percentage removal for total coliforms for all of the filters when comparing between the first sampling (5-6 days) and second sampling (50 days). However, two of the filters show improved removal for fecal coliforms with a mature biolayer, while the third filter does not. Starting with Sibi 02 the total and fecal coliforms in the first sampling showed 52% and 75% reductions, respectively. In the second sampling the reductions had improved to 72% and 100%, respectively – showing improvement for both tests. Next Sibi 05, showed reductions in total and fecal coliforms in the first sampling of 70% and 98%, respectively. However, in the second sampling although the total coliform reduction improved to 81%, the fecal coliform reduction actually dropped to 57%. Lastly, Sibi 06 demonstrated total and fecal coliform reduction in the first sampling of 100%. In the second sampling, it again showed 100% reduction for both. Therefore, since Sibi 02 and Sibi 06 showed improved reduction for total and fecal coliforms (or stayed the same), Sibi 05 is identified as the BSF that is skewing the data to the left. If the 57% point is removed from the fecal coliform data set the average reduction would show an average reduction of 100% in the second round of sampling – an improvement from 91% in the first sampling.

The reason for the low fecal coliform reduction of 57% in Sibi 05 can be explained by two possible solutions: (1) the household had just maintained their filter, or (2) a spike event occurred with the source water. Using the "swirl-and-dump" method, the *schmutzdecke* is disturbed and removed from within the first two inches. This reduces the predation process within the biolayer, and significantly decreases reduction of fecal bacteria. As suggested by the second solution, the household may not have fetched water from the usual location and the new source water had a higher concentration of nutrients and pathogens. With the influent water changed to a more contaminated source, the microorganisms were not able to consume the increased amount of fecal bacteria, which can cause a reduction in water quality for several days until the biolayer adjusts to the new levels of substrate.

Another simple explanation is that the filtered water sample was contaminated at the time of collection. For example, a dirty spout on the filter, a finger that touches the effluent water, or sediment falling into the bottle could all cause increased concentrations of fecal coliforms within the sample, which then appears as a lower reduction when compared against the source water.

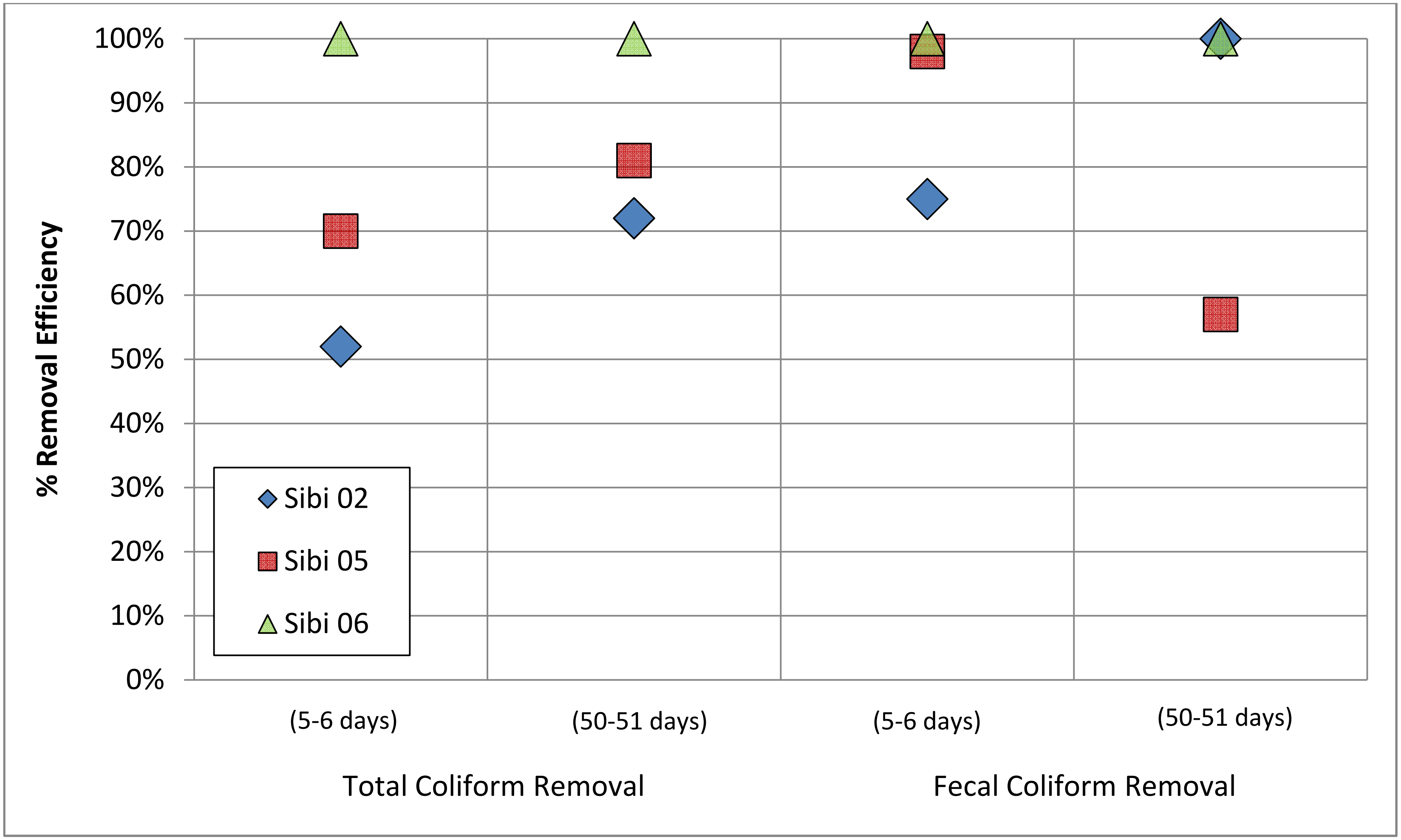

Figure 47: A comparison of total and fecal coliform removal before (5-6 days) and after biolayer maturation (50 days) for BioSand Filters Sibi 02, 05 and 06. The graph shows a trend of improved reduction with the mature biolayer – seen in all except with fecal coliform removal in Sibi 05.

Chapter Six: User Assessment

This chapter presents the results and discusses the impacts of the HydrAid™ BSF on the people who use it. Since it is a newly introduced technology for the area, it is important to analyze user acceptance issues, specifically how often the households use the filter, what their preferences are when comparing the filtered drinking water to the source water, and how much they would be willing to pay toward the cost of a new filter. Another important issue, user comprehension, is analyzed to determine to what degree the households understand how to properly use, maintain, and store the effluent from their filters. Finally, the last section of this chapter looks at quantifying the health impacts of the filter by approximating the number of diarrheal cases in each household prior to and after BSF intervention. This information is taken from the twelve survey-interviews conducted with the Sibi 01 through 12 households from October 22-25, 2007 (See Appendix D, Table 27 for the compiled survey results).

6.1 Household Comparison

General household demographics and BSF distribution can be gained from the survey-interviews conducted with the twelve households from Phase 1 and 2. Eight of the thirteen clans in the community are represented in the study, including multiple BSFs in the larger clans of Bigbem (2) and Binajub (3). All of the households engage in farming activities; It is the primary income for the majority of them. However, a carpenter, teacher, and several part-time market sellers were identified as the primary heads for five households. As the political leaders of the community the Chief, Assembly Man, and Youth Leader's households were also asked to participate in the project. Each household had an average of twelve people that used the BSF, but this varied from three to twenty-two people. Some also reported neighbors coming and filtering water with their BSF but this was not captured in the survey. Seven of the households chose for their filter to be installed in a completely protected place, such as inside a room, whereas five of the households located theirs in a partially enclosed or open area such as under a verandah. This choice was a personal one for the household but generally the households that chose to place their filters inside were concerned with protecting it, while those that chose to place their filters outside were concerned about convenience or displaying it for others to see.

Nine men and three women primarily acted as the household heads for the study. However, the surveys identified that five men and nineteen women operated the filter on a regular basis. This indicates that the role women in household water management retains its importance, even if the husband or father was the one interested in receiving and in turn paid the money for the household to have the filter. Eight of the households identified their primary water source as the Sibi Stream, while the remaining four households carried water from the Kabunbuk Stream. Looking at the households in relation to their principal fetching points (see community map, Figure 44) it appears that the main reason for fetching water where they do is related to distance, with the shortest distance winning, of course.

6.2 User Acceptance

Unless a technology is acceptable to the user it will not be seen as an appropriate solution for a specific problem. This is also the case for POU water treatment technologies in lesser developed countries like Ghana. The households in Sibi Hilltop were accustomed to a certain form of POU water treatment – a simple filtration through a cloth filter to remove Guinea Worm larvae. Though admittedly, many households had stopped this practice after the cases of Guinea Worm in the community had decreased substantially. With that aside, perhaps it was not a big step for the households to operate a different POU treatment technology like the BSF.

Nine questions addressed the issue of user acceptance in the household interviews:

1. Do you feel the BSF is strong and durable?
2. If you did not have a BSF and you could buy one in the market, would you?
3. What is the most you would be willing to pay for the HydrAid BSF: (A) GHC 0-5.00, (B) GHC 5-7.50, (C) GHC 7.50-10.00, or (D) over GHC 10.00
4. What problems are you having with your BSF?
5. How often do you use your BSF?
6. Is the BSF flow rate sufficient for your needs?
7. Do you prefer the effluent's taste to the influent?
8. Do you prefer the effluent's color to the influent?
9. Do you prefer the effluent's odor to the influent?

6.2.1 Robustness of Design

Potential concerns prior to installation were mainly the exposed portion of the PVC outlet pipe and potential leakage from the threaded PVC components at the outlet joint. As discussed in Chapter Three there were initial problems during Phase 1 regarding filter durability. The threaded outlet joint attached to the container mold ripped on one of the BSFs, and the other two filters leaked water from cracked PVC pieces that connected to the outlet. These issues were resolved by using Teflon tape on all plastic threaded pieces and avoiding over tightening to the assembling process. Consequently, there were no associated problems reported during the two months of operation and in answer to the survey question, 100% of the households felt the HydrAid™ BSF was strong and durable. Recent revisions to the HydrAid™ BSF have addressed protection of the bottom outlet joint and outer pipe through bracing.

6.2.2 Willingness to Pay

What is the technology really worth in the eyes of the user? Or more specifically, how much would they be willing to pay for it in a typical local market scenario? These questions are really trying to resolve the issues of technology value and buyer price. From the survey, 100% of the households said they would buy a BSF if they did not have one, and it was available in the market. Ghanaian currency is called the Ghana Cedi (GHC) and $1.00 USD equals approximately GHC 0.92. From the four categories of prices, ten households responded that they would pay over GHC 10.00 (>$10.87 USD), one household would pay GHC 7.50-10.00 ($8.15-10.87 USD), and one would pay GHC 5.00-7.50 ($5.44-8.15 USD) for the filter. This is shown in Figure 48 as a pie chart.

Taking into consideration that each of the households were charged only GHC 2.00 ($2.17 USD) to "buy" the HydrAid™ BSF they were currently using in the project , the survey answers demonstrate a relative high value of worth for the technology. It must be noted that since the total cost of the HydrAid™ BSF is roughly $50.00 USD, the buyer price only makes up a fraction of the actual cost of the product. For example, BSF Sibi 03's household responded in the survey that they would be willing to pay as much as GHC 15.00 ($16.30 USD) for a new filter in the market. However, even at this price (a large investment for a household in Sibi Hilltop) only about one-third of the actual cost of the technology would be covered by the user.

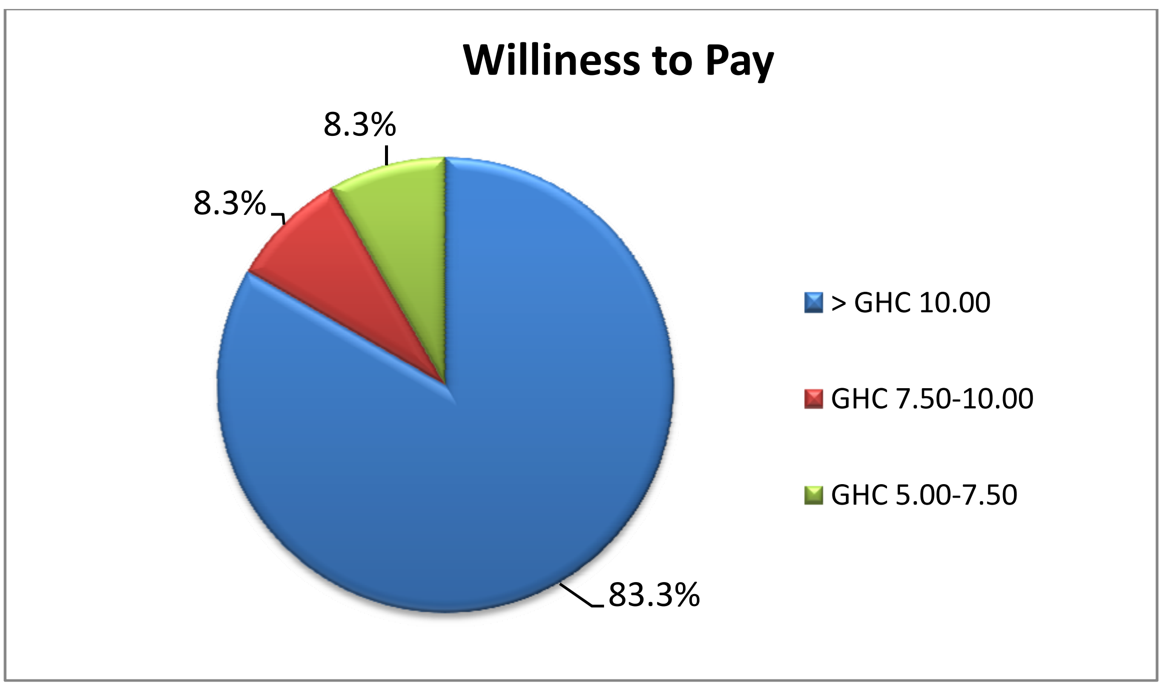

Figure 48: Phase 1 and 2 HydrAid™ BioSand Filter household survey results for the amount they would be willing to pay for the technology if they did not have a filter and it was sold in the local market.

6.2.3 Frequency of Use

All of the households reported using their filters on a regular basis. Actual frequency of use was estimated during the interview and tended to correlate directly with the size of the household. The results are presented in Figure 49 as a pie chart. This shows the percentage of households that reported using their filter once per day was 16.7%, twice per day was 33.3%, thrice per day was 16.7% and at varying times was 33.3%. On average each household uses their filter almost twice daily (40 L/d), which when calculated for the average household size of twelve would provide over three liters of drinking water per person. This appears to be a realistic average rate of consumption, and thus demonstrates user confidence in the technology.

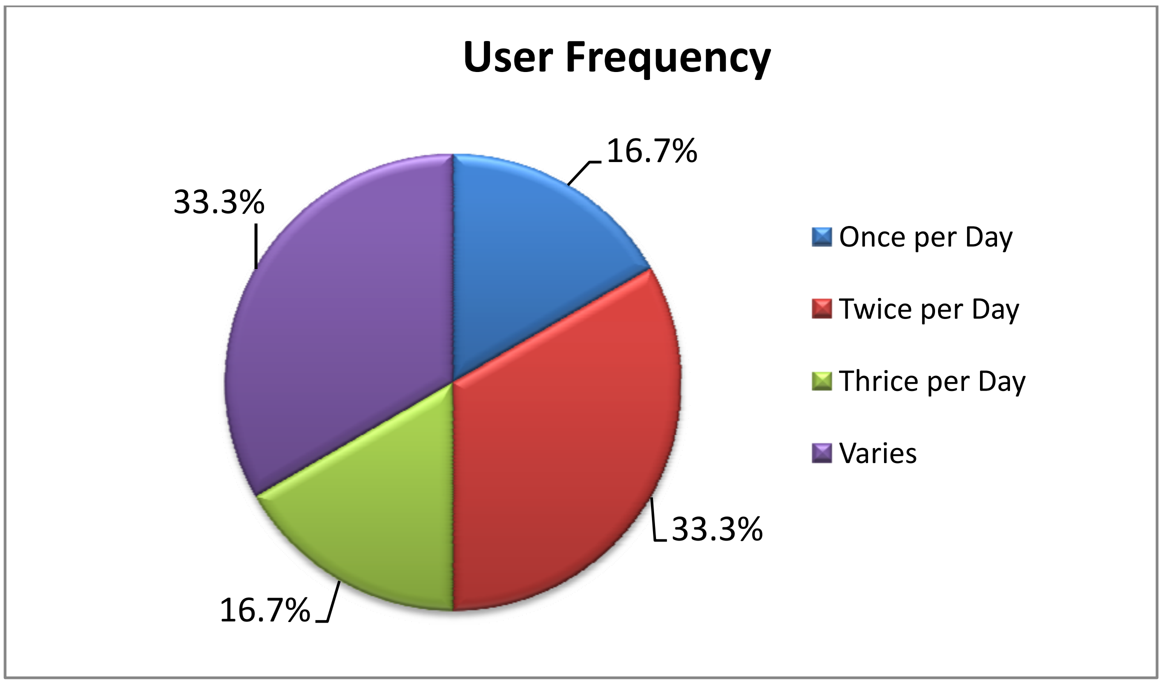

Figure 49: Phase 1 and 2 household survey results for user frequency of the HydrAid™ BioSand Filter. The 33.3% (four households) whose answers vary include frequencies of 8, 10 and 11 times/week.

6.2.4 Sufficient Flow Rate

Another survey question related to water supply asked the households whether the HydrAid™ BSF flow rate is sufficient for their needs. The results of filter performance regarding water supply and flow rates were presented, analyzed and discussed in Chapter Five. However, from the human perspective, 100% of the households replied that the flow rate was sufficient.

6.2.5 Water Preference

The widespread success of the water sachet (500-mL of potable water sold in a sealed plastic bag for approximately $0.03-0.05 USD) in Ghana has arguably done more to promote safe drinking water than many government and aid organizations combined. Although somewhat misleading, this widespread connection to sachet water (called "pure water" by vendors) means that people even in rural areas automatically assume that safe drinking water looks and tastes a certain way. This overriding association then conveys itself onto the expected characteristics of the effluent water from POU water treatment technologies. Fortunately, the BSF improved the appearance of the raw water by reducing color and turbidity in a majority of the filters tested (Figure 50). During the final weekly monitoring when the Sibi 01 through 12 households were surveyed, photographs of influent and effluent water samples were taken to reveal the contrast between the two samples. These were labeled as: Very Clear, Clear, Improved or No Apparent Change (NAC). The results are presented in Figure 51 and include 33.3% of the effluent samples being identified as Very Clear, 16.7% as Clear, 25% as Improved and 25% as NAC. This same comparison was also made – but no photographs taken – for 24 of the BSFs in Phase 3 during the last monitoring visits, roughly one week after installation. The results are presented in Figure 52 and include 41.7% of effluent water samples identified as Very Clear, 4.2% as Clear, 29.2% as Improved and 25% as NAC.

Participating households have also noted that the water tastes like pipe water (i.e. water from a borehole/deep well). Three questions in the survey-interview address this issue by asking the household to give their preferences for taste, color and odor when comparing the source and filtered water. As another indicator of user acceptance, 100% of the households said they preferred the filtered water over the raw water for all three categories.

Figure 50: Photograph of the influent (left) and effluent (right) water samples from HydrAid™ BioSand Filter Sibi 03, which shows a clear improvement in color.

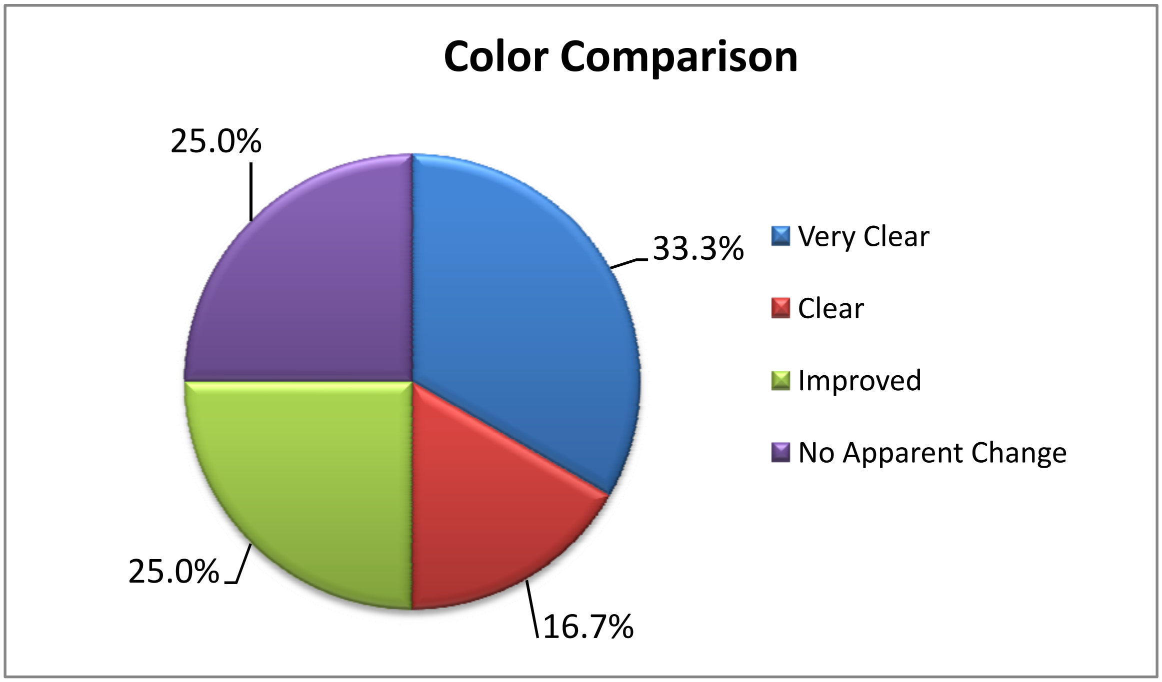

Figure 51: Comparison between the color of influent and effluent water samples for twelve HydrAid™ BioSand Filters in Phase 1 and 2

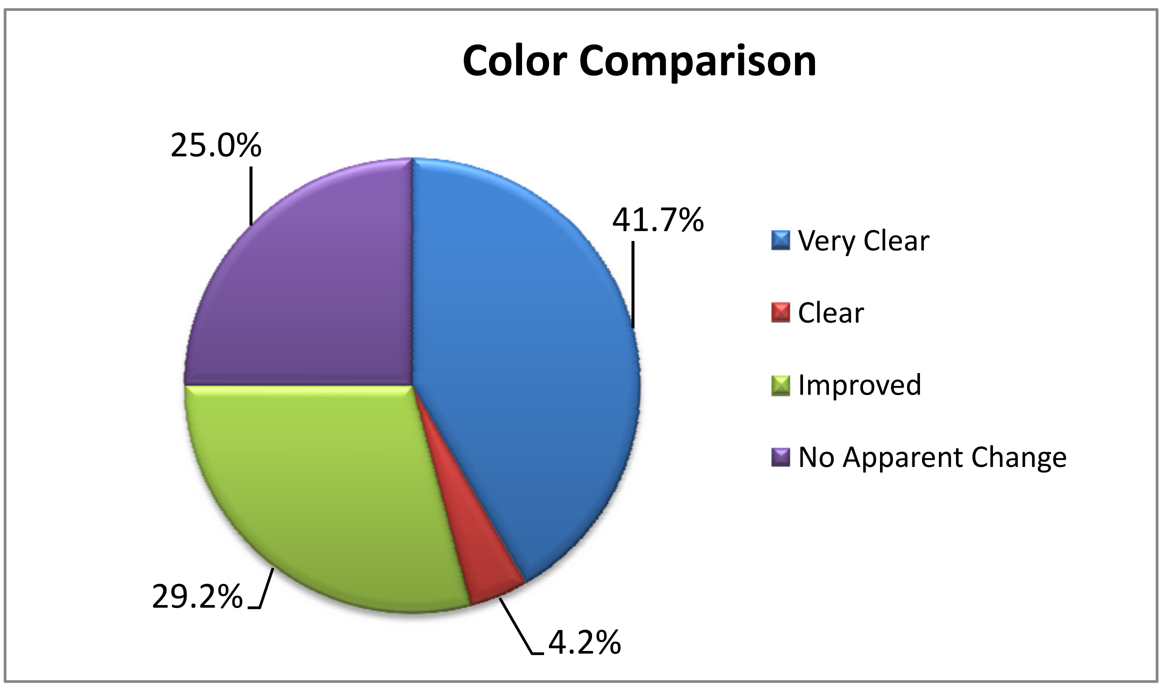

Figure 52: Comparison between color of influent and effluent water samples for twenty-four HydrAid™ BioSand Filters in Phase 3

6.3 User Comprehension

Prior to installation in Phase 1 and 2, details about how the BSF works were discussed with a member from each participating household. After the household had agreed to the project terms and the filter was installed, they received an educational health talk including a simplified version of the technology's removal processes, and maintenance and storage techniques. Since Phase 3 involved a larger number of filters, the community volunteers for the Guinea Worm Eradication Program (GWEP) were given these tasks and the job of recruiting other people from the clan area for the project. Educating the user/household on safe water issues and the benefits derived from adopting behavioral changes in hygiene and sanitation are important complimentary interventions to the actual technology itself. However, for this study health talks were only given on the subject of "safe water," which included specifics about the HydrAid™ BSF.

Thirteen questions addressed the issue of user comprehension in the household interviews:

1. How would you rate the BSF ease of operation: (A) Easy, (B) Moderate, (C) Difficult
2. What do you use the filtered water for?
3. Do you drink any other water apart from the BSF effluent?
4. What container do you use to collect the effluent? Is it open or closed?
5. How often do you clean the container?
6. Is the effluent transferred to another storage container? Is it open or closed?
7. What is the cleaning frequency of that container?
8. Have you maintained your BSF using the "swirl-and-dump" method?
9. How frequently do you maintain it?
10. How would you rate the ease of maintenance: (A) Easy, (B) Moderate, (C) Difficult
11. Does the flow rate increase after maintenance?
12. Does the taste of the effluent change after maintenance?
13. Do you clean the exterior of the filter?

The responses from these questions were used to determine how well the households understood the use and maintenance aspects of their filter. Overall, even a month after the health talks had been given, the households tended to have an acceptable understanding of operation, collection, storage and maintenance issues.

6.3.1 Operation

Being a simple technology with no moving parts or need for electricity, 100% of households stated that operating the BSF is "Easy." While performing weekly monitoring there was only one apparent case of a household misusing their filter. One of the children in the house of Sibi 07 had placed a cup of sugar inside the filter on top of the diffuser plate, and the inside of the filter was covered with ants. With regard to effluent use, 58% report using it for drinking and cooking, while 42% only use it for drinking. Five out of twelve, or 42% of household members only drink the filtered water since receiving their filter. However, 58% said they drink the BSF effluent plus other sources. These include borehole water, rainwater, and stream water while at their farms.

6.3.2 Collection & Storage

The households use a variety of containers for collecting the filtered water. These include head pans and buckets of different sizes, plastic jerry cans, metal pots, and locally made clay pots. A majority of the households, 83%, wash their container daily or prior to collection, and 17% wash their container twice per week. Only 33% of the households cover the collection containers to help prevent recontamination of the filtered water. However, 75% of those that do not cover their collection container transfer the effluent to a locally made clay pot with a lid, which utilizes evaporative cooling to refrigerate the water. Therefore, a total of 83% of the households cover their final storage container to prevent recontamination. The households with the clay pots clean them regularly: 50% daily and 50% approximately every three days.

The issue of collection and storage is an area that needs to be improved upon. Unfortunately, bleach or chorine solution is not available locally to disinfect the filtered water and reduce the risk of recontamination in the storage water. Therefore, the participating households need to understand the seriousness of cleaning and covering their collection and storage containers. Using the money that the households contributed to the project, jerry cans were purchased for each household as a container to be used specifically for collecting (and storing) filtered water. These are perhaps the most appropriate containers for collection that can be bought locally, since they are reused vegetable oil jugs. After being washed out thoroughly they can be used strictly for collection with the benefits including a small opening at the top with a tightly fitting cap that will reduce the risk of dirt entering and recontaminating the water.

6.3.3 Maintenance

Five of the twelve households, or 42% had maintained their BSF using the swirl-and-dump method since installation. The maintenance frequency varied with these households from a daily to monthly basis, however, 60% reported that they do it approximately once per week. From the outset it appears then that maintenance is being performed on a more frequent basis than necessary; especially since 58% of the BSFs were not being maintained and their flow rates were still sufficient for their household's needs. Of the households that had performed maintenance 80% reported that it was easy, and 20% that it was a moderate task. All stated that the flow rate increased afterward and 80% reported that the taste of the effluent remained the same (one household reported a slight change in taste). The exterior of the filter, including the spout is cleaned by 100% of the households on a regular basis.

The households that had not previously performed maintenance were given a demonstration after the interview so they would be encouraged to do it in the future when the flow rate drops to an unacceptable level.

6.4 Health Impacts

The goals of this study did not include performing a comprehensive health impact analysis on HydrAid™ BSFs. However, with that being said, questions were asked during the interview process to determine if the number of diarrhea cases could be estimated prior to and following the installation of the BSFs. Non-quantitative questions were also asked in order to determine if the user "felt" improvement over their previous drinking water supply.

Seven questions addressed the health impacts of the BSF in the household interviews:

1. Why did you want a BioSand Filter?
2. Do you feel the BioSand Filter improves your family's health?
3. How many people in your household are in the following age brackets: (a) 0-5 yrs, (b) 6-12 yrs, (c) 13-18 yrs, and (d) >18 yrs
4. What is the incidence of diarrhea in each age bracket since the dam dried up at the end of March?
5. What is the incidence of diarrhea in each age bracket since the installation of your BSF?
6. At this time last year what water were you drinking?
7. Did you treat the water? In what way?

6.4.1 Incidence of Diarrhea

The households were asked to estimate how many cases of diarrhea in each age category since the Sibi Dam dried up (March 27) because this is a memorable once-a-year event for the people in the community. It always marked a period of water shortage for everyone before the rainy season came. This was approximately five months prior to the installation of the BSFs, which is then compared against the two month period after the BSF intervention was in place.

Table 9 shows the estimated incidence of diarrheal cases for the twelve households – broken down by age category – before (Pre-BSF) and after (Post-BSF) the installation of the BSFs. The table shows an average of 0.75 cases of diarrhea per household over the five month period prior to BSF installation, and 0.42 cases of diarrhea per household over the two month period after BSF installation. When averaged on a monthly basis, there was an estimation of 0.15 diarrheal cases per household prior to BSF installation, and 0.21 diarrheal cases per household after installation. This equals a 40% increase in the estimated diarrheal cases after the installation of the BSF.

Not only is this unlikely because the water quality tests showed the BSFs were reducing bacterial concentrations, but the incidence of diarrheal cases appears to be far too low for an area in rural Ghana with poor sanitation and hygiene. Certain biases that could have affected the survey include the definition of a diarrheal case, an unawareness of the true number of cases in the household on the part of the family head, and memory bias. In Ghana diarrhea is referred to as "running stomach" and it is in fact quite common, especially in children, due to living conditions that lack improved drinking water, sanitation facilities, or good hygiene practices. When asking the households for a number of times a person in each age bracket had "running stomach" it is possible the number was underestimated because they were ashamed to admit to a health worker that there was sickness in the house, or perhaps (since they live with it routinely) only the number of severe cases were given. It is also possible that the household head and women interviewed did not know the actual number since it is a private matter that people do not discuss openly. People go to the bush to do their business in what is referred to as "free ranging" and even small children find a place to go behind their house and out of sight from their parents. A case of diarrhea may not even be particularly noteworthy unless it persists and is severe.

As discussed in Chapter Two, the case study from Cambodia identified 44% less incidence of diarrhea with BSF intervention by performing a comprehensive health impact study. However, the methods used for the Cambodia case study to determine the health impacts were much more extensive. They included a larger sample pool of roughly 100 BSF users, a control group of the same number, monthly visits to the households to record the number of diarrheal cases, and the same time frame (five month period) to compare the results from the two groups. Since the households in Sibi Hilltop were asked to recall diarrheal cases over a seven month period, it is reasonable to conclude that the more recent cases would be remembered over the ones that occurred a longer time ago. This would mean that more cases were estimated during the two month period after installation as an affect of memory-bias than the five month period after, which is not based on actual incidence. Also seasonal factors could affect the incidence rate of diarrhea and better results could be obtained if separate user and non-user groups were tested during the same period as seen in the Cambodia study. Therefore, there is not much confidence in the results gained from the survey questions asked of the twelve households in Sibi Hilltop.

6.4.2 User-Felt Improvement

Another reason that the results from the estimated diarrheal incidence comparison cannot be used as an indicator of actual health impact was because the households themselves gave positive answers in the survey regarding the benefits gained from using the BSF. All of the households generally stated that their reason for wanting a BSF was "to prevent sickness from drinking contaminated water," especially Guinea Worm. At the same time a year ago, 100% of the households that are now using BSFs were drinking stream water that they treated by filtering through a cloth filter (free from the Carter Center) that was designed specifically to remove copepods as a host for Guinea worm larvae. Currently, the same households are drinking water that is not only free of Guinea worm but that also has a significant reduction in pathogens like fecal bacteria, viruses and other parasites. Perhaps a better reflection, and another indicator of user acceptance, is that 100% of households stated that they felt the BSF improves their family's health.

Table 9: Estimated incidence of diarrheal cases approximately five months prior and two months after installation of BioSand Filters Sibi 01-12

Household #'s:	Sibi 01	Sibi 02	Sibi 03	Sibi 04	Sibi 05	Sibi 06	Sibi 07	Sibi 08	Sibi 09	Sibi 10	Sibi 11	Sibi 12	Average:
Age 0-5 yrs	2	0	1	2	3	2	3	2	5	4	4	2	2.5
Age 6-12 yrs	3	1	0	1	5	4	2	1	1	5	4	0	2.25
Age 13-18 yrs	2	1	1	1	7	1	2	2	2	6	0	0	2.08
Age +18 yrs	5	1	5	3	6	6	7	3	9	7	8	2	5.17
Total:	***12***	***3***	***7***	***7***	***21***	***13***	***14***	***8***	***17***	***22***	***16***	***4***	***12***
Pre-BSF Cases 0-5 yrs	0	0	0	0	0	1	0	0	0	2	0	0	0.25
Pre-BSF Cases 6-12 yrs	0	0	0	0	0	2	0	0	0	0	0	0	0.17
Pre-BSF Cases 13-18 yrs	0	0	0	0	0	0	0	0	0	0	0	0	0
Pre-BSF Cases +18 yrs	0	0	0	0	2	0	0	0	0	2	0	0	0.33
Total:	***0***	***0***	***0***	***0***	***2***	***3***	***0***	***0***	***0***	***4***	***0***	***0***	***0.75***
Post-BSF Cases 0-5 yrs	2	0	0	0	0	0	1	0	0	1	0	0	0.33
Post-BSF Cases 6-12 yrs	0	0	0	0	0	0	0	0	0	0	0	0	0
Post-BSF Cases 13-18 yrs	0	0	0	0	0	0	0	0	0	0	0	0	0
Post-BSF Cases +18 yrs	0	0	0	0	0	0	0	0	0	1	0	0	0.08
Total:	***2***	***0***	***0***	***0***	***0***	***0***	***1***	***0***	***0***	***2***	***0***	***0***	***0.42***

Chapter Seven: BioSand Filter Comparison

The last research objective was to provide a comparison of the advantages and disadvantages of the two types of Intermittent BioSand Filters: traditional concrete and the plastic HydrAid™ model. Although only the HydrAid™ BSF was studied and implemented in this project, there is plenty of literature regarding the traditional concrete model, which has been developed, modified and successfully used as an effective POU treatment method for over ten years (biosandfilter.org 2004; Duke, et al 2006; Lang, et al 2008). Different plastic models, such as Davnor's Canada Bangladesh Filter and now International Aid's HydrAid™ BioSand Filter have tried to improve upon certain components of the project life-cycle. This chapter will show that some improvements can be gained with the plastic model, however not without compromising other significant parameters of the filter's implementation process. By comparing specific parameters for BSF technology, a better informed choice can be made by implementing agencies and organizations. Table 10 at the end of this chapter provides a summary of these parameters and attempts to give guidance in this manner.

7.1 Cost

Cost plays an important role in making a decision for or against certain technologies. This is true when the user is paying full price for the product of their choice. However, it remains no less important a decision for an NGO or other agency that wishes to provide the product to the user at a subsidized price. The point is that someone has to pick up the tab somewhere down the line. International Aid makes the pitch on their website (www.hydraid.org): "If someone told you $32 was all it would take to save a life, what would you do?" Instead it should be noted that the real cost is much higher than this; they are simply asking for a donation to cover part of the total cost. Transportation within the manufacturing country (U.S.A.), from the U.S. to destination countries, and within the receiving country, filter media production and installation all add to the final product costs. This puts the HydrAid™ BSF more realistically around $50.00 USD, and only includes the most basic line items that do not account for implementing agency support costs, such as the training and purchasing of tools for the installation teams.

On the other hand, the cost associated with the traditional concrete BioSand Filter is a bit more difficult to determine. Different projects by myriad organizations in various countries have resulted in a range of prices from $10.75 – $39.50 USD (CAWST 2006). Since these projects tend to involve more grassroots efforts – artisan training, community education, and resources – there is a larger overhead cost by the implementing agency. However, the material costs per filter (cement, aggregate, sand, pipe, wood, etc.) are on average less expensive than that of the HydrAid™ or similar plastic models. A recent project in the Volta Region of Ghana by the NGO Afram Plains Development Organization (APDO) encourages artisans they have trained to sell their concrete BSFs for GHC 20.00, or roughly $21.74 USD. Therefore, the traditional concrete BSF appears to have an advantage over the HydrAid™ BSF when looking at technology costs.

7.2 Durability

Both of the BSF designs are considered strong and robust. The traditional concrete model was designed specifically with this in mind so that it would have a long lifetime of use, and very little upkeep or maintenance on the physical structure. The copper tubing used for the outlet pipe is housed inside of the concrete container, and the only items that may have to be replaced over time are the cover and diffuser plate (depending on the materials; e.g. wood used for the diffuser plate will rot). The HydrAid™ BSF container is made from injection molded, food-grade plastic, which is also quite strong and durable. However, the outlet pipe is assembled with different PVC pipes and threaded components, and is housed on the exterior of the filter. Even with normal wear and tear these filter should also have a long lifetime of use. However, there is a greater chance that the outlet pipe will be damaged in comparison to the concrete filter. Another issue that may be avoided with proper household education is that if the HydrAid™ BSF is knocked or pounded on the exterior the sand inside will shift and compact, causing a decrease in the flow rate. Recall from Chapter 3 that this was a problem during the beginning of Phase 1 for BSF Sibi 02. "Swirl-and-dump" maintenance will not overcome a low flow rate problem caused by this; instead, the filter media will have to be removed and installed again. This should not be a problem with the concrete BSF due to the thickness of the container walls and strength of the material itself. Due to this and the placement of the outlet pipe internally, the concrete BSF would have an advantage in this category.

During the survey-interviews conducted with the twelve households from Phase 1 and 2 in Sibi Hilltop, questions were asked regarding the strength and durability of the HydrAid™ model. Although the households had never seen a concrete BSF, they are familiar with concrete as a building material. After describing the concrete BSF, they were asked which they thought would be stronger. The results showed that 33.3% thought the concrete BSF would be stronger, 25% thought the HydrAid™ would be stronger, and 41.7% were unsure.

7.3 Performance

Since they are both intermittent biological sand filters, there is no difference in the treatment processes used by the two filters. As long as the same number of layers, filter media, layer depth, and installation processes are used, similar results for flow rates and water quality will be seen for the concrete and HydrAid™ models.

In the case of the HydrAid™ BSF, where an agency may want to install thousands of filters within a country, a manufacturer could be contracted to produce the filter media. By determining the characteristics of the filter media by running pilot BSFs with the media, the exact depths of the layers can be calculated to yield a suitable flow rate. Better quality control will result when installing four layers of filter media within the filters, and the top layer can be adjusted plus or minus one centimeter to decrease or increase the flow rate, respectively. However, with smaller concrete BSF projects the simpler three-layer system is used and the flow rate is controlled by washing. Both provide similar results for water quality and flow rates.

7.4 Production

One of the disadvantages of the concrete BSF is that it takes roughly two hours for the construction process, and that is once an artisan is proficient. Therefore, in a given day only four or five filters can be constructed. However, with the HydrAid™ BSF the injection molded container and PVC components can be constructed much quicker – perhaps on the order of hundreds or thousands each day. After shipping these to the installation site, the assembly time in the field is about ten minutes per filter. This improvement in production efficiency creates a definite advantage for the HydrAid™ BSF, and increases the overall availability of filters for distribution.

7.5 Distribution

By far the most notable advantage of the HydrAid™ BSF is discovered when looking at the issue of mass distribution of the technology. As discussed in Chapter Two, one of the problems behind scaling-up efforts to provide greater BSF coverage was that due to the weight and size of the filter it could not be easily transported (Figure 53). An empty concrete filter can weigh over 300 lbs empty, which requires about four people to lift and move to its installation location. Moreover, there must be a trained artisan constructing the filters within the community, or there will be a barrier to mass distribution of the technology to other geographic areas. The HydrAid™ BSF overcomes this problem by using a lightweight plastic container of only seven lbs that stacks one inside another, making it easier to distribute a large number of filters at once even in the most remote areas. So not only is there a larger number of available filters due to the production advantage of the HydrAid™ model but there is also an impetus to mass distribute the technology. Only when appropriate and user-acceptable technology can be mass produced and distributed to those in remote areas, then the number of people without access to safe drinking water supplies will be halved according to the U.N. Millennium Development Goals.

Figure 53: Weighing over 300 lbs empty the concrete BioSand Filter presents challenges with mass distribution (CAWST 2004)

7.6 Installation

The installation processes are the same for both filters, and depending on the number of filter layers, they would take approximately the same amount of time. In a larger implementation program, if the filter media was processed by contract and arrived clean at the site this would decrease the installation time substantially. For a smaller concrete BSF project using locally processed filter media, washing would be needed, which adds a great deal of time to the installation process. For this HydrAid™ BSF project, the filter media was produced by a contractor near Accra but was very dirty and needed to be washed before installation. Therefore, neither the HydrAid™ nor the concrete BSF have an advantage over the other when it comes to installation.

7.7 User Preference

Since the filters perform the same in terms of water quality and quantity, user preference is more or less based on the filter's aesthetics. Unless the concrete BSF is painted (which is common in Haiti) it remains a dull gray color and rough to the touch – quite unlike the sleek, blue HydrAid™ model with white stenciling of the International Aid logo that also states that it is from the USA (Chapter 3, Figure 21). Although the households were told in the interviews that the concrete and HydrAid™ BSFs perform the same, when asked if they would be willing to pay more for a concrete filter, 41.7% responded "Yes" while 58.3% responded "No." Albeit, those who answered "No" could have meant that they would pay the same price as the HydrAid™ but not more. However, when asked how much they would then be willing to pay for the concrete BSF 58.3% said over GHC 10.00 ($10.87 USD), 25% said between GHC 5.00-7.50 ($5.44-8.15 USD), 8.3% said between GHC 0.00-5.00, and 8.3% said between GHC 7.50-10.00 ($8.15-10.87 USD). When using the midpoints of these ranges, the average amount is estimated at GHC 8.32 ($9.04 USD). This is lower in comparison with the responses by the households interviewed for the HydrAid™ BSF (average is GHC 9.58 or $10.71 USD) as discussed in Chapter Six (Figure 54).

It is interesting to note that more households thought the concrete BSF would be the stronger and more durable filter, yet the majority was not willing to pay more for the concrete BSF than what they had paid for the HydrAid™ BSF. This could be due to user-bias since the households had specifically been using the HydrAid™ for almost two months at this point, or an influence of the interviewer being the one who introduced that model to them. However, it is also possible that the users were that much more attracted to the aesthetics of the HydrAid™ BSF. Whatever reason, they tended to prefer the HydrAid™ BSF, which gains the advantage in this category.

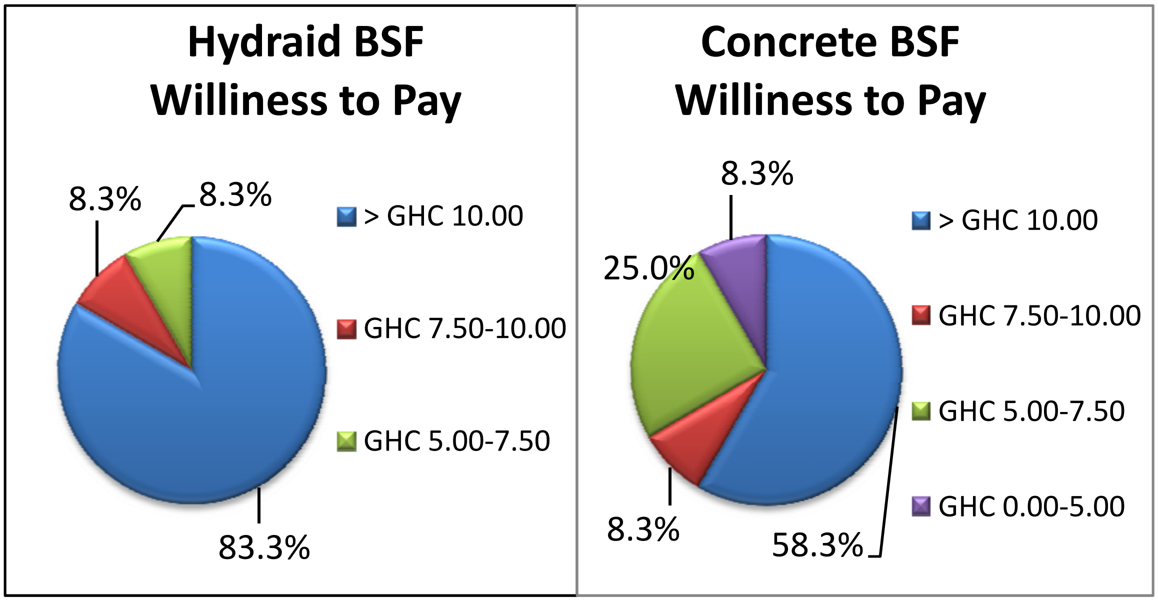

Figure 54: A comparison of the two pie charts indicates that the majority of households in Sibi Hilltop would be willing to pay more for a HydrAid™ than concrete BSF.

7.8 Project Sustainability

The biggest advantage for the concrete BSF relates to project sustainability. This is a component built into many projects that CAWST has collaborated on, and they have plenty of information regarding it. The basic idea is that given the instruction and resources, people can be trained as artisans in their community to construct the concrete BSF as a micro-enterprise. Usually the coordinating agency will give (or loan) the artisans the tools, steel mold, and either the initial capital or materials to get started. (If loaned the artisan pays either all or a subsidized amount back to the implementing agency over time.) Since all of the construction materials like cement, sand, stones, wood, and piping are locally available to a certain extent, they construct the filters as needed and sell them to community members who want to buy one for their household. The price includes a small profit for the artisan, and he/she will also install the filter and provide health education to the buyer's household. If there are any problems with the filter in the future, the artisan is there to help since they are the field technician/resident expert for the BSFs in their community. If the filter is acceptable to people in the community diffusion of the technology will occur over time and even poorer households will save their money so they can achieve the status quo when the technology prevalence has reached a tipping point.

Unlike other projects implemented by NGOs or aid agencies that arrive on the scene of a problem, intervene with a solution, tally the results, and leave, this type of artisan-trained, entrepreneurial solution allows the problem to be addressed by the needs of the market and community. Furthermore, unless the artisan moves away, there will always be a trained technician to assist with problems that crop up after the project is technically "over." Until the HydrAid™ BSF is able to be produced in Ghana, any sort of intervention would not be selfsufficient in this sort of way. For example, say a NGO implemented a project where only half the households in a community wanted HydrAid™ BSFs and several months or years after the project was over the rest of the households realized the benefits of POU water treatment and wanted one for their own household. What would happen? Those households would either be forced to wait until the NGO returned to implement another round of implementation, or they would not be so lucky. The difference in the micro-enterprise solution is that the artisan in that situation could simply construct as many that are needed, and at the same time make a little bit of money that does its part in stimulating the local economy as well.

7.9 Summary

For the comparative analysis eight different parameters, as associated attributes of the filter itself or a component of the implementation process, were analyzed for the HydrAid™ and concrete BioSand Filter models. As seen in Table 10, the model with the advantage in each category received a point (✓) unless there was no distinguishable difference between the two, in which case both received a point (✓). Keeping in mind that the HydrAid™ was developed as an upgrade to the concrete BSF, it earned a total of five points in the categories of Performance, Production, Distribution, Installation, and User Preference. However, the concrete model also received five points in the parameters of Cost, Durability, Performance, Installation and Project Sustainability. Since both filters are governed by the same processes, the flow rate and water quality should also be similar, therefore warranting a tie for Performance. This is also the case for Installation because once the filters have been transported to the households the same installation procedures are used, granted that the same number of filter media layers are used in each. (This may not always be the case since the concrete filter is often implemented in small numbers and would tend to use a three-layer filter media system, while the HydrAid™ being better suited to larger projects would use the four layers of filter media for quality control issues.)

The main strengths of the HydrAid™ BioSand Filter include its ability to be efficiently produced and mass distributed to remote locations, where difficult transportation issues are typical. Although the concrete model may be more durable *in situ*, the HydrAid™ BSF's plastic base is more elastic, not to mention lightweight, and would be far less likely to crack or break while bumping down a rutted dirt road on the way to a community in need. However, the gains made in these particular areas come at the expense of others. The current cost of the HydrAid™ is higher than the range of costs cited by CAWST for the concrete model – partly due to the transportation costs that are associated with the HydrAid™ being manufactured in Spring Lake, MI. Also the ability for a project to be self-sustaining after the implementing agency has moved on to the next community is a major advantage for the concrete model. These are critical issues that, if able to be resolved, could lead towards a major advantage for intermittent BSFs over other POU water treatment interventions being implemented in lesser developed countries around the globe.

However, with all things considered in the present, the results from this study suggest that the two BSF models are roughly equal in terms of effective POU water treatment options. Assigning a greater value to any of the parameters could tip the balance either way. Since each community has different needs and every implement agency different resources, this will ultimately be decided by project-specific information. Furthermore, it is difficult to say that one has greater worth than other; perhaps they simply have different strengths and weaknesses and should be utilized as such. In fact having more options available for the same type of technology could be seen as an overall advantage for intermittent BioSand Filter technology since it has a greater capacity to be catered toward the goals of the individual project.

Table 10: Comparison summary of the traditional concrete and HydrAid™ BioSand Filter

Parameter:		HydrAid™ BioSand Filter		Concrete BioSand Filter
Cost		> $50.00 USD	✓	$10.75 - $39.50 USD
Durability (in situ)		Food-grade plastic shell with external PVC outlet pipe	✓	Concrete shell with internal pipe
Performance	✓	Flow rate and water quality controlled by same processes	✓	Flow rate and water quality controlled by same processes
Production	✓	Injection molded plastic shell and PVC piece quickly produced in a factory		Laborious and time-consuming to produce one BSF at a time
Distribution	✓	Lightweight (7lbs empty) and easy to stack inside each other		Very heavy - approximately 300 lbs empty; difficult to transport
Installation	✓	Same installation process	✓	Same installation process
User Preference	✓	Plastic model more aesthetically appealing		Concrete common; Needs to be painted to look more appealing
Project Sustainability		Produced in U.S.A and shipped overseas, replacement pieces not available	✓	Locally available materials; filters produced locally by artisans; Artisans can provide assistance to malfunctioning filters
Total:	5	✓✓✓✓✓	5	✓✓✓✓✓

Chapter Eight: Conclusions

The four main objectives identified for this study were to:

1. Determine installation guidelines for the HydrAid™ BioSand Water Filter
2. Study the performance of the HydrAid™ BioSand Water Filter in its ability to provide a household with a significantly improved quality and sufficient supply of water for all cooking and drinking needs
3. Analyze user acceptability and comprehension of HydrAid™ BioSand Water Filter technology
4. Compare the advantages and disadvantages associated with the HydrAid™ BioSand Water Filter to those of the traditional concrete BioSand Filter

8.1 Major Findings

Based upon the results from the four main research objectives, the HydrAid™ BioSand Water Filter has been found to be a successful POU water treatment technology for Sibi Hilltop, Ghana, and proves an attractive option for similar communities in West Africa.

Through the installation of fifty-three HydrAid™ Bio Sand Filters (BSFs) in three separate phases installation guidelines were developed. It was determined that with the right resources a significantly large number of filters can be installed over a short period of time. The twelve filters installed in Phase 1 and 2 (Sibi 01 through 12) were monitored over roughly a two month period. Through analyzing flow rate measurements, the HydrAid™ BSF demonstrated the ability to filter a sufficient supply of water to meet the needs of the households using them. The average installation flow rate was 0.96 L/min, which decreased over the two month period to around 0.61 L/min. Utilizing the data from the twelve BSFs a flow rate modeling equation was developed to provide guidance into the behavior of the filters over a sixty-day period. Shown by graphing the modeling equation, the resulting flow spent 60% or thirty-six days within the range of rates suggested by the Centre for Affordable Water and Sanitation Technology (CAWST) and International Aid (IA), 0.6 and 0.8 L/min, respectively. These findings also suggest that maintenance should be performed approximately every thirty-six days to restore the BSF flow to this range of rates. From the collection of water samples and subsequent analysis by a qualified laboratory, the average reduction efficiency for three BSFs after five to six days of operation was 74% for total coliforms and 91% for fecal coliforms. After fifty to fifty-one days of operation the reduction efficiency was 84% for total coliforms and 86% for fecal coliforms. Two of the BSFs in the second round showed a reduction of 100% for both total and fecal coliforms. Overall, the reduction efficiency is similar to the results from previous concrete BSF studies performed in various places around the world and indicates a significant improvement in water quality as compared to the raw water sources.

The survey-interviews conducted with the twelve households in October 2007 indicate a high user acceptance and a moderate-to-high user comprehension of the HydrAid™ BSF. All households responded that the filter is strong and durable, a technology they would buy in the market if it was available, provides a sufficient flow rate, provides better tasting, looking and smelling water than the source, and that the filter improves the health of their family. Eighty-three percent of the households stated that they would pay over GHC 10.00 ($10.87 USD) for a HydrAid™ BSF, which shows that the technology is actually valued by the users in rural Ghana. To develop user comprehension of the filter, education about safe water and the operation and maintenance of the filter was given in August 2007. Approximately two months later, 100% of the households reported that the filter is easy to use, they use it frequently, and that they wash their effluent collection container on a regular basis. A total of 83% of households reported covering their POU containers to prevent recontamination of the filtered water.

A comparative study between the HydrAid™ and traditional concrete BSF showed mixed results. The major improvements made by the HydrAid™ BSF as a technology are in its ability to produce and distribute a significantly larger number of filters in a much more efficient manner than the concrete model. However, those advantages also present drawbacks in cost, durability and project sustainability, which remain distinct advantages for the concrete BSF. There may also be a slight user preference for the HydrAid™ BSF based on aesthetics but both filters perform the same with regard to water quantity and quality and installation methods. Therefore, based on the comparison of the eight different parameters in the study both the HydrAid™ and concrete BSF come out even, each having an advantage in three categories and being equal in two categories. The decision to choose one model over the other as a POU treatment technology will come from the needs of the community and resources of the implementing agency. Perhaps one is not better than the other, simply a variation that serves the same purpose of providing households with an improved supply of drinking water.

8.2 Recommendations

Along with these conclusions, the experience gained from this study provides the basis for many recommendations for future work and research with the HydrAid™ BioSand Filter.

Scale-Up Project to Community Level

The first recommendation is to essentially allow all community members equal opportunity to purchase a HydrAid™ BSF (at a reduced cost). This would simulate a community-wide project and allow all households the choice to participate. In the Sibi Hilltop study only a limited number of filters were available and many of the benefitting households were selected by the Peace Corps Volunteer (PCV), simply because the household member/head was a volunteer with the Guinea Worm Eradication Program (GWEP). Due to their work as community health volunteers, many of them are better educated and informed about health issues than other community members. This could have an effect on survey results aimed at measuring acceptability and understanding on the part of the user by making them more subjective. A community-wide project would increase objectivity and help anyone willing to help themselves.

Installation Process

Because no clear instruction was given to the installation teams regarding maximum height of water above the various filter layers during the installation process, many of the filters could have experienced stratification of the third layer of well-sorted sand if the water height was above eight inches. This results in lower flow rates in those particular filters and a greater range of flow rates within the group results. This can be avoided in the future by following Manz's guidelines for the four layer system, which recommend approximately four inches (and no more than eight inches) of standing water above each filter media layer prior to the installation of the next layer. This will provide a normal distribution of particles within the third filter media layer without stratification and help with quality control in the installation process.

Household Education

Utilizing more interactive health education and visual aids would help increase user comprehension. CAWST has a variety of colorful learning aids that could be used. By training either the installation teams or a group of community members to give the presentations about safe water practices along with use and maintenance of the HydrAid™ BSF, the software aspect of the technology would be given in a more efficient and comprehensive manner. This would hopefully improve upon safe water storage methods, which was an issue for the households in Sibi Hilltop. To compliment this, a component on hygiene and sanitation education should also be taught. Supplemental health education would promote overall public health and help decrease the incidence of diarrheal cases, especially in vulnerable groups like children under five years of age and the elderly.

Weekly Monitoring

In order to better determine the performance of the HydrAid™ BSF with regard to flow rate over time, more comprehensive data is needed. This is especially true for the first week after installation when it is recommended that the flow rate measurements be collected from each filter on a daily basis so that the initial drop in flow (from Day 1 to Day 2) can be measured. It is also suggested that weekly monitoring be performed for every BSF in the group on the same day of the week to avoid interpolation between collected data points. Ultimately, this is difficult because it depends on the schedule of each household and whether there is water available in the house at the time of visit. However, with better organization, more field technicians, and a regular schedule (e.g. every market day) it would be possible to improve filter monitoring.

Water Quality Analyses

The number of HydrAid™ BSFs sampled for this study was rather small and more conclusive water quality results could be obtained by expanding the pool of filters. Also, both the number of samples per water source (at least three), and the number of water sources sampled should be expanded to include samples from the POU collection container. Another recommendation would be to increase the number of rounds of testing to correspond with key days in the operation run-time such as installation (Day 1), ripened biolayer (roughly Day 21), after a maintenance event, etc. Each round of water quality analysis should test the same indicators and parameters as the other rounds, such as fecal/total coliforms and specific physico-chemical characteristics. This is so comparisons can be made between each round and trends can be observed between the key dates/events.

Health Impact Study

The final recommendation concerns the facilitation of a health impact study. By defining diarrhea as two or more loose stools a day, weekly data should be gathered from a group of households using HydrAid™ BSFs and a control group of non-users over a specific period of time. In this way there is no seasonal variability affecting the data and no problems with the households forgetting cases of diarrhea that occurred several weeks or months earlier.

8.3 Future Work

By expanding upon the results and recommendations in this report, more research ideas should be considered for implementation of future projects. This will not only add to the base of BioSand Filter knowledge but more importantly will provide communities and implementing agencies with information to make better decisions about the most appropriate POU water treatment technologies for their situation.

Utilizing the recommendations above, a field study that installs and monitors HydrAid™ and concrete BSFs within the same community would provide results to directly compare the two types of filters in terms of performance and user preference. Five groups in all could be studied: (1) HydrAid™ BSF-users taught to maintain their filters, (2) HydrAid™ BSF-users not taught to maintain their filters, (3) concrete BSF-users taught to maintain their filters, (4) concrete BSF-users not taught to maintain their filters, and (5) a non-user control group. The outcomes for the first four groups would provide a comparison of flow rate changes over time, removal efficiency over time, and user acceptability. The results from all five groups concerning measured diarrheal cases (through weekly household visits) could also be compared to determine the relative health impact.

On the same note of comparing the HydrAid™ and concrete BSFs, a framework for user acceptability could be developed and applied to the study, which would also be useful for comparing all POU water treatment technologies. This should include an evaluation of the sustainability of the technology. Specifically in this case, the evaluation could show the life-cycle impacts from producing, using and disposing of concrete BSFs compared with that of the plastic model HydrAid™ BSF.

Opportunities currently exist for Ghana PCVs within the Health, Water and Sanitation and Small Enterprise Development sectors to implement concrete BSF projects. The Afram Plains Development Organization (APDO) located in the Volta Region has implemented a program – using CAWST information – to train artisans and equip them with the resources to produce concrete BSFs as microenterprises in their communities. By collaborating with APDO and other NGOs, PCVs could help facilitate similar workshops, training and projects within communities whose main source of drinking water comes from contaminated surface water. Information and training about POU treatment methods and specifically the concrete BSF could also be incorporated in the Health, Water and Sanitation Pre-Service Training to teach future PCVs about the benefits and limitations of the technology.

Much research could be performed on the affects of improving human capital in a community by training individuals to be technology artisans as is the case for many concrete BSF projects that encourage microenterprises. The issue is then whether an infusion of innovation into a community spurs additional innovation and increased development within a society. A number of years ago the Nkwanta District Water and Sanitation Team in the Volta Region of Ghana trained many artisans to construct specific types of low cost latrines and equipped them with the tools and resources to start small businesses out of the work. However, in Sibi Hilltop and the Damanko Sub-District, trained community members later moved to larger towns in different areas that had a higher market demand for their skills (a.k.a. brain drain). Would the same pattern hold true for BioSand Filter artisans?

Other fascinating work includes understanding existing social capital and integrating that into the deployment strategy for introducing new technologies. Unknowingly, this was done by utilizing the network of community health volunteers that were part of the Guinea Worm Eradication Program (GWEP) to participate in the HydrAid™ BioSand Filter project. The network of volunteers could be viewed as readily-available early adaptors in the diffusion of the technology throughout the community.

It will be interesting to see how International Aid (IA) will proceed with the implementation of the HydrAid™ BSF in Ghana in the future. The goal of installing several thousand filters in 2007-08 was aimed at testing the technology in the field and providing a POU water treatment intervention for the Carter Center to use in the GWEP, or in a capacity they saw fit. IA collaborated with Dr. Mark Sobsey from UNC-Chapel Hill, and his team of graduate students is currently performing a health impact study on HydrAid™ BSF intervention in the Northern Region of Ghana. If IA finds a way to manufacture the HydrAid™ model within Ghana the cost of the filter would dramatically decrease and open the door to partnerships with other agencies to implement BSF programs. At that point a social marketing study could be conducted to determine community members' willingness to buy the technology wholesale or at a subsidized rate, and the framework for user acceptability consulted. Based on the results, a distribution and sales program could then be developed and implemented to reach target areas in the country, where communities continue to suffer without access to an improved source of water.

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Appendix A: Profiles of Sibi 01-12 Households

Sibi 01 – Yao Donkor, Binajub Clan

Figure 55: Sibi Hilltop community map (middle) identifying the household location (bottom) where the homeowner (top) and his family use HydrAid™ BioSand Filter Sibi 01

Survey Results

1. Name: Yao Donkor
2. BSF #: Sibi 01
3. Clan: Binajub
4. Age: 54
5. Profession: Farmer
6. Total # of people in the household: 17
7. Are all using the BSF's water? No, only 12
8. Location of BSF: under the verandah
9. Rainwater Harvesting potential: 2/3 of roofing is metal, 8-ft of gutters plus a corner section
10. Ease of operation: (A) Easy
11. Who operates the BSF? Yao and his wife
12. What source water is used in the BSF? Sibi Stream at the bridge side
13. Do you feel the BSF is strong and durable? Yes
14. Which do you think would be a stronger BSF material? (A) Plastic, (B) Concrete: I don't know; haven't seen the concrete model
15. If you didn't have a BSF and you could buy one in the market, would you? Yes
16. What is the most you would be willing to pay for the IA BSF: (D) over ¢100,000
17. Would you be willing to pay more for a concrete model? No
18. How much? (According to the above scale) (B) ¢50-75,000
19. What problems are you having with the BSF? None
20. BSF use frequency: Twice per day
21. Volume per use: To the top, ~30 L
22. What do you use the filtered water for? Drinking and cooking
23. Do you drink any other water apart from the BSF effluent? No
24. Is the BSF flow rate sufficient for your needs? Yes
25. Do you prefer the effluent's taste to the influent? Yes
26. Do you prefer the effluent's color to the influent? Yes
27. Do you prefer the effluent's odor to the influent? Yes
28. Container used to collect effluent: different head pans and buckets
29. Cleaning frequency of container: every time before use
30. Closed/Open container: Open
31. Is the effluent transferred to another storage vessel? Yes, a clay pot
32. Cleaning frequency of that vessel? Daily
33. Why did you want a BSF? To prevent sickness from water
34. Have you maintained your BSF using the "swirl and dump" method? Yes
35. Maintenance frequency: Monthly
36. Ease of cleaning: (A) Easy
37. Does the flow rate increase after maintenance? Yes
38. Does the taste change after maintenance (compared to the normal effluent)? No
39. Do you clean the exterior of the BSF? Yes
40. # of household members in age brackets: (a.) 0-5 yrs = 2, (b.) 6-12 yrs = 3, (c.) 13-18 yrs = 2, (d.) above 18 yrs = 5
41. Incidence of diarrhea in each age bracket since the dam dried up (end of March) and the BSF was installed: None
42. Diarrhea incidence since BSF installation in each age bracket: (a.) 2, (b-d.) 0
43. At this time last year what water were you drinking? Stream water
44. Did you treat the water? How? Yes, used a guinea worm cloth filter
45. Do you think the BSF improves your family's health? Yes

Table 11: HydrAid™ BSF Sibi 01 flow rate raw data

Date:	Day:	Time:	Q (L/min):
14-Jul	1	8:27	0.22
14-Jul	1	9:47	0.23
14-Jul	1	13:28	0.21
14-Jul	1	17:10	0.14
*Maintenance-------------------------------			
15-Jul	2	9:17	0.5
22-Jul	9	7:03	0.32
22-Jul	9	8:00	0.33
22-Jul	9	9:02	0.32
22-Jul	9	9:58	0.3
22-Jul	9	11:08	0.27
22-Jul	9	12:01	0.25
22-Jul	9	13:02	0.23
22-Jul	9	14:00	0.21
22-Jul	9	15:05	0.2
*Maintenance---------------------------------			
22-Jul	9	16:05	0.48
22-Jul	9	17:04	0.43
22-Jul	9	18:04	0.38
*Removed & Washed Filter Media 4x			
13-Aug	31	13:20	1.71
13-Aug	31	13:39	1.71
13-Aug	31	13:51	1.56
13-Aug	31	13:52	1.46
13-Aug	31	17:55	0.29
13-Aug	31	17:58	0.32
*Maintenance---------------------------------			
13-Aug	31	18:11	1.5
13-Aug	31	18:12	1.36
20-Aug	38	17:54	1.46
20-Aug	38	17:56	1.43
20-Aug	38	17:58	1.43
*Installed 4th Layer on 22-Aug---------			
22-Aug	40	16:03	1.09
22-Aug	40	16:05	1.09
23-Aug	41	9:18	0.03
*Maintenance---------------------------------			
23-Aug	41	9:33	0.86
23-Aug	41	9:35	0.91
23-Aug	41	17:43	0.88
23-Aug	41	17:45	0.86
24-Aug	42	10:16	0.77
24-Aug	42	10:17	0.75
24-Aug	42	15:59	0.3
*Maintenance---------------------------------			
28-Aug	46	12:22	0.75
28-Aug	46	12:24	0.75
17-Sep	66	16:38	0.76
20-Sep	69	16:07	0.71
20-Sep	69	16:09	0.72
28-Sep	77	17:39	0.81
28-Sep	77	17:41	0.79
8-Oct	87	17:49	0.62
8-Oct	87	17:53	0.61
17-Oct	96	13:30	0.19
18-Oct	97	10:58	0.41
*Maintenance---------------------------------			
18-Oct	97	11:02	0.43
23-Oct	102	8:10	0.6
23-Oct	102	8:11	0.6
23-Oct	102	8:12	0.59

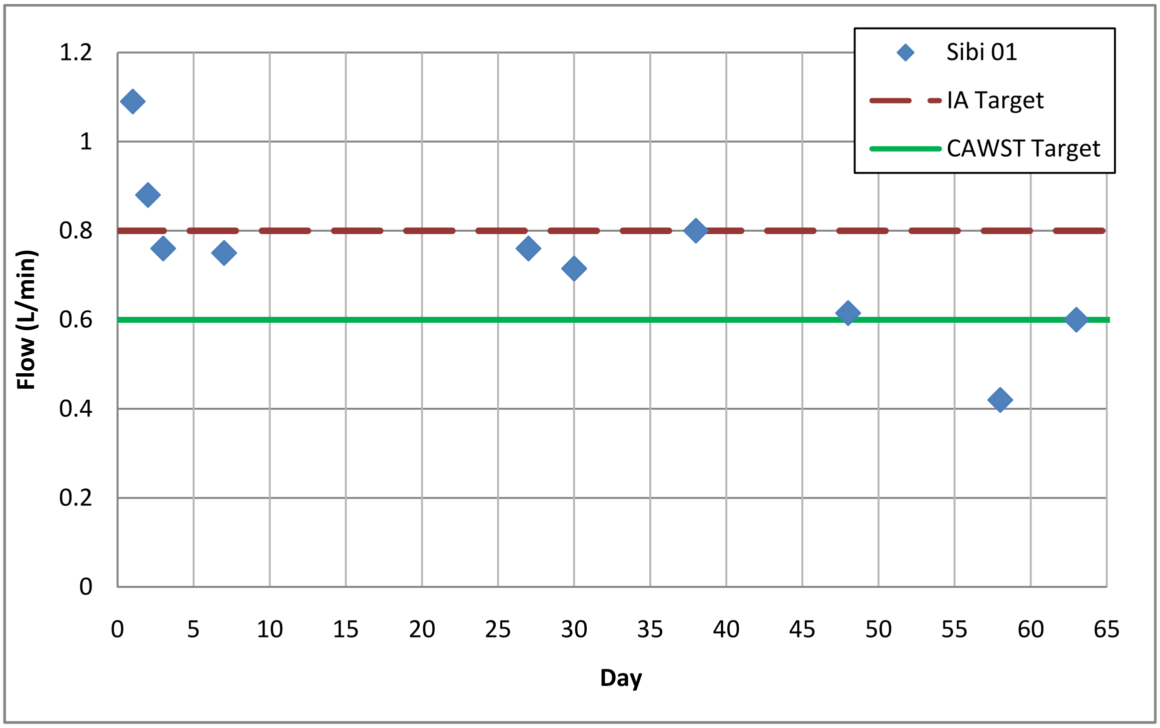

Figure 56: Adjusted-average flow rate measurements for HydrAid™ BioSand Filter Sibi 01. Recommended flow rates by the Center for Affordable Water and Sanitation Technology (CAWST) and International Aid (IA) are also graphed at 0.6 L/min and 0.8 L/min, respectively. A general range of acceptable flow rates is from a maximum of 1 L/min to a minimum that is determined by the user to be lowest the acceptable flow rate (e.g. 0.4 L/min).

Figure 57: Effluent water sample (right) from HydrAid™ BioSand Filter Sibi 01 showing "Clear" color in comparison with the raw source water (left)

Sibi 02 – Kwasi Wumbe, Binajub Clan

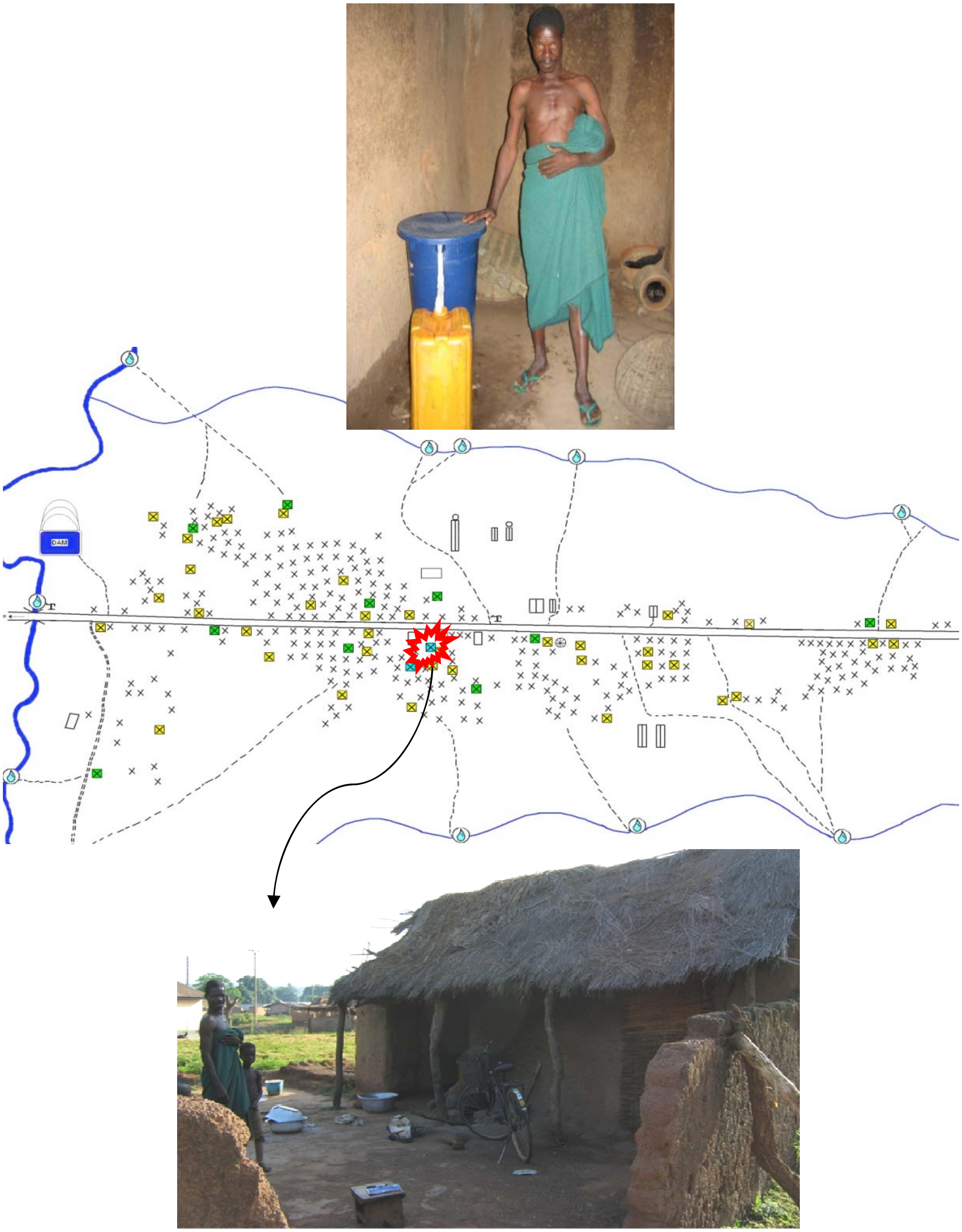

Figure 58: Sibi Hilltop community map (middle) identifying the household location (bottom) where the homeowner (top) and his family use HydrAid™ BioSand Filter Sibi 02

Survey Results

1. Name: Kwasi Wumbe
2. BSF #: Sibi 02
3. Clan: Binajub
4. Age: 39
5. Profession: Farmer
6. Total # of people in the household: 3
7. Are all using the BSF's water? Yes
8. Location of BSF: under a thatched alcove
9. Rainwater Harvesting potential: Limited, all thatched roofs
10. Ease of operation: (A) Easy
11. Who operates the BSF? Kwasi and his daughter
12. What source water is used in the BSF? Kabunbuk Stream
13. Do you feel the BSF is strong and durable? Yes
14. Which do you think would be a stronger BSF material? (A) Plastic, (B) Concrete: I don't know; haven't seen the concrete model
15. If you didn't have a BSF and you could buy one in the market, would you? Yes
16. What is the most you would be willing to pay for the IA BSF: (D) over ¢100,000
17. Would you be willing to pay more for a concrete model? No, the same
18. How much? (According to the above scale) (D) over ¢100,000
19. What problems are you having with the BSF? None
20. BSF use frequency: Twice per day
21. Volume per use: To the top, ~30 L
22. What do you use the filtered water for? Drinking and cooking
23. Do you drink any other water apart from the BSF effluent? No
24. Is the BSF flow rate sufficient for your needs? Yes
25. Do you prefer the effluent's taste to the influent? Yes
26. Do you prefer the effluent's color to the influent? Yes
27. Do you prefer the effluent's odor to the influent? Yes
28. Container used to collect effluent: jerry can
29. Cleaning frequency of container: rinses with water daily
30. Closed/Open container: closed
31. Is the effluent transferred to another storage vessel? No
32. Cleaning frequency of that vessel? N/A
33. Why did you want a BSF? Because of sickness
34. Have you maintained your BSF using the "swirl and dump" method? Yes
35. Maintenance frequency: Daily
36. Ease of cleaning: (A) Easy
37. Does the flow rate increase after maintenance? Yes
38. Does the taste change after maintenance (compared to the normal effluent)? No
39. Do you clean the exterior of the BSF? Yes
40. # of household members in age brackets: (a.) 0-5 yrs = 0, (b.) 6-12 yrs = 1, (c.) 13-18 yrs = 1, (d.) above 18 yrs = 1
41. Incidence of diarrhea in each age bracket since the dam dried up (end of March) and the BSF was installed: None
42. Diarrhea incidence since BSF installation in each age bracket: None
43. At this time last year what water were you drinking? Stream water
44. Did you treat the water? How? Yes, used a guinea worm cloth filter
45. Do you think the BSF improves your family's health? Yes

Table 12: HydrAid™ BSF Sibi 02 flow rate raw data

Date:	Day:	Time:	Q (L/min):
14-Jul	1	9:42	0.12
14-Jul	1	13:23	0.1
14-Jul	1	16:59	0.05
15-Jul	2	9:34	0.08
*Removed & Washed Filter Media 1x			
15-Jul	2	11:36	0.44
22-Jul	9	6:48	0.03
*Maintenance----------------------------------			
22-Jul	9	7:33	0.03
22-Jul	9	8:18	0.01
22-Jul	9	9:07	0.02
*Maintenance and shaking filter---------			
22-Jul	9	9:31	0.04
22-Jul	9	9:53	0.06
22-Jul	9	10:58	0.03
22-Jul	9	12:07	0.03
22-Jul	9	13:09	0.02
22-Jul	9	14:09	0.03
22-Jul	9	15:12	0.02
*Maintenance----------------------------------			
22-Jul	9	15:40	0.03
22-Jul	9	16:39	0.01
22-Jul	9	17:08	0.01
22-Jul	9	18:11	0.01
*Washed Filter Media 2x - 12-Aug			
12-Aug	30	16:34	0.39
12-Aug	30	16:41	0.28
*Washed Filter Media 2x - 18-Aug			
18-Aug	36	10:28	1.71
18-Aug	36	10:29	1.76
18-Aug	36	10:30	1.71
18-Aug	36	10:43	1.62
18-Aug	36	11:29	1.54
18-Aug	36	11:31	1.62
18-Aug	36	15:40	0.57
18-Aug	36	15:42	0.58
*Maintenance----------------------------------			
21-Aug	39	6:05	1.54
21-Aug	39	6:06	1.54
*Installed 4th Layer ---- 22-Aug----------			
22-Aug	40	14:59	1.11
22-Aug	40	15:01	1.11
23-Aug	41	10:02	0.88
23-Aug	41	10:04	0.88
23-Aug	41	17:34	0.78
23-Aug	41	17:36	0.79
24-Aug	42	10:29	0.83
24-Aug	42	10:30	0.86
24-Aug	42	15:48	0.68
28-Aug	46	12:09	0.61
28-Aug	46	12:11	0.61
17-Sep	66	16:25	0.58
28-Sep	77	17:23	0.61
28-Sep	77	17:25	0.6
8-Oct	87	17:39	0.61
8-Oct	87	17:44	0.61
12-Oct	91	11:58	0.42
12-Oct	91	12:00	0.43
25-Oct	104	7:02	0.53
25-Oct	104	7:04	0.53
25-Oct	104	7:06	0.54

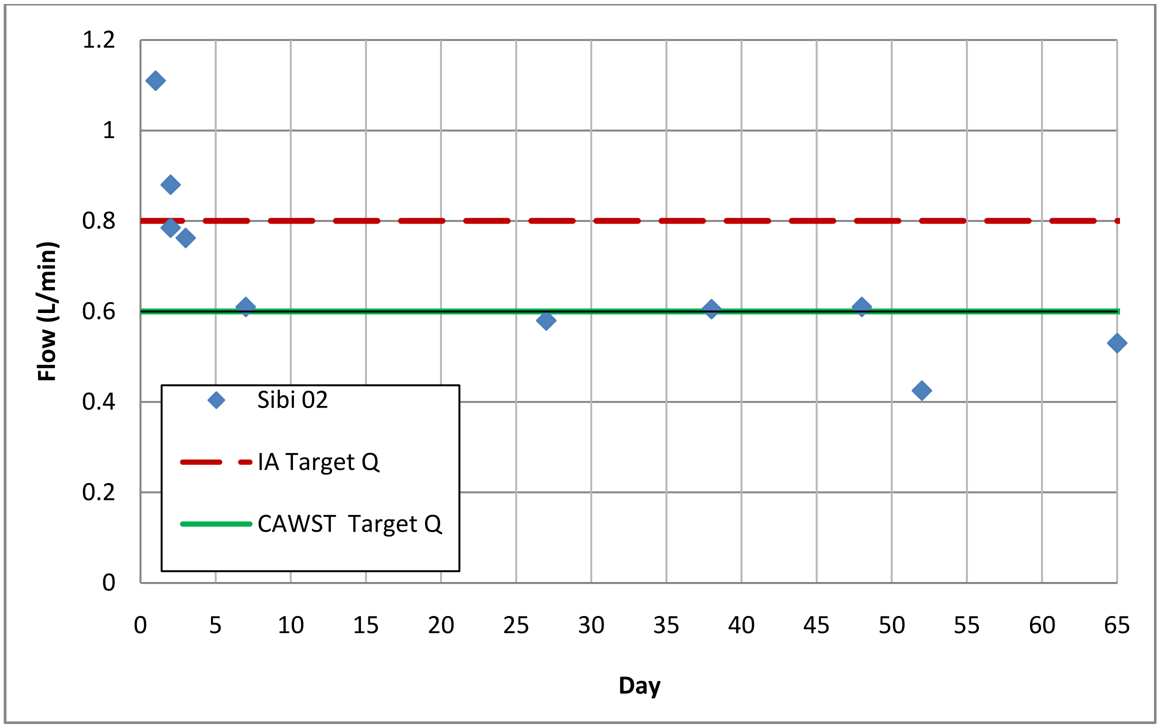

Figure 59: Adjusted-average flow rate measurements for HydrAid[TM] BioSand Filter Sibi 01. Recommended flow rates by the Center for Affordable Water and Sanitation Technology (CAWST) and International Aid (IA) are also graphed at 0.6 L/min and 0.8 L/min, respectively. A general range of acceptable flow rates is from a maximum of 1 L/min to a minimum that is determined by the user to be the lowest acceptable flow rate (e.g. 0.4 L/min).

Figure 60: Effluent water sample (right) from HydrAid[TM] BioSand Filter Sibi 02 showing "Very Clear" color in comparison with the raw source water (left)

Sibi 03 – Abraham Tabanti, Binajub Clan

Figure 61: Sibi Hilltop community map (middle) identifying the household location (bottom) where the homeowner (top) and his family use HydrAid^{TM} BioSand Filter Sibi 03

Survey Results

1. Name: Abraham Tabanti
2. BSF#: Sibi 03
3. Clan: Binajub
4. Age: 34
5. Profession: Farmer & Assembly Man
6. Total # of people in the household: 7
7. Are all using the BSF's water? Yes
8. Location of BSF: under the verandah
9. Rainwater Harvesting potential: All of roofing is metal, 15-ft of gutters plus a corner section
10. Ease of operation: (A) Easy
11. Who operates the BSF? Abraham's wife
12. What source water is used in the BSF? Sibi Stream at the bridge side
13. Do you feel the BSF is strong and durable? Yes
14. Which do you think would be a stronger BSF material? (A) Plastic
15. If you didn't have a BSF and you could buy one in the market, would you? Yes
16. What is the most you would be willing to pay for the IA BSF: (D) over ¢100,000
17. Would you be willing to pay more for a concrete model? Yes
18. How much? (According to the above scale) D) over ¢100,000
19. What problems are you having with the BSF? None
20. BSF use frequency: Twice per day
21. Volume per use: To the top, ~30 L
22. What do you use the filtered water for? Drinking
23. Do you drink any other water apart from the BSF effluent? Yes, rainwater
24. Is the BSF flow rate sufficient for your needs? Yes
25. Do you prefer the effluent's taste to the influent? Yes
26. Do you prefer the effluent's color to the influent? Yes
27. Do you prefer the effluent's odor to the influent? Yes
28. Container used to collect effluent: different head pans and buckets
29. Cleaning frequency of container: every time before use
30. Closed/Open container: Open
31. Is the effluent transferred to another storage vessel? Yes, a clay pot with lid
32. Cleaning frequency of that vessel? Every 3 days
33. Why did you want a BSF? It gives us clean water. It stops water borne disease.
34. Have you maintained your BSF using the "swirl and dump" method? No
35. Maintenance frequency: N/A
36. Ease of cleaning: N/A
37. Does the flow rate increase after maintenance? N/A
38. Does the taste change after maintenance (compared to the normal effluent)? N/A
39. Do you clean the exterior of the BSF? Yes
40. # of household members in age brackets: (a.) 0-5 yrs = 1, (b.) 6-12 yrs = 0, (c.) 13-18 yrs = 1, (d.) above 18 yrs = 5
41. Incidence of diarrhea in each age bracket since the dam dried up (end of March) and the BSF was installed: None
42. Diarrhea incidence since BSF installation in each age bracket: None
43. At this time last year what water were you drinking? Stream water
44. Did you treat the water? How? Yes, used a guinea worm cloth filter
45. Do you think the BSF improves your family's health? Yes

Table 13: HydrAid™ BSF Sibi 03 flow rate raw data

Date:	Day	Time:	Q (L/min):
22-Aug	1	18:30	0.92
22-Aug	1	18:32	0.92
23-Aug	2	10:11	0.05
*Maintenance---------------------------------			
23-Aug	2	10:23	0.71
23-Aug	2	10:24	0.72
23-Aug	2	17:55	0.71
23-Aug	2	17:57	0.7
24-Aug	3	10:36	0.53
24-Aug	3	10:38	0.53
24-Aug	3	16:09	0.43
28-Aug	7	11:58	0.59
28-Aug	7	12:00	0.58
1-Sep	11	16:40	0.32
*Maintenance---------------------------------			
1-Sep	11	16:54	0.38
13-Sep	23	10:24	0.4
*Washed 1/2 of 3rd and all 4th layer x2			
13-Sep	23	14:24	1.22
13-Sep	23	14:26	1.25
13-Sep	23	18:05	1.15
13-Sep	23	18:06	1.15
17-Sep	27	16:50	1.15
20-Sep	30	16:27	1.13
20-Sep	30	16:28	1.13
28-Sep	38	17:47	1.05
28-Sep	38	17:50	1.03
8-Oct	48	16:55	1.03
8-Oct	48	16:57	1.05
17-Oct	57	13:47	1
17-Oct	57	13:49	1
17-Oct	57	13:50	1
23-Oct	63	9:03	0.88
23-Oct	63	9:04	0.88
23-Oct	63	9:05	0.88

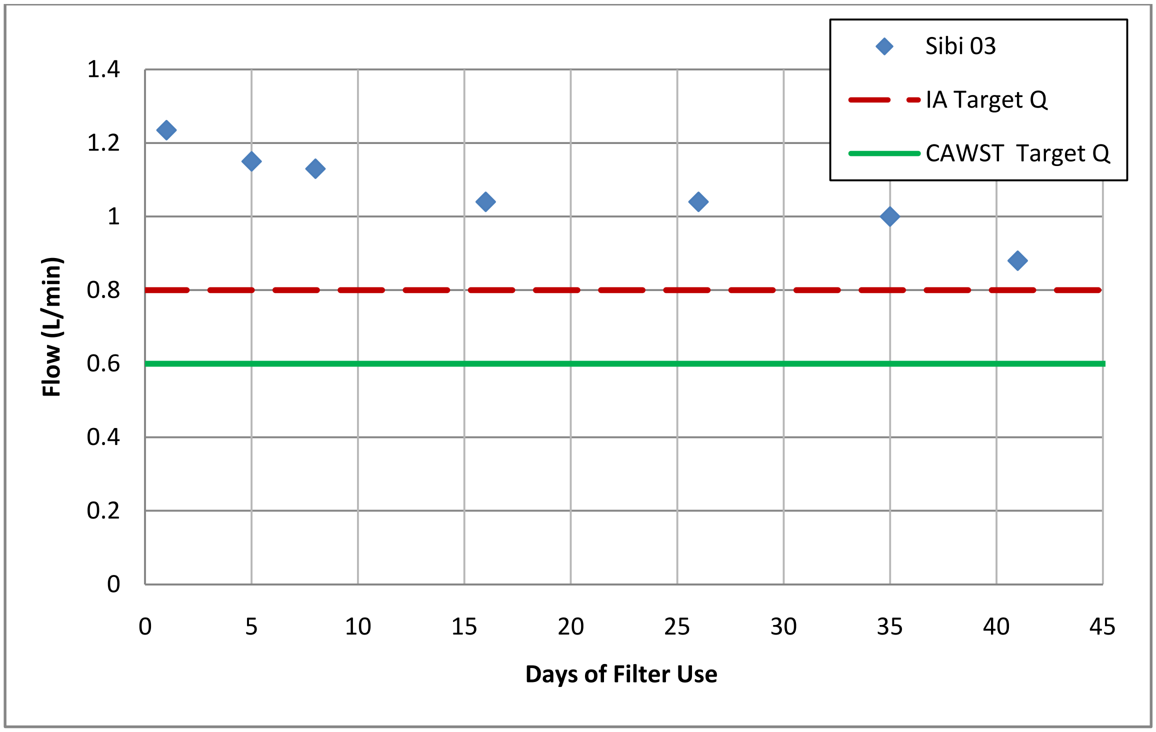

Figure 62: Adjusted-average flow rate measurements for HydrAid™ BioSand Filter Sibi 03. Recommended flow rates by the Center for Affordable Water and Sanitation Technology (CAWST) and International Aid (IA) are also graphed at 0.6 L/min and 0.8 L/min, respectively. A general range of acceptable flow rates is from a maximum of 1 L/min to a minimum that is determined by the user to be the lowest acceptable flow rate (e.g. 0.4 L/min).

Figure 63: Effluent water sample (right) from HydrAid™ BioSand Filter Sibi 02 showing "Very Clear" color in comparison with the raw source water (left)

Sibi 04 – Joseph Osei, Bigbem Clan

Figure 64; Sibi Hilltop community map (middle) identifying the household location (bottom) where the homeowner (top) and his family use HydrAid™ BioSand Filter Sibi 03

Survey Results

1. Name: Joseph Osei
2. BSF #: Sibi 04
3. Clan: Bigbem
4. Age: 32
5. Profession: Carpenter & Petrol Seller
6. Total # of people in the household: 7
7. Are all using the BSF's water? Yes
8. Location of BSF: Inside room
9. Rainwater Harvesting potential: All of roofing is metal, 23-ft of gutters
10. Ease of operation: (A) Easy
11. Who operates the BSF? Joseph's wife
12. What source water is used in the BSF? Kabunbok Stream
13. Do you feel the BSF is strong and durable? Yes
14. Which do you think would be a stronger BSF material? I don't know – haven't seen the concrete model
15. If you didn't have a BSF and you could buy one in the market, would you? Yes
16. What is the most you would be willing to pay for the IA BSF: (D) over ¢100,000 (specified ¢150,000)
17. Would you be willing to pay more for a concrete model? No
18. How much? (According to the above scale) B) ¢50-75,000 (specified ¢70,000). Prefers the plastic stating that maybe the concrete one would crack if knocked over.
19. What problems are you having with the BSF? None
20. BSF use frequency: Once/day
21. Volume per use: To the top, ~30 L
22. What do you use the filtered water for? Drinking
23. Do you drink any other water apart from the BSF effluent? Not while in the community, unless he travels
24. Is the BSF flow rate sufficient for your needs? Yes
25. Do you prefer the effluent's taste to the influent? Yes
26. Do you prefer the effluent's color to the influent? Yes
27. Do you prefer the effluent's odor to the influent? Yes
28. Container used to collect effluent: large metal pot
29. Cleaning frequency of container: unknown
30. Closed/Open container: Open
31. Is the effluent transferred to another storage vessel? Yes, two clay pots with lids
32. Cleaning frequency of that vessel? Daily
33. Why did you want a BSF? To prevent illnesses.
34. Have you maintained your BSF using the "swirl and dump" method? No
35. Maintenance frequency: N/A
36. Ease of cleaning: N/A
37. Does the flow rate increase after maintenance? N/A
38. Does the taste change after maintenance (compared to the normal effluent)? N/A
39. Do you clean the exterior of the BSF? Yes
40. # of household members in age brackets: (a.) 0-5 yrs = 2, (b.) 6-12 yrs = 1, (c.) 13-18 yrs = 1, (d.) above 18 yrs = 3
41. Incidence of diarrhea in each age bracket since the dam dried up (end of March) and the BSF was installed: None
42. Diarrhea incidence since BSF installation in each age bracket: None
43. At this time last year what water were you drinking? Stream water
44. Did you treat the water? How? Yes, used a guinea worm cloth filter
45. Do you think the BSF improves your family's health? Yes

Table 14: HydrAid BSF Sibi 04 flow rate raw data

Date:	Day:	Time:	Q (L/min):
23-Aug	1	13:50	1
23-Aug	1	13:51	1.07
24-Aug	2	10:48	0.85
24-Aug	2	10:50	0.86
24-Aug	2	16:20	0.85
28-Aug	6	11:39	0.65
28-Aug	6	11:41	0.65
20-Sep	29	18:31	0.86
20-Sep	29	18:33	0.86
29-Sep	38	6:08	0.86
29-Sep	38	6:10	0.88
9-Oct	48	8:34	0.83
9-Oct	48	8:35	0.79
17-Oct	56	11:42	0.88
17-Oct	56	11:45	0.88
22-Oct	61	10:26	0.73
22-Oct	61	10:27	0.71
22-Oct	61	10:28	0.71
*Maintenance--------------------------------			
22-Oct	61	11:04	0.77

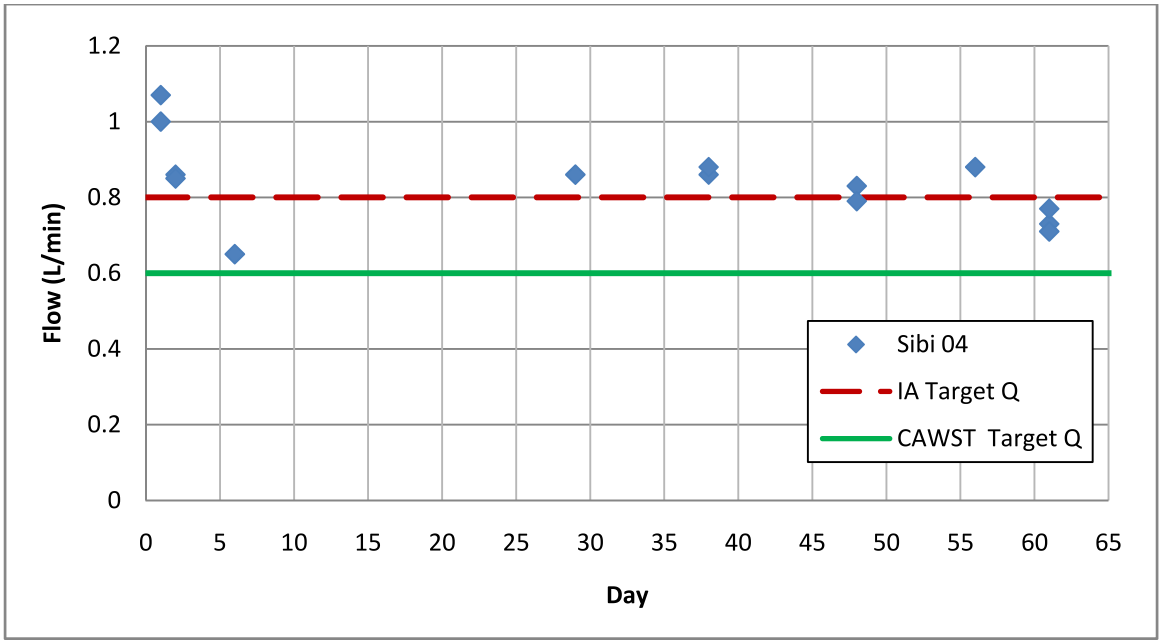

Figure 65: Adjusted-average flow rate measurements for HydrAid™ BioSand Filter Sibi 04. Recommended flow rates by the Center for Affordable Water and Sanitation Technology (CAWST) and International Aid (IA) are also graphed at 0.6 L/min and 0.8 L/min, respectively. A general range of acceptable flow rates is from a maximum of 1 L/min to a minimum that is determined by the user to be the lowest acceptable flow rate (e.g. 0.4 L/min).

Figure 66: Effluent water sample (right) from HydrAid™ BioSand Filter Sibi 02 showing "Very Clear" color in comparison with the raw source water (left)

Sibi 05 – Akua Yimbidan, Kpajotib Clan

Figure 67: Sibi Hilltop community map (middle) identifying the household location (bottom) where the homeowner (top) and her family use HydrAid™ BioSand Filter Sibi 05

Survey Results

1. Name: Akua Yimbidan
2. BSF #: Sibi 05
3. Clan: Kpajotib
4. Age: 30
5. Profession: Farmer & Trader
6. Total # of people in the household: 21
7. Are all using the BSF's water? Yes
8. Location of BSF: Inside room
9. Rainwater Harvesting potential: Limited – all thatch roofing; No gutters
10. Ease of operation: (A) Easy
11. Who operates the BSF? Akua, Mother-in-Law, daughters and friends
12. What source water is used in the BSF? Sibi Stream at "Madane" (My Dream) spot
13. Do you feel the BSF is strong and durable? Yes
14. Which do you think would be a stronger BSF material? (A) Plastic
15. If you didn't have a BSF and you could buy one in the market, would you? Yes
16. What is the most you would be willing to pay for the IA BSF: (D) over ¢100,000
17. Would you be willing to pay more for a concrete model? No,
18. How much? (According to the above scale) (A) ¢0-50,000¢70,000).
19. What problems are you having with the BSF? None
20. BSF use frequency: Once or Twice Daily (~11x per week)
21. Volume per use: To the top, ~30 L
22. What do you use the filtered water for? Drinking and Cooking
23. Do you drink any other water apart from the BSF effluent? Yes, at farm they drink stream water
24. Is the BSF flow rate sufficient for your needs? Yes
25. Do you prefer the effluent's taste to the influent? Yes
26. Do you prefer the effluent's color to the influent? Yes
27. Do you prefer the effluent's odor to the influent? Yes
28. Container used to collect effluent: plastic bucket and a pan
29. Cleaning frequency of container: daily
30. Closed/Open container: Open, no cover
31. Is the effluent transferred to another storage vessel? No
32. Cleaning frequency of that vessel? N/A
33. Why did you want a BSF? To prevent guinea worm
34. Have you maintained your BSF using the "swirl and dump" method? Yes
35. Maintenance frequency: weekly
36. Ease of cleaning: (A) Easy
37. Does the flow rate increase after maintenance? Yes
38. Does the taste change after maintenance (compared to the normal effluent)? No
39. Do you clean the exterior of the BSF? Yes
40. # of household members in age brackets: (a.) 0-5 yrs = 3, (b.) 6-12 yrs = 5, (c.) 13-18 yrs = 7, (d.) above 18 yrs = 6
41. Incidence of diarrhea in each age bracket since the dam dried up (end of March) and the BSF was installed: (a-c.) None, (d.) 2x
42. Diarrhea incidence since BSF installation in each age bracket: None
43. At this time last year what water were you drinking? Stream water
44. Did you treat the water? How? Yes, used a guinea worm cloth filter
45. Do you think the BSF improves your family's health? Yes

Table 15: HydrAid BSF Sibi 05 flow rate raw data

Date:	Day:	Time:	Q (L/min):
23-Aug	1	16:20	0.97
23-Aug	1	16:22	0.97
24-Aug	2	11:18	0.55
*Maintenance-------------------------------------			
24-Aug	2	11:30	0.67
28-Aug	6	10:23	0.71
28-Aug	6	10:25	0.75
15-Sep	24	10:36	0.62
15-Sep	24	10:37	0.64
20-Sep	29	17:13	0.59
20-Sep	29	17:15	0.58
29-Sep	38	16:55	0.55
29-Sep	38	16:58	0.53
11-Oct	50	17:45	0.52
11-Oct	50	17:47	0.5
12-Oct	51	12:23	0.46
22-Oct	61	15:42	0.7
22-Oct	61	15:43	0.7
22-Oct	61	15:44	0.67

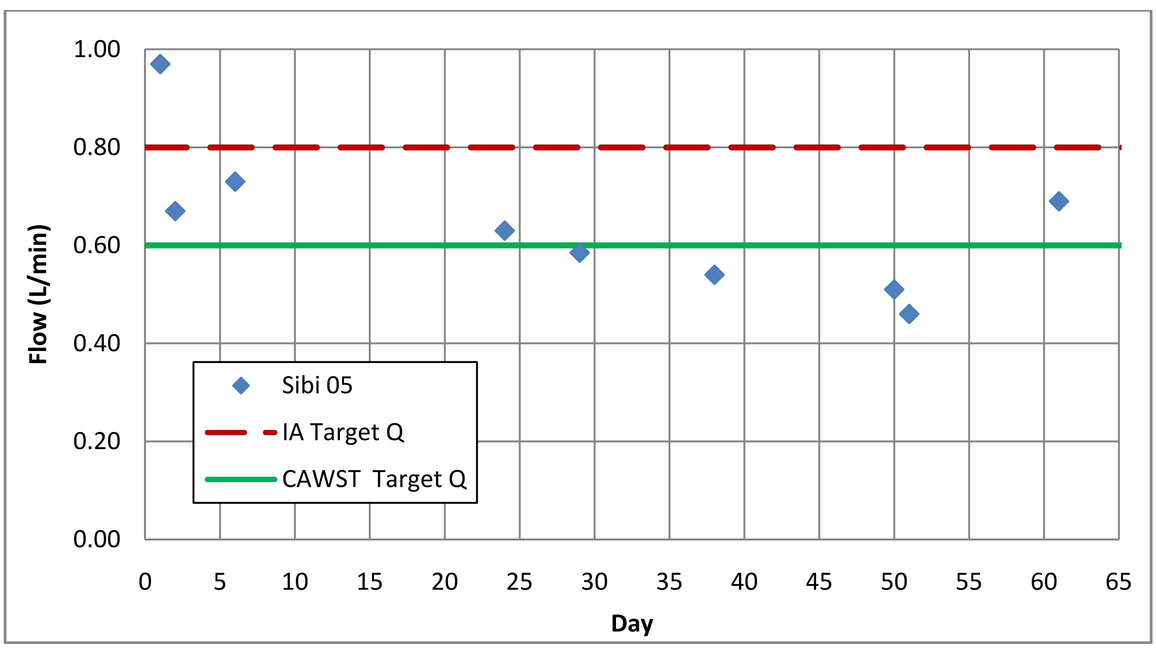

Figure 68: Adjusted-average flow rate measurements for HydrAid™ BioSand Filter Sibi 05. Recommended flow rates by the Center for Affordable Water and Sanitation Technology (CAWST) and International Aid (IA) are also graphed at 0.6 L/min and 0.8 L/min, respectively. A general range of acceptable flow rates is from a maximum of 1 L/min to a minimum that is determined by the user to be the lowest acceptable flow rate (e.g. 0.4 L/min).

Figure 69: Effluent water sample (right) from HydrAid™ BioSand Filter Sibi 05 showing "No Apparent Change" in color in comparison with the raw source water (left)

Sibi 06 – Afia Yiyal, Bekom East Clan

Figure 70: Sibi Hilltop community map (middle) identifying the household location (bottom) where the homeowner (top) and her family use HydrAid™ BioSand Filter Sibi 06

Survey Results

1. Name: Afia Yiyal
2. BSF #: Sibi 06
3. Clan: Bekom East
4. Age: 42
5. Profession: Farmer & Trader
6. Total # of people in the household: 13
7. Are all using the BSF's water? Yes
8. Location of BSF: Inside room
9. Rainwater Harvesting potential: Good - 2/3 metal roofing and 17' of gutters
10. Ease of operation: (A) Easy
11. Who operates the BSF? Afia
12. What source water is used in the BSF? Sibi Stream at the Top
13. Do you feel the BSF is strong and durable? Yes, it will last a long time
14. Which do you think would be a stronger BSF material? (B) Concrete
15. If you didn't have a BSF and you could buy one in the market, would you? Yes
16. What is the most you would be willing to pay for the IA BSF: (B) ¢50-75,000
17. Would you be willing to pay more for a concrete model? Yes, (D) over ¢100,000
18. How much? (According to the above scale) (A) ¢0-50,000¢70,000).
19. What problems are you having with the BSF? None
20. BSF use frequency: Once or Twice Daily (~10x per week)
21. Volume per use: To the top, ~30 L
22. What do you use the filtered water for? Drinking and Cooking
23. Do you drink any other water apart from the BSF effluent? No
24. Is the BSF flow rate sufficient for your needs? Yes
25. Do you prefer the effluent's taste to the influent? Yes
26. Do you prefer the effluent's color to the influent? Yes
27. Do you prefer the effluent's odor to the influent? Yes
28. Container used to collect effluent: plastic bucket
29. Cleaning frequency of container: daily before use
30. Closed/Open container: Open, no cover
31. Is the effluent transferred to another storage vessel? Yes
32. Cleaning frequency of that vessel? Every 3 days
33. Why did you want a BSF? Because of guinea worm prevention
34. Have you maintained your BSF using the "swirl and dump" method? Yes
35. Maintenance frequency: weekly
36. Ease of cleaning: (A) Easy
37. Does the flow rate increase after maintenance? Yes
38. Does the taste change after maintenance (compared to the normal effluent)? "Yes, after cleaning the water tastes like pipe (borehole) water." She doesn't prefer it to the one that was previously coming or the one after that use.
39. Do you clean the exterior of the BSF? Yes
40. # of household members in age brackets: (a.) 0-5 yrs = 2, (b.) 6-12 yrs = 4, (c.) 13-18 yrs = 1, (d.) above 18 yrs = 6
41. Incidence of diarrhea in each age bracket since the dam dried up (end of March) and the BSF was installed: (a.) 1x, (b.) 2x, (c & d.) None
42. Diarrhea incidence since BSF installation in each age bracket: None
43. At this time last year what water were you drinking? Stream water
44. Did you treat the water? How? Yes, used a guinea worm cloth filter
45. Do you think the BSF improves your family's health? Yes

Table 16: HydrAid BSF Sibi 06 flow rate raw data

Date:	Day:	Time:	Q (L/min):
23-Aug	1	18:46	1.07
23-Aug	1	18:48	1.11
24-Aug	2	10:48	0.85
24-Aug	2	10:50	0.86
28-Aug	6	14:15	0.8
28-Aug	6	14:17	0.79
15-Sep	24	11:22	1
15-Sep	24	11:23	0.98
20-Sep	29	17:51	0.71
20-Sep	29	17:52	0.7
29-Sep	38	17:31	0.92
29-Sep	38	17:34	0.92
9-Oct	48	8:23	0.6
9-Oct	48	8:24	0.6
12-Oct	51	12:43	0.71
12-Oct	51	12:45	0.71
22-Oct	61	8:06	0.71
22-Oct	61	8:07	0.73
22-Oct	61	8:08	0.71

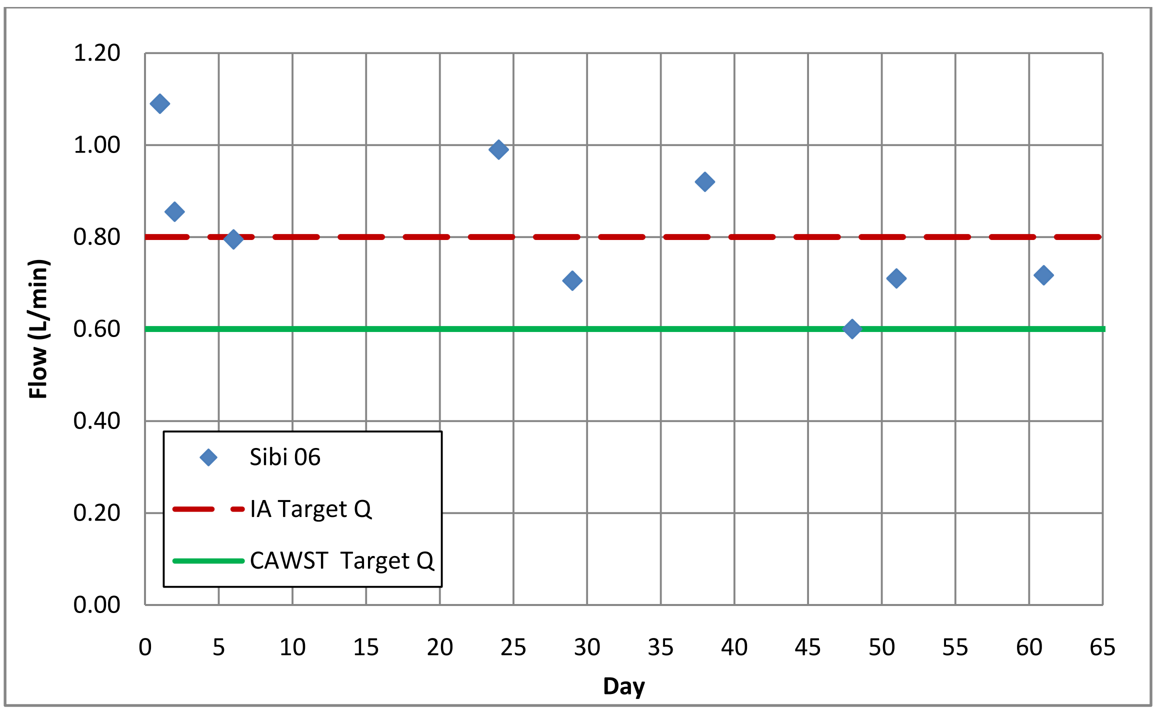

Figure 71: Adjusted-average flow rate measurements for HydrAid^{TM} BioSand Filter Sibi 06. Recommended flow rates by the Center for Affordable Water and Sanitation Technology (CAWST) and International Aid (IA) are also graphed at 0.6 L/min and 0.8 L/min, respectively. A general range of acceptable flow rates is from a maximum of 1 L/min to a minimum that is determined by the user to be the lowest acceptable flow rate (e.g. 0.4 L/min).

Figure 72: Effluent water sample (right) from HydrAid^{TM} BioSand Filter Sibi 06 showing "Clear" color in comparison with the raw source water (left)

Sibi 07 – Mborja Batigna, Kochatib Clan

Figure 73: Sibi Hilltop community map (middle) identifying the household location (bottom) where the homeowner (top) and her family use HydrAid™ BioSand Filter Sibi 07

Survey Results

1. Name: Mborja Batigna
2. BSF #: Sibi 07
3. Clan: Kochatib
4. Age: 45
5. Profession: Farmer & Trader
6. Total # of people in the household: 14
7. Are all using the BSF's water? Yes
8. Location of BSF: Inside room
9. Rainwater Harvesting potential: Excellent - All metal roofing and ~34' of gutters
10. Ease of operation: (A) Easy
11. Who operates the BSF? Mborja
12. What source water is used in the BSF? Sibi Stream at the Bridge
13. Do you feel the BSF is strong and durable? Yes
14. Which do you think would be a stronger BSF material? I don't know
15. If you didn't have a BSF and you could buy one in the market, would you? Yes
16. What is the most you would be willing to pay for the IA BSF: (D) Over ¢100,000
17. Would you be willing to pay more for a concrete model? No
18. How much? (According to the above scale) (C) ¢75-100,000
19. What problems are you having with the BSF? None
20. BSF use frequency: Three times daily
21. Volume per use: To the top, ~30 L
22. What do you use the filtered water for? Drinking
23. Do you drink any other water apart from the BSF effluent? No
24. Is the BSF flow rate sufficient for your needs? Yes
25. Do you prefer the effluent's taste to the influent? Yes
26. Do you prefer the effluent's color to the influent? Yes
27. Do you prefer the effluent's odor to the influent? Yes
28. Container used to collect effluent: small head pans
29. Cleaning frequency of container: daily before use with soap and water
30. Closed/Open container: Open, no cover
31. Is the effluent transferred to another storage vessel? Yes, 2 clay pots
32. Cleaning frequency of that vessel? Almost daily
33. Why did you want a BSF? To prevent illnesses
34. Have you maintained your BSF using the "swirl and dump" method? No
35. Maintenance frequency: N/A
36. Ease of cleaning: N/A
37. Does the flow rate increase after maintenance? N/A
38. Does the taste change after maintenance (compared to the normal effluent)? N/A
39. Do you clean the exterior of the BSF? Yes
40. # of household members in age brackets: (a.) 0-5 yrs = 3, (b.) 6-12 yrs = 2, (c.) 13-18 yrs = 2, (d.) above 18 yrs = 7
41. Incidence of diarrhea in each age bracket since the dam dried up (end of March) and the BSF was installed: None
42. Diarrhea incidence since BSF installation in each age bracket: (a.) 1x, (b-d.) None
43. At this time last year what water were you drinking? Stream water
44. Did you treat the water? How? Yes, used a guinea worm cloth filter and a coagulant for the dam water
45. Do you think the BSF improves your family's health? Yes

Table 17: HydrAid™ BSF Sibi 07 flow rate raw data

Date:	Day	Time:	Q (L/min):
24-Aug	1	12:45	2.31
24-Aug	1	12:47	2.31
28-Aug	5	9:59	2.31
28-Aug	5	10:00	2
28-Aug	5	10:03	2.07
31-Aug	8	15:49	2.14
*Installed 4th Layer------31-Aug-------------			
31-Aug	8	16:18	1
31-Aug	8	16:23	1
15-Sep	23	9:52	0.83
15-Sep	23	9:53	0.83
23-Sep	31	17:29	0.86
23-Sep	31	17:33	0.86
29-Sep	37	17:56	0.82
29-Sep	37	17:58	0.85
9-Oct	48	8:55	0.73
9-Oct	48	8:59	0.73
17-Oct	56	13:17	0.7
17-Oct	56	13:18	0.75
17-Oct	56	13:20	0.73
22-Oct	61	9:33	0.63
22-Oct	61	9:34	0.61
22-Oct	61	9:35	0.61
*Maintenance-------------------------------------			
22-Oct	61	10:12	0.61

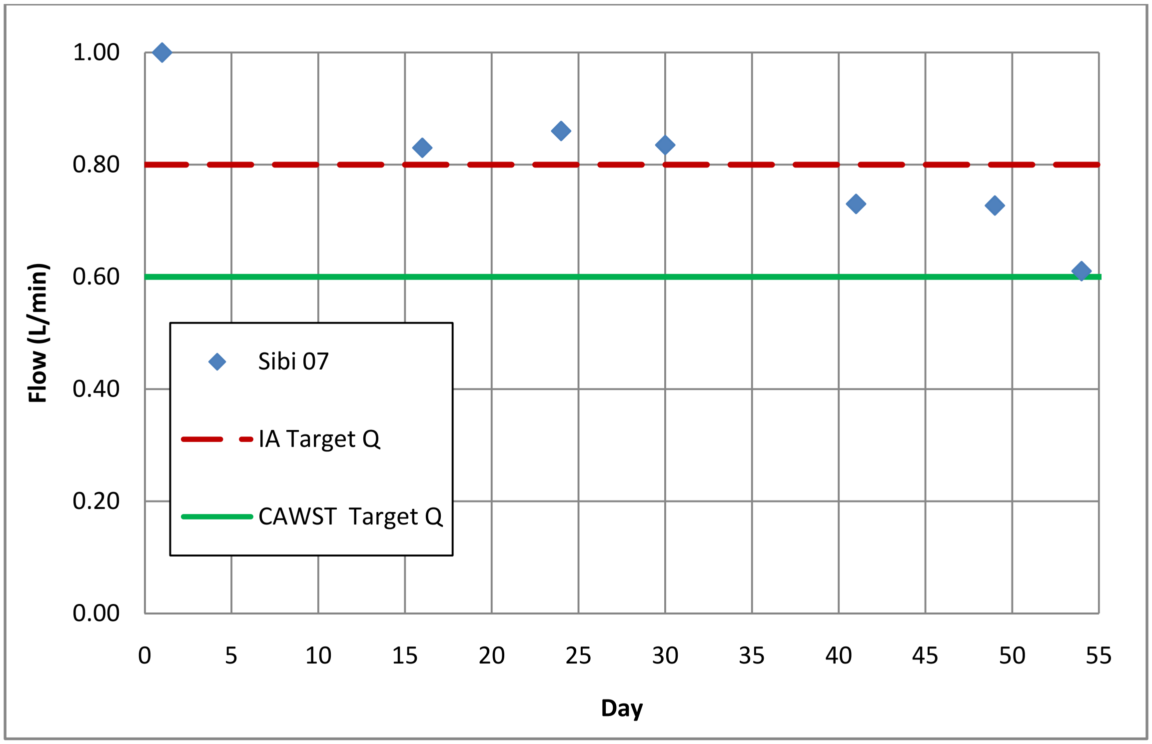

Figure 74: Adjusted-average flow rate measurements for HydrAid™ BioSand Filter Sibi 07. Recommended flow rates by the Center for Affordable Water and Sanitation Technology (CAWST) and International Aid (IA) are also graphed at 0.6 L/min and 0.8 L/min, respectively. A general range of acceptable flow rates is from a maximum of 1 L/min to a minimum that is determined by the user to be the lowest acceptable flow rate (e.g. 0.4 L/min).

Figure 75: Effluent water sample (right) from HydrAid™ BioSand Filter Sibi 07 showing "Clear" color in comparison with the raw source water (left)

Sibi 08 – Obori Gmanja Lalir II, Nakpando Clan

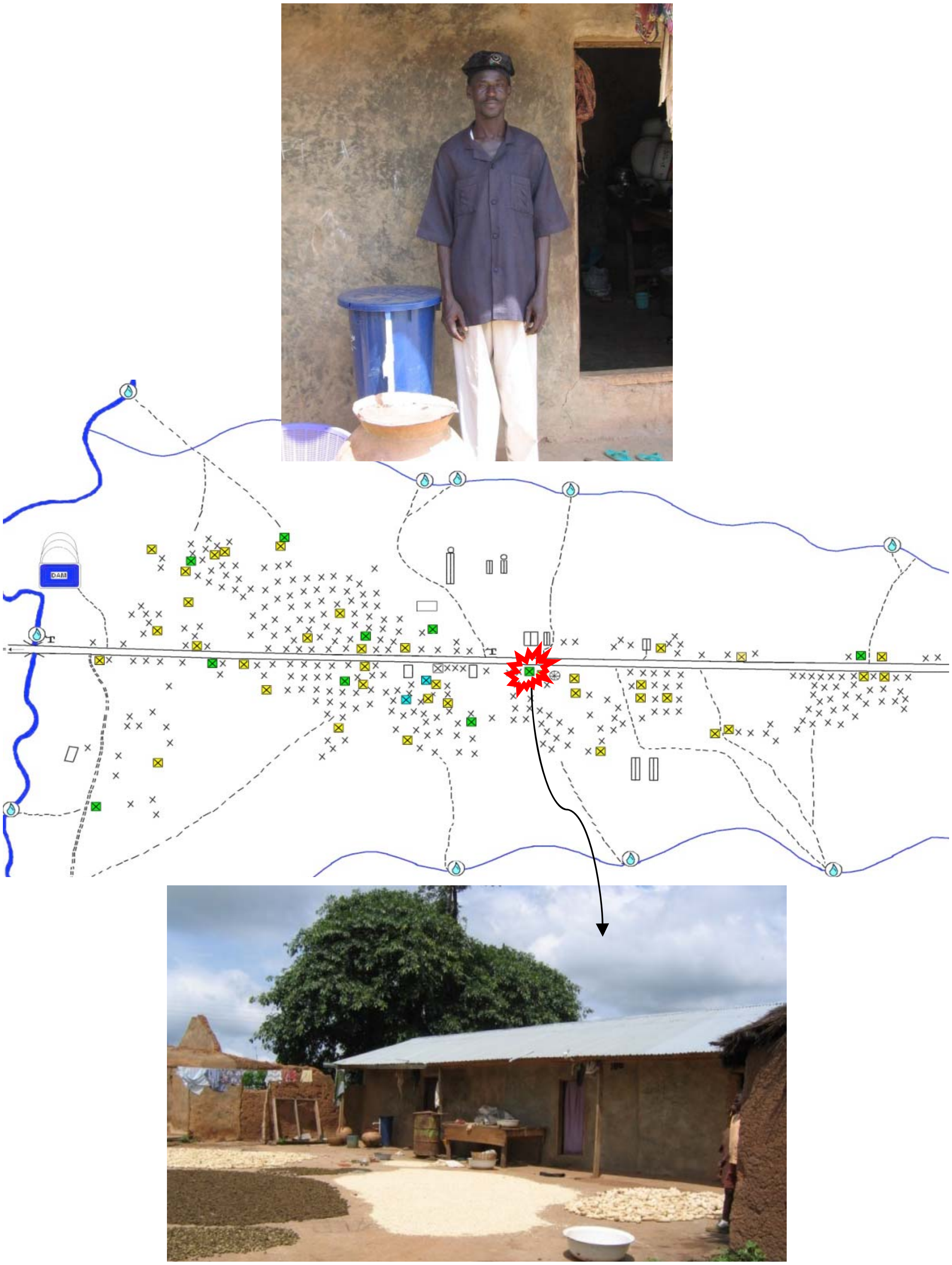

Figure 76: Sibi Hilltop community map (middle) identifying the household location (bottom) where the homeowner (top) and his family use HydrAid™ BioSand Filter Sibi 08

Survey Results

1. Name: Obori Gmanja Lalir II
2. BSF #: Sibi 08
3. Clan: Nakpando
4. Age: 43
5. Profession: Farmer & Chief
6. Total # of people in the household: 8
7. Are all using the BSF's water? Yes
8. Location of BSF: Under verandah
9. Rainwater Harvesting potential: Good – 3/4 metal roofing (thatched kitchen) and ~18' of gutters
10. Ease of operation: (A) Easy
11. Who operates the BSF? Chief's wife
12. What source water is used in the BSF? Kabunbuk Stream
13. Do you feel the BSF is strong and durable? Yes
14. Which do you think would be a stronger BSF material? (B) Concrete
15. If you didn't have a BSF and you could buy one in the market, would you? Yes
16. What is the most you would be willing to pay for the IA BSF: (D) Over ¢100,000
17. Would you be willing to pay more for a concrete model? Yes
18. How much? (According to the above scale) (D) Over ¢100,000
19. What problems are you having with the BSF? None
20. BSF use frequency: Four days per week, Two times each day
21. Volume per use: To the top, ~30 L
22. What do you use the filtered water for? Drinking and sometimes cooking
23. Do you drink any other water apart from the BSF effluent? Yes, Borehole and Rainwater
24. Is the BSF flow rate sufficient for your needs? Yes
25. Do you prefer the effluent's taste to the influent? Yes
26. Do you prefer the effluent's color to the influent? Yes
27. Do you prefer the effluent's odor to the influent? Yes
28. Container used to collect effluent: clay pot
29. Cleaning frequency of container: twice per week
30. Closed/Open container: Closed with lid
31. Is the effluent transferred to another storage vessel? No
32. Cleaning frequency of that vessel? N/A
33. Why did you want a BSF? "For getting clean water so I won't be affected by guinea worm."
34. Have you maintained your BSF using the "swirl and dump" method? No
35. Maintenance frequency: N/A
36. Ease of cleaning: N/A
37. Does the flow rate increase after maintenance? N/A
38. Does the taste change after maintenance (compared to the normal effluent)? N/A
39. Do you clean the exterior of the BSF? Yes
40. # of household members in age brackets: (a.) 0-5 yrs = 2, (b.) 6-12 yrs = 1, (c.) 13-18 yrs = 2, (d.) above 18 yrs = 3
41. Incidence of diarrhea in each age bracket since the dam dried up (end of March) and the BSF was installed: None
42. Diarrhea incidence since BSF installation in each age bracket: None
43. At this time last year what water were you drinking? All in house were drinking stream water except the chief, who was drinking borehole water
44. Did you treat the water? How? Yes, used a guinea worm cloth filter
45. Do you think the BSF improves your family's health? Yes

Table 18: HydrAid BSF Sibi 08 flow rate raw data

Date:	Day:	Time:	Q (L/min):
24-Aug	1	14:07	1.76
24-Aug	1	14:09	1.76
28-Aug	5	12:53	2.22
28-Aug	5	12:55	2.22
*Installed 4th Layer------30-Aug------------			
30-Aug	7	11:29	0.82
30-Aug	7	11:31	0.81
13-Sep	21	18:24	0.8
13-Sep	21	18:25	0.8
17-Sep	25	17:11	0.78
23-Sep	31	17:08	0.76
23-Sep	31	17:10	0.73
28-Sep	36	17:58	0.78
28-Sep	36	17:59	0.75
8-Oct	46	17:24	0.7
8-Oct	46	17:27	0.7
12-Oct	50	13:06	0.61
*Maintenance------------------------------------			
12-Oct	50	13:17	0.7
23-Oct	61	10:24	0.57
23-Oct	61	10:25	0.55
23-Oct	61	10:26	0.56

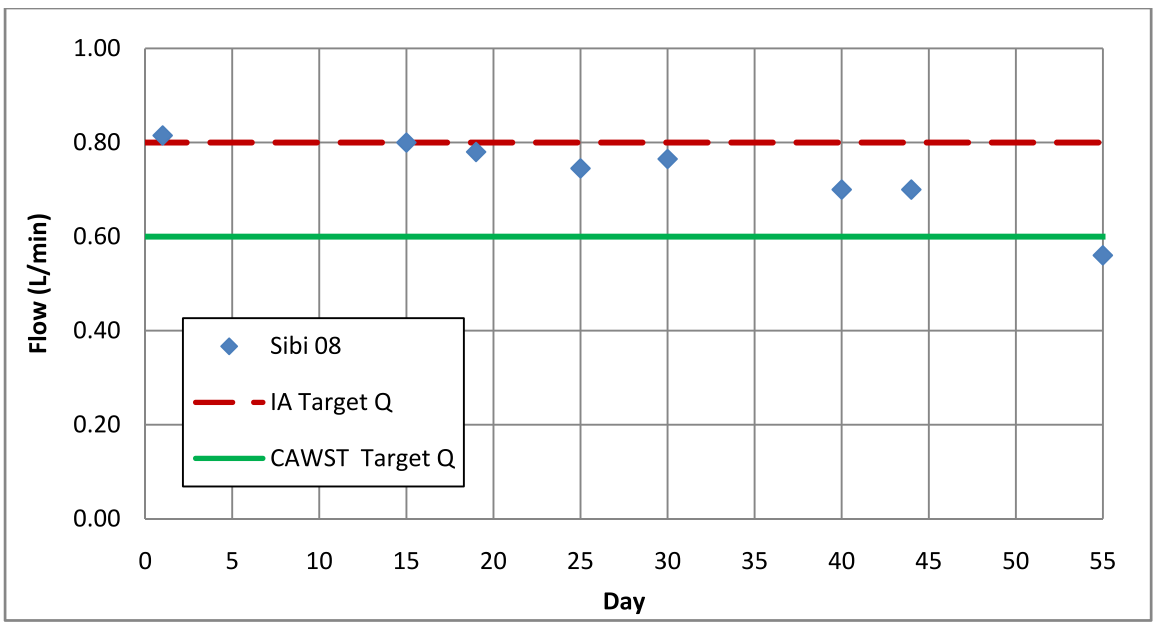

Figure 77: Adjusted-average flow rate measurements for HydrAid™ BioSand Filter Sibi 08. Recommended flow rates by the Center for Affordable Water and Sanitation Technology (CAWST) and International Aid (IA) are also graphed at 0.6 L/min and 0.8 L/min, respectively. A general range of acceptable flow rates is from a maximum of 1 L/min to a minimum that is determined by the user to be the lowest acceptable flow rate (e.g. 0.4 L/min).

Figure 78: Effluent water sample (right) from HydrAid™ BioSand Filter Sibi 08 showing "Improved" color in comparison with the raw source water (left)

Sibi 09 – Attah K. John, Basatib West Clan

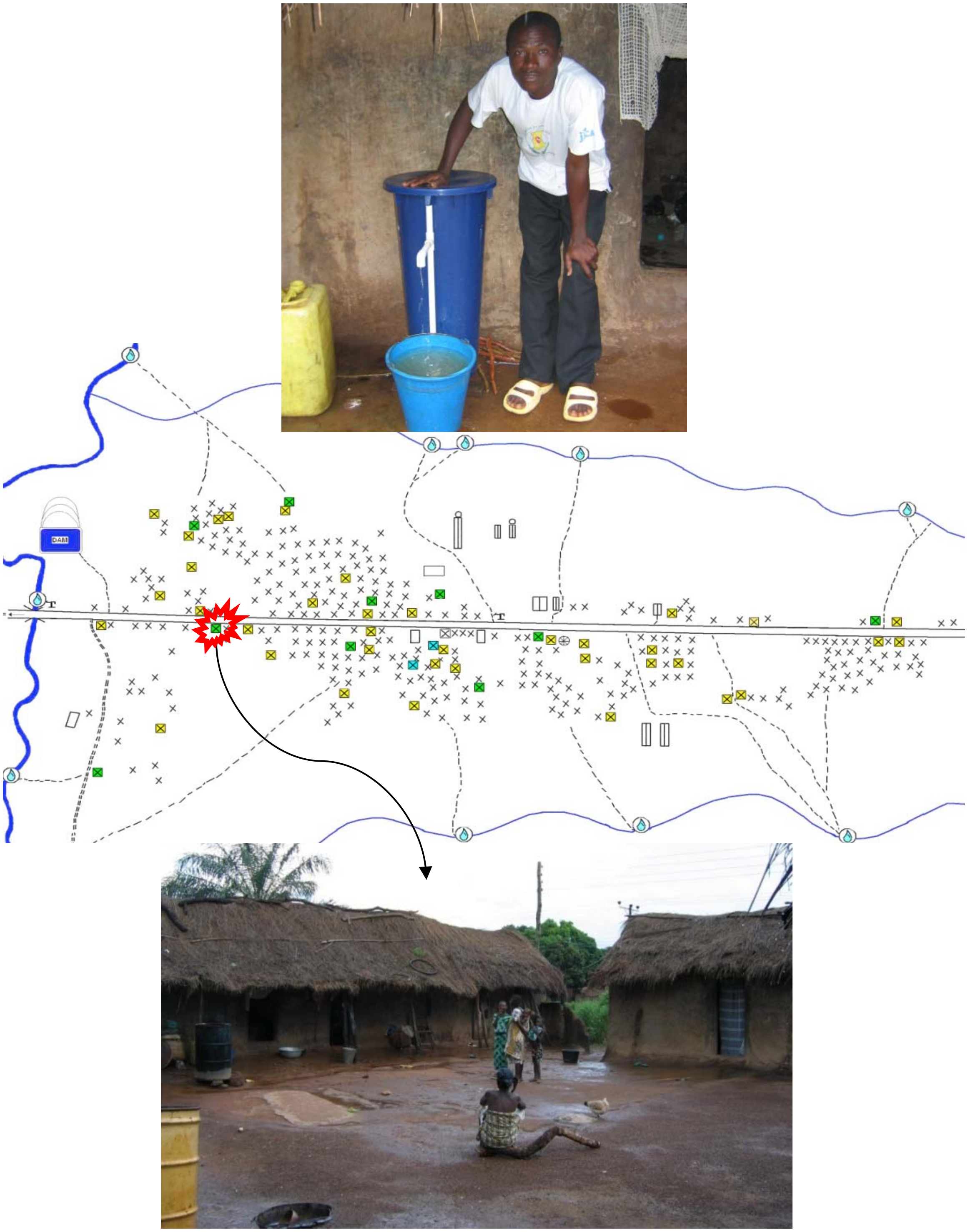

Figure 79: Sibi Hilltop community map (middle) identifying the household location (bottom) where the homeowner (top) and his family use HydrAid™ BioSand Filter Sibi 09

Survey Results

1. Name: Attah K. John
2. BSF #: Sibi 09
3. Clan: Basatib West
4. Age: 24
5. Profession: Farmer & Teacher
6. Total # of people in the household: 17
7. Are all using the BSF's water? Yes
8. Location of BSF: Under thatched verandah
9. Rainwater Harvesting potential: Limited, All thatched roofing and no gutters
10. Ease of operation: (A) Easy
11. Who operates the BSF? John, his wife, mother and brother's wife
12. What source water is used in the BSF? Sibi Stream at the bridge side
13. Do you feel the BSF is strong and durable? "Yes, unless it is misused."
14. Which do you think would be a stronger BSF material? (B) Concrete
15. If you didn't have a BSF and you could buy one in the market, would you? Yes
16. What is the most you would be willing to pay for the IA BSF: (D) Over ¢100,000
17. Would you be willing to pay more for a concrete model? Yes
18. How much? (According to the above scale) (D) Over ¢100,000
19. What problems are you having with the BSF? The flow rate is too slow! After he moved the BSF from a room to under the verandah it reduced by ½.
20. BSF use frequency: Three times per day
21. Volume per use: To the top, ~30 L
22. What do you use the filtered water for? Drinking and cooking
23. Do you drink any other water apart from the BSF effluent? No
24. Is the BSF flow rate sufficient for your needs? Yes
25. Do you prefer the effluent's taste to the influent? Yes
26. Do you prefer the effluent's color to the influent? Yes
27. Do you prefer the effluent's odor to the influent? Yes
28. Container used to collect effluent: Rubber bucket
29. Cleaning frequency of container: once a day
30. Closed/Open container: Closed with lid
31. Is the effluent transferred to another storage vessel? No
32. Cleaning frequency of that vessel? N/A
33. Why did you want a BSF? To prevent waterborne disease
34. Have you maintained your BSF using the "swirl and dump" method? Yes
35. Maintenance frequency: Sometimes daily, other times once in a week "if I washed it well."
36. Ease of cleaning: (B) Moderate
37. Does the flow rate increase after maintenance? Yes
38. Does the taste change after maintenance (compared to the normal effluent)? No
39. Do you clean the exterior of the BSF? Yes
40. # of household members in age brackets: (a.) 0-5 yrs = 5, (b.) 6-12 yrs = 1, (c.) 13-18 yrs = 2, (d.) above 18 yrs = 9
41. Incidence of diarrhea in each age bracket since the dam dried up (end of March) and the BSF was installed: None
42. Diarrhea incidence since BSF installation in each age bracket: None
43. At this time last year what water were you drinking? Stream water
44. Did you treat the water? How? Yes, used a guinea worm cloth filter
45. Do you think the BSF improves your family's health? Yes

Table 19: HydrAid BSF Sibi 09 flow rate raw data

Date:	Day:	Time:	Q (L/min):
24-Aug	1	14:47	1.25
24-Aug	1	14:49	1.25
28-Aug	5	10:41	0.48
28-Aug	5	10:43	0.47
***Maintenance------------------------------------**			
28-Aug	5	10:52	0.73
28-Aug	5	10:54	0.73
31-Aug	8	12:20	0.45
***Washed 1/2 of 3rd Layer**			
31-Aug	8.4	13:08	1.58
31-Aug	8.4	13:10	1.58
***Installed 4th layer**			
31-Aug	8.8	13:29	0.77
31-Aug	8.8	13:30	0.77
15-Sep	23	10:10	0.58
15-Sep	23	10:11	0.57
20-Sep	28	16:50	0.48
***Maintenance------------------------------------**			
20-Sep	28	17:03	0.56
20-Sep	28	17:05	0.56
29-Sep	37	16:39	0.32
29-Sep	37	16:42	0.31
9-Oct	47	9:05	0.37
9-Oct	47	9:09	0.37
12-Oct	50	12:08	0.29
22-Oct	60	3:00	0.26
22-Oct	60	3:02	0.25
22-Oct	60	3:04	0.25

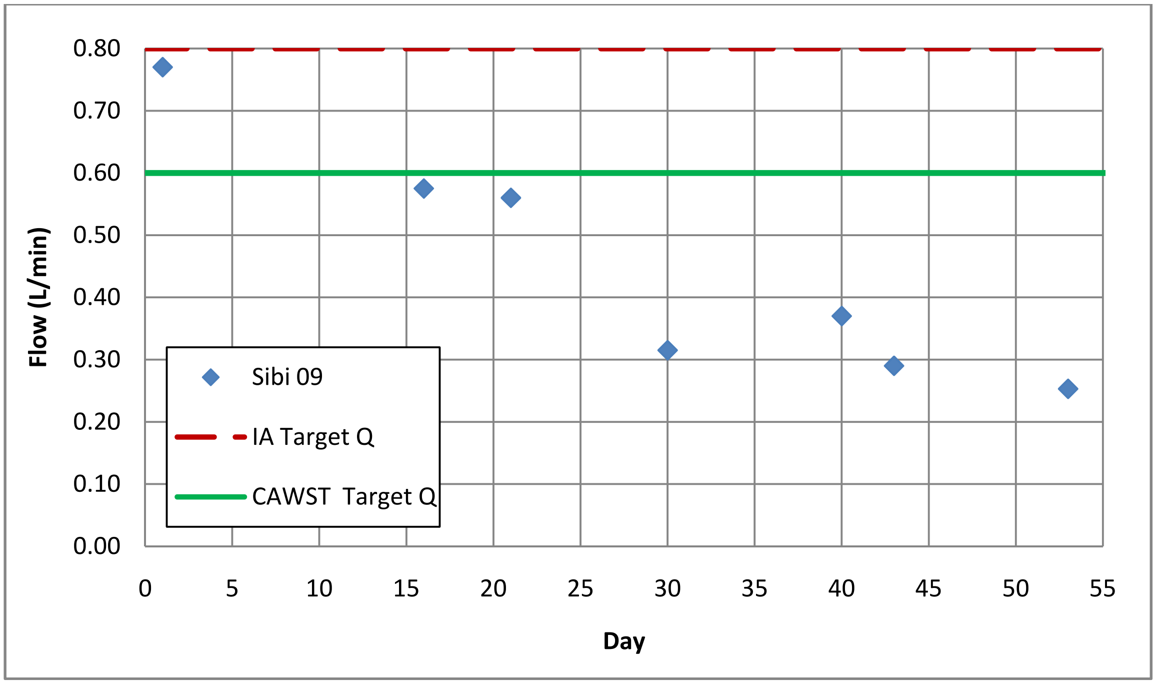

Figure 80: Adjusted-average flow rate measurements for HydrAid™ BioSand Filter Sibi 09. Recommended flow rates by the Center for Affordable Water and Sanitation Technology (CAWST) and International Aid (IA) are also graphed at 0.6 L/min and 0.8 L/min, respectively. A general range of acceptable flow rates is from a maximum of 1 L/min to a minimum that is determined by the user to be the lowest acceptable flow rate (e.g. 0.4 L/min).

Figure 81: Effluent water sample (right) from HydrAid™ BioSand Filter Sibi 09 showing "No Apparent Changes" in color in comparison with the raw source water (left)

Sibi 10 – Adam Chanuri, Bigbem Clan

Figure 82: Sibi Hilltop community map (middle) identifying the household location (bottom) where the homeowner (top) and his family use HydrAid™ BioSand Filter Sibi 10

Survey Results

1. Name: Adam Chanuri
2. BSF #: Sibi 10
3. Clan: Bigbem Clan
4. Age: 49
5. Profession: Farmer, Youth Leader & Land Owner
6. Total # of people in the household: 22
7. Are all using the BSF's water? Yes
8. Location of BSF: Inside room
9. Rainwater Harvesting potential: Excellent, all metallic roofing, 4' section of gutters plus 2 corners
10. Ease of operation: (A) Easy
11. Who operates the BSF? Adam's 3 wives
12. What source water is used in the BSF? Sibi Stream
13. Do you feel the BSF is strong and durable? Yes, "because it stays in one place."
14. Which do you think would be a stronger BSF material? (B) Concrete
15. If you didn't have a BSF and you could buy one in the market, would you? Yes
16. What is the most you would be willing to pay for the IA BSF: (C) ¢75-100,000
17. Would you be willing to pay more for a concrete model? Yes
18. How much? (According to the above scale) (D) Over ¢100,000
19. What problems are you having with the BSF? None
20. BSF use frequency: 2-3 days/week, twice each day used
21. Volume per use: To the top, ~30 L
22. What do you use the filtered water for? Drinking only
23. Do you drink any other water apart from the BSF effluent? No
24. Is the BSF flow rate sufficient for your needs? Yes
25. Do you prefer the effluent's taste to the influent? Yes
26. Do you prefer the effluent's color to the influent? Yes
27. Do you prefer the effluent's odor to the influent? Yes
28. Container used to collect effluent: different head pans
29. Cleaning frequency of container: before each use
30. Closed/Open container: Open
31. Is the effluent transferred to another storage vessel? Yes
32. Cleaning frequency of that vessel? 2-3 times per week
33. Why did you want a BSF? "Because of germs in the water."
34. Have you maintained your BSF using the "swirl and dump" method? No
35. Maintenance frequency: N/A
36. Ease of cleaning: N/A
37. Does the flow rate increase after maintenance? N/A
38. Does the taste change after maintenance (compared to the normal effluent)? N/A
39. Do you clean the exterior of the BSF? Yes
40. # of household members in age brackets: (a.) 0-5 yrs = 4, (b.) 6-12 yrs = 5, (c.) 13-18 yrs = 6, (d.) above 18 yrs = 7
41. Incidence of diarrhea in each age bracket since the dam dried up (end of March) and the BSF was installed: (a.) 2x (b.) 0 (c.) 0 (d.) 2x
42. Diarrhea incidence since BSF installation in each age bracket: (a.) 1x (b.) 0 (c.) 0 (d.) 1x
43. At this time last year what water were you drinking? Stream water
44. Did you treat the water? How? Yes, used a guinea worm cloth filter
45. Do you think the BSF improves your family's health? Yes

Table 20: HydrAid BSF Sibi 10 flow rate raw data

Date:	Day:	Time:	Q (L/min):
25-Aug	1	11:46	2
25-Aug	1	11:48	2
28-Aug	4	11:30	2.22
28-Aug	4	11:32	2.14
30-Aug	6	12:06	2.07
30-Aug	6	12:08	2.07
*Installed 4th Layer -----30-Aug----------------			
30-Aug	6	12:27	0.92
30-Aug	6	12:29	0.91
15-Sep	22	11:36	0.79
15-Sep	22	11:37	0.79
20-Sep	27	18:14	0.83
20-Sep	27	18:15	0.81
29-Sep	36	6:26	0.79
29-Sep	36	6:28	0.78
9-Oct	46	17:28	0.77
9-Oct	46	17:31	0.77
22-Oct	59	6:51	0.71
22-Oct	59	6:52	0.71
22-Oct	59	6:53	0.71

Figure 83: Adjusted-average flow rate measurements for HydrAid™ BioSand Filter Sibi 10. Recommended flow rates by the Center for Affordable Water and Sanitation Technology (CAWST) and International Aid (IA) are also graphed at 0.6 L/min and 0.8 L/min, respectively. A general range of acceptable flow rates is from a maximum of 1 L/min to a minimum that is determined by the user to be the lowest acceptable flow rate (e.g. 0.4 L/min).

Figure 84: Effluent water sample (right) from HydrAid™ BioSand Filter Sibi 10 showing "Very Clear" color in comparison with the raw source water (left)

Sibi 11 – Stephen Agba, Bissagmam Clan

Figure 85: Sibi Hilltop community map (middle) identifying the household location (bottom) where the homeowner (top) and his family use HydrAid™ BioSand Filter Sibi 11

Survey Results

1. Name: Stephen Agba
2. BSF #: Sibi 11
3. Clan: Bissagmam Clan
4. Age: 29
5. Profession: Farmer
6. Total # of people in the household: 16
7. Are all using the BSF's water? Yes
8. Location of BSF: Inside extended alcove
9. Rainwater Harvesting potential: Excellent, all metallic roofing, ~20' section of gutters plus 2 corners
10. Ease of operation: (A) Easy
11. Who operates the BSF? Stephen and his wife
12. What source water is used in the BSF? Sibi Stream at the top
13. Do you feel the BSF is strong and durable? Yes
14. Which do you think would be a stronger BSF material? I don't know
15. If you didn't have a BSF and you could buy one in the market, would you? Yes
16. What is the most you would be willing to pay for the IA BSF: (D) over ¢100,000
17. Would you be willing to pay more for a concrete model? No
18. How much? (According to the above scale) (B) ¢50-75,000
19. What problems are you having with the BSF? None
20. BSF use frequency: 2x per day
21. Volume per use: To the top, ~30 L
22. What do you use the filtered water for? Drinking only
23. Do you drink any other water apart from the BSF effluent? Yes, when going to farm he drinks stream water
24. Is the flow rate sufficient for your needs? Yes
25. Do you prefer the effluent's taste to the influent? Yes
26. Do you prefer the effluent's color to the influent? Yes
27. Do you prefer the effluent's odor to the influent? Yes
28. Container used to collect effluent: clay pot
29. Cleaning frequency of container: every 3 days
30. Closed/Open container: Open
31. Is the effluent transferred to another storage vessel? No
32. Cleaning frequency of that vessel? N/A
33. Why did you want a BSF? "It saves me from drinking bad water and it saves me from getting guinea worm."
34. Have you maintained your BSF using the "swirl and dump" method? No
35. Maintenance frequency: N/A
36. Ease of cleaning: N/A
37. Does the flow rate increase after maintenance? N/A
38. Does the taste change after maintenance (compared to the normal effluent)? N/A
39. Do you clean the exterior of the BSF? Yes
40. # of household members in age brackets: (a.) 0-5 yrs = 4, (b.) 6-12 yrs = 4, (c.) 13-18 yrs = 0, (d.) above 18 yrs = 8
41. Incidence of diarrhea in each age bracket since the dam dried up (end of March) and the BSF was installed: None
42. Diarrhea incidence since BSF installation in each age bracket: None
43. At this time last year what water were you drinking? Stream water
44. Did you treat the water? How? Yes, used a guinea worm cloth filter
45. Do you think the BSF improves your family's health? Yes

Table 21: HydrAid™ BSF Sibi 11 flow rate raw data

Date:	Day:	Time:	Q (L/min):
25-Aug	1	12:43	1.67
25-Aug	1	12:45	1.67
28-Aug	4	11:10	1.5
28-Aug	4	11:12	1.5
31-Aug	7	17:30	1.43
31-Aug	7	17:32	1.5
*Installed 4th Layer -----31-Aug-----------------			
31-Aug	7	17:50	0.75
31-Aug	7	17:52	0.71
15-Sep	22	11:06	0.56
15-Sep	22	11:07	0.56
20-Sep	27	17:39	0.6
20-Sep	27	17:41	0.6
29-Sep	36	17:08	0.56
29-Sep	36	17:10	0.56
9-Oct	46	8:10	0.46
9-Oct	46	8:12	0.48
17-Oct	54	12:33	0.48
*Maintenance------------------------------------			
17-Oct	54	12:45	0.48
17-Oct	54	12:47	0.48
22-Oct	59	16:54	0.46
22-Oct	59	16:55	0.45
22-Oct	59	16:56	0.45
*Maintenance------------------------------------			
22-Oct	59	17:24	0.47

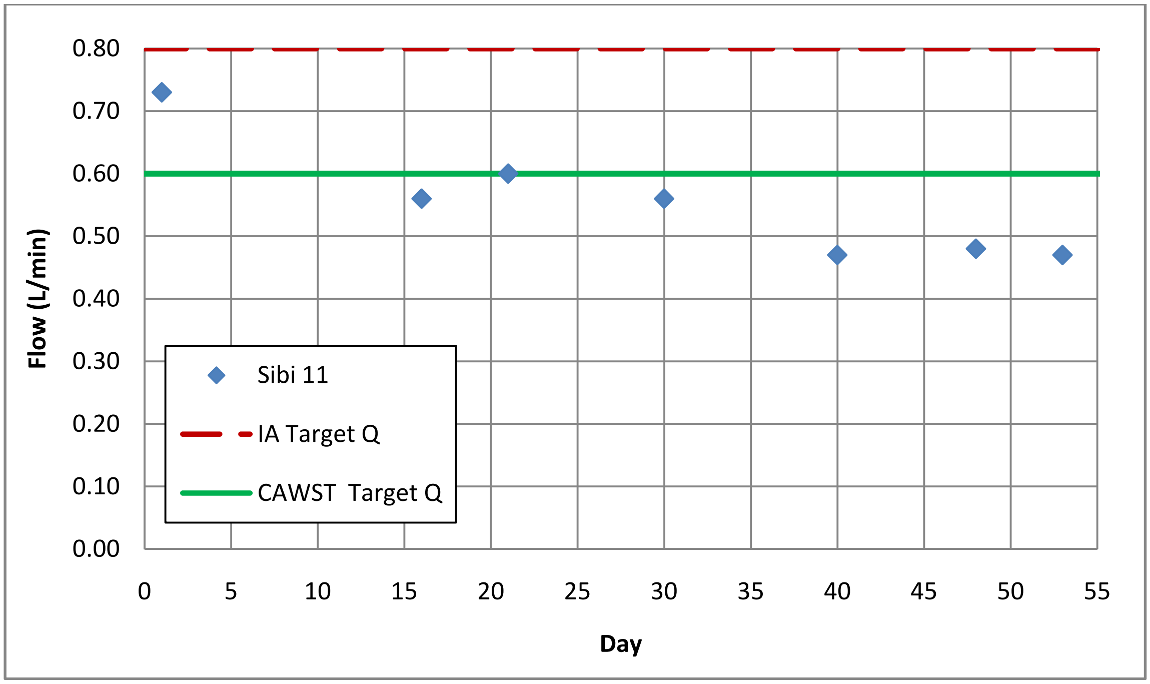

Figure 86: Adjusted-average flow rate measurements for HydrAid™ BioSand Filter Sibi 11. Recommended flow rates by the Center for Affordable Water and Sanitation Technology (CAWST) and International Aid (IA) are also graphed at 0.6 L/min and 0.8 L/min, respectively. A general range of acceptable flow rates is from a maximum of 1 L/min to a minimum that is determined by the user to be the lowest acceptable flow rate (e.g. 0.4 L/min).

Figure 87: Effluent water sample (right) from HydrAid™ BioSand Filter Sibi 11 showing "No Apparent Change" in color in comparison with the raw source water (left)

Sibi 12 – John Naboer, Wayutib West Clan

Figure 88: Sibi Hilltop community map (middle) identifying the household location (bottom) where the homeowner (top) and his family use HydrAid™ BioSand Filter Sibi 03

Survey Results

1. Name: John Naboer
2. BSF #: Sibi 12
3. Clan: Wayutib West Clan
4. Age: 27
5. Profession: Farmer
6. Total # of people in the household: 4
7. Are all using the BSF's water? Yes
8. Location of BSF: Inside enclosed kitchen with thatch roof
9. Rainwater Harvesting potential: Limited, all thatch roofing and no gutters
10. Ease of operation: (A) Easy
11. Who operates the BSF? John and his wife
12. What source water is used in the BSF? Kabunbok stream
13. Do you feel the BSF is strong and durable? Yes
14. Which do you think would be a stronger BSF material? (A) Plastic
15. If you didn't have a BSF and you could buy one in the market, would you? Yes
16. What is the most you would be willing to pay for the IA BSF: (D) over ¢100,000
17. Would you be willing to pay more for a concrete model? No
18. How much? (According to the above scale) (D) over ¢100,000
19. What problems are you having with the BSF? None
20. BSF use frequency: Once per day
21. Volume per use: To the top, ~30 L
22. What do you use the filtered water for? Drinking and cooking
23. Do you drink any other water apart from the BSF effluent? Yes, when going to farm he drinks stream water
24. Is the flow rate sufficient for your needs? Yes
25. Do you prefer the effluent's taste to the influent? Yes
26. Do you prefer the effluent's color to the influent? Yes
27. Do you prefer the effluent's odor to the influent? Yes
28. Container used to collect effluent: large head pan
29. Cleaning frequency of container: daily
30. Closed/Open container: Closed
31. Is the effluent transferred to another storage vessel? No
32. Cleaning frequency of that vessel? N/A
33. Why did you want a BSF? "To filter water for drinking and cooking for the family."
34. Have you maintained your BSF using the "swirl and dump" method? No
35. Maintenance frequency: N/A
36. Ease of cleaning: N/A
37. Does the flow rate increase after maintenance? N/A
38. Does the taste change after maintenance (compared to the normal effluent)? N/A
39. Do you clean the exterior of the BSF? Yes
40. # of household members in age brackets: (a.) 0-5 yrs = 2, (b.) 6-12 yrs = 0, (c.) 13-18 yrs = 0, (d.) above 18 yrs = 2
41. Incidence of diarrhea in each age bracket since the dam dried up (end of March) and the BSF was installed: None
42. Diarrhea incidence since BSF installation in each age bracket: None
43. At this time last year what water were you drinking? Stream water
44. Did you treat the water? How? Yes, used a guinea worm cloth filter
45. Do you think the BSF improves your family's health? Yes

Table 22: HydrAid™ BSF Sibi 12 flow rate raw data

Date:	Day:	Time:	Q (L/min):
25-Aug	1	13:38	2.31
25-Aug	1	13:40	2.14
28-Aug	4	12:45	1.36
28-Aug	4	12:47	1.36
***Installed 4th Layer -----30-Aug----------------**			
30-Aug	6	16:45	0.73
***Maintenance--**			
30-Aug	6	16:55	0.75
16-Sep	23	17:42	0.56
16-Sep	23	17:43	0.57
***Maintenance--**			
16-Sep	23	18:21	0.63
23-Sep	30	16:56	0.55
23-Sep	30	16:58	0.55
29-Sep	36	7:03	0.44
29-Sep	36	7:05	0.45
9-Oct	46	8:10	0.29
9-Oct	46	8:15	0.29
12-Oct	49	12:55	0.46
20-Oct	57	13:23	0.51
20-Oct	57	13:25	0.53
20-Oct	57	13:27	0.52
22-Oct	59	17:43	0.43
22-Oct	59	17:44	0.44
22-Oct	59	17:45	0.45

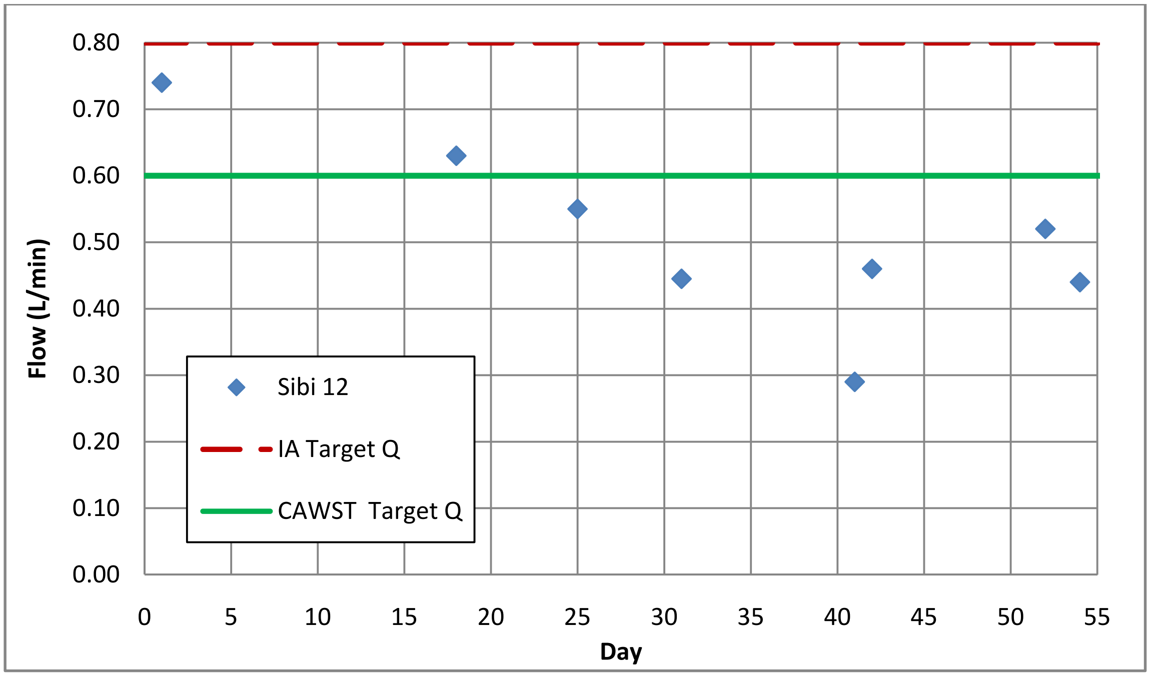

Figure 89: Adjusted-average flow rate measurements for HydrAid™ BioSand Filter Sibi 12. Recommended flow rates by the Center for Affordable Water and Sanitation Technology (CAWST) and International Aid (IA) are also graphed at 0.6 L/min and 0.8 L/min, respectively. A general range of acceptable flow rates is from a maximum of 1 L/min to a minimum that is determined by the user to be the lowest acceptable flow rate (e.g. 0.4 L/min).

Figure 90: Effluent water sample (right) from HydrAid™ BioSand Filter Sibi 12 showing "Improved" color in comparison with the raw source water (left)

Appendix B: Laboratory Results for Water Quality Testing

First Sampling

Summary of Results for Coliform Testing

COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH

WATER RESEARCH INSTITUTE

Our Ref:........................ 3rd September, 2007

ANALYTICAL REPORT

INTERNATIONAL AID,.
P. O. BOX CT 3439,
CANTONMENTS, ACCRA

Attn: MR. OSMANU MUMUNI

Date of arrival : 29.08.07
Time of analysis : 4.05 p.m.
Start of analysis : 29.08.07
End of analysis : 31.08.07

Journal Number **EBDH 08-07-45**

Sample Identification	**Total Coliform (TC) (CFU/100ml) Method:** APHA 9222A	**Faecal Coliform (FC) (CFU/100ml) Method:** APHA 9222D	**Total Heterotrophic Bacteria (CFU/1ml) Method:** APHA 9215B
CB 021A Raw	3520	837	808
CB 021A Filtered	1675	208	332
CB 051A Raw	2230	651	544
CB 051A Filtered	672	12	232
CB 061A Raw	2420	232	772
CB 061A Filtered	6	0	308
Ghana Standards	0	0	1000
WHO Guidelines	0	0	-

REMARKS: **All the Water samples supplied fro analysis do not** qualify to be used as drinking water sources. They do not conform to WHO guidelines and GS 175 Standard of zero total and faecal coliform bacteria per 100ml of the water sample. There is remarkable reduction in bacteria population when the raw water is filtered in all cases. However, the filtration systems do not remove all the bacteria pathogens.

Yours sincerely,

(Dr. J. A. Ampofo)
Head of Microbiology
Environmental Biology & Health Division

Head Office: P. O. Box AH 38, Achimota, Ghana Or P. O. Box M 32 Accra
Tel: (+233-21) 775351/52, 761031
Fax: (+233-21) 777170, 761030. Eimail:wri@ghana.com

Location: CSIR Premises, Airport Res. Area
Behind Golden Tulip
Off 37 - Achimota Road

Sibi 02 – Physico-Chemical Characteristic Results, Raw Water

Analysis Results

Water Research Institute, Environmental Chemistry Division
CSIR Premises, Airport Res. Area
P. O. Box M. 32
Accra, Ghana
Phone: (+233-21) 775351/52 Fax: (+233-21) 777170 E-mail: wri@ghana.com

Order ID — ***Company Name*** ***International Aid***
Contact First Name — *Contact Last Name*
Billing Address
Postal Code — ***City*** ***Accra***

Lab Code — ***Site Name***
Sample ID ***CBO 2/A Raw*** — ***Receipt date*** ***30/8/07***
Analysis start date ***31/9/07*** — ***Analysis stop date*** ***6/9/07***

Parameter	Method No.	Unit	Value	WHO Guideline
Turbidity	3	NTU	119	5
Colour (apparent)	2	Hz	20.0	15
Odour		-	-	Inoffensive
pH	4	pH Units	7.30	6.5-8.5
Conductivity	1	µS/cm	64.3	-
Tot. Susp. Solids (SS)	5	mg/l	30.0	-
Tot. Dis. Solids (TDS)	6	mg/l	35.4	1000
Sodium	30	mg/l	10.0	200
Potassium	29	mg/l	1.50	30
Calcium	23	mg/l	7.20	200
Magnesium	26	mg/l	2.40	150
Total Iron	31	mg/l	2.84	0.3
Ammonium (NH_4-N)	13	mg/l	<0.001	0.00-1.5
Chloride	24	mg/l	2.00	250
Sulphate (SO_4)	19	mg/l	17.0	400
Phosphate (PO_4-P)	17	mg/l	0.457	-
Manganese	26	mg/l	0.046	0.5

Nitrite (NO_2-N)	14	mg/l	0.058	1.0
Nitrate (NO_3-N)	15	mg/l	1.33	10
Total Hardness (as $CaCO_3$)	25	mg/l	28.0	500
Total Alkalinity (as $CaCO_3$)	22	mg/l	36.0	-
Calcium Hardness (as $CaCO_3$)	23	mg/l	18.0	-
Mag. Hardness (as $CaCO_3$)	26	mg/l	10.0	-
Fluoride	20	mg/l	<0.005	1.5
Bicarbonate (as $CaCO_3$)	22	mg/l	43.9	
Carbonate	22	mg/l	0.00	

Remarks: **Iron and Turbidity levels exceeded the guideline values. However, the other physico-chemical constituents of the water sample are satisfactory.**

Approved by:

Dr. Osmund D. Ansa-Asare (Head, ECD)

CSIR WATER RESEARCH INSTITUTE
P. O: BOX M 32, ACCRA
P: O: BOX 38 ACHIMOTA

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Sibi 02 – Physico-Chemical Characteristic Results, Filtered Water

Analysis Results

Water Research Institute, Environmental Chemistry Division
CSIR Premises, Airport Res. Area
P. O. Box M. 32
Accra, Ghana
Phone: (+233-21) 775351/52 Fax: (+233-21) 777170 E-mail: wri@ghana.com

Order ID ***Company Name*** ***International Aid***
Contact First Name *Contact Last Name*
Billing Address
Postal Code ***City*** ***Accra***

Lab Code ***Site Name***
Sample ID ***CBO 2/A Filtered*** ***Receipt date*** ***30/8/07***
Analysis start date ***31/9/07*** ***Analysis stop date*** ***6/9/07***

Parameter	Method No.	Unit	Value	WHO Guideline
Turbidity	3	NTU	124	5
Colour (apparent)	2	Hz	20.0	15
Odour		-	-	Inoffensive
pH	4	pH Units	7.80	6.5-8.5
Conductivity	1	µS/cm	82.0	-
Tot. Susp. Solids (SS)	5	mg/l	24.0	-
Tot. Dis. Solids (TDS)	6	mg/l	45.1	1000
Sodium	30	mg/l	11.3	200
Potassium	29	mg/l	2.70	30
Calcium	23	mg/l	12.0	200
Magnesium	26	mg/l	2.90	150
Total Iron	31	mg/l	3.23	0.3
Ammonium (NH_4-N)	13	mg/l	<0.001	0.00-1.5
Chloride	24	mg/l	2.00	250
Sulphate (SO_4)	19	mg/l	22.4	400
Phosphate (PO_4-P)	17	mg/l	0.104	-
Manganese	26	mg/l	0.047	0.5

Nitrite (NO_2-N)	14	mg/l	0.044	1.0
Nitrate (NO_3-N)	15	mg/l	1.28	10
Total Hardness (as $CaCO_3$)	25	mg/l	42.0	500
Total Alkalinity (as $CaCO_3$)	22	mg/l	44.0	-
Calcium Hardness (as $CaCO_3$)	23	mg/l	30.1	-
Mag. Hardness (as $CaCO_3$)	26	mg/l	11.9	-
Fluoride	20	mg/l	<0.005	1.5
Bicarbonate (as $CaCO_3$)	22	mg/l	53.7	
Carbonate	22	mg/l	0.00	

Remarks: **Iron and Turbidity level exceeded the guideline values. However, the other physico-chemical constituents of the water sample are satisfactory.**

Approved by:

Osmund

Dr. Osmund D. Ansa-Asare (Head, ECD)

CSIR WATER RESEARCH INSTITUTE
P. O: BOX M 32, ACCRA
P. O: BOX 38 ACHIMOTA

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Sibi 05 – Physico-Chemical Characteristic Results, Raw Water

Analysis Results

Water Research Institute, Environmental Chemistry Division
CSIR Premises, Airport Res. Area
P. O. Box M. 32
Accra, Ghana
Phone: (+233-21) 775351/52 Fax: (+233-21) 777170 E-mail: wri@ghana.com

Order ID | ***Company Name*** ***International Aid***
Contact First Name | *Contact Last Name*
Billing Address
Postal Code | ***City*** ***Accra***

Lab Code | ***Site Name***
Sample ID ***CBO 5/A Raw*** | ***Receipt date*** ***30/8/07***
Analysis start date ***31/9/07*** | ***Analysis stop date*** ***6/9/07***

Parameter	Method No.	Unit	Value	WHO Guideline
Turbidity	3	NTU	118	5
Colour (apparent)	2	Hz	16.0	15
Odour		-	-	Inoffensive
pH	4	pH Units	7.32	6.5-8.5
Conductivity	1	µS/cm	53.5	-
Tot. Susp. Solids (SS)	5	mg/l	25.0	-
Tot. Dis. Solids (TDS)	6	mg/l	29.4	1000
Sodium	30	mg/l	9.60	200
Potassium	29	mg/l	0.882	30
Calcium	23	mg/l	5.60	200
Magnesium	26	mg/l	1.90	150
Total Iron	31	mg/l	1.70	0.3
Ammonium (NH_4-N)	13	mg/l	<0.001	0.00-1.5
Chloride	24	mg/l	2.00	250
Sulphate (SO_4)	19	mg/l	11.1	400
Phosphate (PO_4-P)	17	mg/l	0.355	-
Manganese	26	mg/l	0.004	0.5

Nitrite (NO_2-N)	14	mg/l	0.103	1.0
Nitrate (NO_3-N)	15	mg/l	1.89	10
Total Hardness (as $CaCO_3$)	25	mg/l	22.0	500
Total Alkalinity (as $CaCO_3$)	22	mg/l	32.0	-
Calcium Hardness (as $CaCO_3$)	23	mg/l	14.0	-
Mag. Hardness (as $CaCO_3$)	26	mg/l	8.00	-
Fluoride	20	mg/l	<0.005	1.5
Bicarbonate (as $CaCO_3$)	22	mg/l	39.0	
Carbonate	22	mg/l	0.00	

Remarks: **Iron and Turbidity exceeded their guideline values. However, the other physico-chemical constituents of the water sample are satisfactory.**

Approved by:

Osmund

Dr. Osmund D. Ansa-Asare (Head, ECD)

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Sibi 05 – Physico-Chemical Characteristic Results, Filtered Water

Analysis Results

Water Research Institute, Environmental Chemistry Division
CSIR Premises, Airport Res. Area
P. O. Box M. 32
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Phone: (+233-21) 775351/52 Fax: (+233-21) 777170 E-mail: wri@ghana.com

Order ID — ***Company Name*** ***International Aid***
Contact First Name — *Contact Last Name*
Billing Address
Postal Code — ***City*** ***Accra***

Lab Code — ***Site Name***
Sample ID ***CBO 5/A Filtered*** — ***Receipt date*** ***30/8/07***
Analysis start date ***31/9/07*** — ***Analysis stop date*** ***6/9/07***

Parameter	Method No.	Unit	Value	WHO Guideline
Turbidity	3	NTU	85.0	5
Colour (apparent)	2	Hz	10.0	15
Odour		-	-	Inoffensive
pH	4	pH Units	7.88	6.5-8.5
Conductivity	1	µS/cm	99.5	-
Tot. Susp. Solids (SS)	5	mg/l	12.0	-
Tot. Dis. Solids (TDS)	6	mg/l	54.7	1000
Sodium	30	mg/l	10.3	200
Potassium	29	mg/l	1.20	30
Calcium	23	mg/l	10.4	200
Magnesium	26	mg/l	4.80	150
Total Iron	31	mg/l	1.11	0.3
Ammonium (NH_4-N)	13	mg/l	<0.001	0.00-1.5
Chloride	24	mg/l	2.00	250
Sulphate (SO_4)	19	mg/l	8.53	400
Phosphate (PO_4-P)	17	mg/l	0.607	-
Manganese	26	mg/l	0.007	0.5

Nitrite (NO_2-N)	14	mg/l	0.096	1.0
Nitrate (NO_3-N)	15	mg/l	1.86	10
Total Hardness (as $CaCO_3$)	25	mg/l	46.0	500
Total Alkalinity (as $CaCO_3$)	22	mg/l	56.0	-
Calcium Hardness (as $CaCO_3$)	23	mg/l	26.1	-
Mag. Hardness (as $CaCO_3$)	26	mg/l	19.9	-
Fluoride	20	mg/l	<0.005	1.5
Bicarbonate (as $CaCO_3$)	22	mg/l	68.3	
Carbonate	22	mg/l	0.00	

Remarks: **Iron and Turbidity level exceeded their guideline values. However, the other physico-chemical constituents of the water sample are satisfactory.**

Approved by:

Osmund

Dr. Osmund D. Ansa-Asare (Head, ECD)
CSIR WATER RESEARCH INSTITUTE
P. O: BOX M 32, ACCRA
P: O: BOX 38 ACHIMOTA

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Sibi 06 – Physico-Chemical Characteristic Results, Raw Water

Analysis Results

Water Research Institute, Environmental Chemistry Division
CSIR Premises, Airport Res. Area
P. O. Box M. 32
Accra, Ghana
Phone: (+233-21) 775351/52 Fax: (+233-21) 777170 E-mail: wri@ghana.com

Order ID		***Company Name***	***International Aid***
Contact First Name		*Contact Last Name*	
Billing Address			
Postal Code		***City***	***Accra***

Lab Code		***Site Name***	
Sample ID	***CBO 6/A Raw***	***Receipt date***	***30/8/07***
Analysis start date	***31/9/07***	***Analysis stop date***	***6/9/07***

Parameter	Method No.	Unit	Value	WHO Guideline
Turbidity	3	NTU	25.4	5
Colour (apparent)	2	Hz	5.00	15
Odour		-	-	Inoffensive
pH	4	pH Units	7.14	6.5-8.5
Conductivity	1	µS/cm	34.1	-
Tot. Susp. Solids (SS)	5	mg/l	6.00	-
Tot. Dis. Solids (TDS)	6	mg/l	18.8	1000
Sodium	30	mg/l	3.20	200
Potassium	29	mg/l	0.654	30
Calcium	23	mg/l	3.20	200
Magnesium	26	mg/l	1.90	150
Total Iron	31	mg/l	0.294	0.3
Ammonium (NH_4-N)	13	mg/l	<0.001	0.00-1.5
Chloride	24	mg/l	2.00	250
Sulphate (SO_4)	19	mg/l	1.00	400
Phosphate (PO_4-P)	17	mg/l	0.291	-
Manganese	26	mg/l	0.044	0.5

Nitrite (NO_2-N)	14	mg/l	0.039	1.0
Nitrate (NO_3-N)	15	mg/l	1.82	10
Total Hardness (as $CaCO_3$)	25	mg/l	16.0	500
Total Alkalinity (as $CaCO_3$)	22	mg/l	18.0	-
Calcium Hardness (as $CaCO_3$)	23	mg/l	8.00	-
Mag. Hardness (as $CaCO_3$)	26	mg/l	8.00	-
Fluoride	20	mg/l	<0.005	1.5
Bicarbonate (as $CaCO_3$)	22	mg/l	22.0	
Carbonate	22	mg/l	0.00	

Remarks: **Turbidity level exceeded the guideline value. However the other physico-chemical constituents of the water sample are satisfactory.**

Approved by:

Dr. Osmund D. Ansa-Asare (Head, ECD)

CSIR WATER RESEARCH INSTITUTE
P. O: BOX M 32, ACCRA
P: O: BOX 38 ACHIMOTA

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Sibi 06 – Physico-Chemical Characteristic Results, Filtered Water

Analysis Results

Water Research Institute, Environmental Chemistry Division
CSIR Premises, Airport Res. Area
P. O. Box M. 32
Accra, Ghana
Phone: (+233-21) 775351/52 Fax: (+233-21) 777170 E-mail: wri@ghana.com

Order ID — ***Company Name*** ***International Aid***
Contact First Name — *Contact Last Name*
Billing Address
Postal Code — ***City*** ***Accra***

Lab Code — ***Site Name***
Sample ID ***CBO 61/A Filtered*** — ***Receipt date*** ***30/8/07***
Analysis start date ***31/9/07*** — ***Analysis stop date*** ***6/9/07***

Parameter	Method No.	Unit	Value	WHO Guideline
Turbidity	3	NTU	19.4	5
Colour (apparent)	2	Hz	5.00	15
Odour		-	-	Inoffensive
pH	4	pH Units	7.80	6.5-8.5
Conductivity	1	µS/cm	97.0	-
Tot. Susp. Solids (SS)	5	mg/l	4.00	-
Tot. Dis. Solids (TDS)	6	mg/l	53.4	1000
Sodium	30	mg/l	8.30	200
Potassium	29	mg/l	2.10	30
Calcium	23	mg/l	10.4	200
Magnesium	26	mg/l	3.90	150
Total Iron	31	mg/l	0.069	0.3
Ammonium (NH_4-N)	13	mg/l	<0.001	0.00-1.5
Chloride	24	mg/l	1.00	250
Sulphate (SO_4)	19	mg/l	1.00	400
Phosphate (PO_4-P)	17	mg/l	<0.001	-
Manganese	26	mg/l	0.025	0.5

Nitrite (NO_2-N)	14	mg/l	0.249	1.0
Nitrate (NO_3-N)	15	mg/l	6.54	10
Total Hardness (as $CaCO_3$)	25	mg/l	42.0	500
Total Alkalinity (as $CaCO_3$)	22	mg/l	50.0	-
Calcium Hardness (as $CaCO_3$)	23	mg/l	26.1	-
Mag. Hardness (as $CaCO_3$)	26	mg/l	15.9	-
Fluoride	20	mg/l	<0.005	1.5
Bicarbonate (as $CaCO_3$)	22	mg/l	61.0	
Carbonate	22	mg/l	0.00	

Remarks: **Turbidity level exceeded the guideline value. However, the other physico-chemical constituents of the water sample are satisfactory.**

Approved by:

Osmund

Dr. Osmund D. Ansa-Asare (Head, ECD)

CSIR WATER RESEARCH INSTITUTE
P. O: BOX M 32, ACCRA
P: O: BOX 38 ACHIMOTA

The analytical results relate only to the samples analysed. The bracket (<) indicates value below detection limit. P = Provisional Guideline Value.

Filtered Water Physico-Chemical Comparison with WHO Standards

Table 23: Sibi 02 Physico-chemical characteristic analysis collected on 8/28/2007 (Day 6)

Characteristic:	Raw	Filtered	%	WHO Std	Complies?
Turbidity (NTU)	119	124	4%	5	No
Color (apparent)	20	20	0%	15	No
Odor	-	-	-	Inoffensive	-
pH	7.3	7.8	7%	6.5 - 8.5	Yes
Conductivity	64.3	82	28%	-	-
Tot. Susp. Solids (mg/l)	30	24	-20%	-	-
Tot. Dis. Solids (mg/l)	35.4	45.1	27%	1000	Yes
Sodium (mg/l)	10	11.3	13%	200	Yes
Potassium (mg/l)	1.5	2.7	80%	30	Yes
Calcium (mg/l)	7.2	12	67%	200	Yes
Magnesium (mg/l)	2.4	2.9	21%	150	Yes
Total Iron (mg/l)	2.84	3.23	14%	0.3	No
Ammonium (mg/l)	<0.001	<0.001	-	0 - 1.5	-
Chloride (mg/l)	2	2	0%	250	Yes
Sulfate (mg/l)	17	22.4	32%	400	Yes
Phosphate (mg/l)	0.457	0.104	-77%	-	-
Manganese (mg/l)	0.046	0.047	2%	0.5	Yes
Nitrite (mg/l)	0.058	0.044	-24%	1	Yes
Nitrate (mg/l)	1.33	1.28	-4%	10	Yes
Tot Hardness as CaCO3 (mg/l)	28	42	50%	500	Yes
Tot Alkalinity as CaCO3 (mg/l)	36	44	22%	-	-
Ca Hardness as CaCO3 (mg/l)	18	30.1	67%	-	-
Mg Hardness as CaCO3 (mg/l)	10	11.9	19%	-	-
Fluoride (mg/l)	<0.005	<0.005		1.5	Yes
Bicarbonate as CaCO3 (mg/l)	43.9	53.7	22%	-	-
Carbonate (mg/l)	0	0	-	-	-

Table 24: Sibi 05 Physico-chemical characteristic analysis collected on 8/28/2007 (Day 5)

Characteristic:	Raw	Filtered	%	WHO Std	Complies?
Turbidity (NTU)	118	85	-28%	5	No
Color (apparent)	16	10	-38%	15	No
Odor	-	-	-	Inoffensive	-
pH	7.32	7.88	8%	6.5 - 8.5	Yes
Conductivity	53.5	99.5	86%	-	-
Tot. Susp. Solids (mg/l)	25	12	-52%	-	-
Tot. Dis. Solids (mg/l)	29.4	54.7	86%	1000	Yes
Sodium (mg/l)	9.6	10.3	7%	200	Yes
Potassium (mg/l)	0.882	1.2	36%	30	Yes
Calcium (mg/l)	5.6	10.4	86%	200	Yes
Magnesium (mg/l)	1.9	4.8	153%	150	Yes
Total Iron (mg/l)	1.7	1.11	-35%	0.3	No
Ammonium (mg/l)	<0.001	<0.001	-	0 - 1.5	Yes
Chloride (mg/l)	2	2	0%	250	Yes
Sulfate (mg/l)	11.1	8.53	-23%	400	Yes
Phosphate (mg/l)	0.355	0.607	71%	-	-
Manganese (mg/l)	0.004	0.007	75%	0.5	Yes
Nitrite (mg/l)	0.103	0.096	-7%	1	Yes
Nitrate (mg/l)	1.89	1.86	-2%	10	Yes
Tot Hardness as CaCO3 (mg/l)	22	46	109%	500	Yes
Tot Alkalinity as CaCO3 (mg/l)	32	56	75%	-	-
Ca Hardness as CaCO3 (mg/l)	14	26.1	86%	-	-
Mg Hardness as CaCO3 (mg/l)	8	19.9	149%	-	-
Fluoride (mg/l)	<0.005	<0.005	-	1.5	Yes
Bicarbonate as CaCO3 (mg/l)	39	68.3	75%	-	-
Carbonate (mg/l)	0	0	-	-	-

Table 25: Sibi 06 Physico-chemical characteristic analysis collected on 8/28/2007 (Day 5)

Characteristic:	Raw	Filtered	%	WHO Std	Complies?
Turbidity (NTU)	25.4	19.4	-24%	5	No
Color (apparent)	5	5	0%	15	Yes
Odor	-	-	-	Inoffensive	-
pH	7.14	7.8	9%	6.5 - 8.5	Yes
Conductivity	34.1	97	184%	-	-
Tot. Susp. Solids (mg/l)	6	4	-33%	-	-
Tot. Dis. Solids (mg/l)	18.8	53.4	184%	1000	Yes
Sodium (mg/l)	3.2	8.3	159%	200	Yes
Potassium (mg/l)	0.654	2.1	221%	30	Yes
Calcium (mg/l)	3.2	10.4	225%	200	Yes
Magnesium (mg/l)	1.9	3.9	105%	150	Yes
Total Iron (mg/l)	0.294	0.069	-77%	0.3	Yes
Ammonium (mg/l)	<0.001	<0.001		0 - 1.5	Yes
Chloride (mg/l)	2	1	-50%	250	Yes
Sulfate (mg/l)	1	1	0%	400	Yes
Phosphate (mg/l)	0.291	<0.001	>99.6%	-	-
Manganese (mg/l)	0.044	0.025	-43%	0.5	Yes
Nitrite (mg/l)	0.039	0.249	538%	1	Yes
Nitrate (mg/l)	1.82	6.54	259%	10	Yes
Tot Hardness as CaCO3 (mg/l)	16	42	163%	500	Yes
Tot Alkalinity as CaCO3 (mg/l)	18	50	178%	-	-
Ca Hardness as CaCO3 (mg/l)	8	26.1	226%	-	-
Mg Hardness as CaCO3 (mg/l)	8	15.9	99%	-	-
Fluoride (mg/l)	<0.005	<0.005	-	1.5	Yes
Bicarbonate as CaCO3 (mg/l)	22	61	177%	-	-
Carbonate (mg/l)	0	0	-	-	-

Second Sampling: Summary of Results for Coliform Testing

COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH

WATER RESEARCH INSTITUTE

WATER QUALITY LABORATORY
P.O. Box TL 695, TAMALE.
Tel. 071 23448,Fax 071 23449

RESULTS OF MICROBIOLOGICAL ANALYSIS

Analysis Start Date: 17/10/07 Analysis Stop Date: 19/10/07

CLIENT: International Aid CONTACT: Mumuni Osman

No.	SOURCE	TOTAL COLIFORM (cfu/100ml)	FAECAL COLIFORM (cfu/100ml)
1	Sibi 02 (Raw)	760	90
2	Sibi 02 (Filtered)	215	0
3	Sibi 05 (Raw)	1880	140
4	Sibi 05 (Filtered)	365	60
5	Sibi 06 (Raw)	780	115
6	Sibi 06 (Filtered)	0	0
7	Sibi 08 (Raw)	2500	145
8	Sibi 08 (Filtered)	200	10
9	Sibi 09 (Raw)	1560	350
10	Sibi 09 (Filtered)	200	75
11	Sibi 12 (Raw)	260	185
12	Sibi 12 (Filtered)	0	0

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Samuel J.Cobbina
(Officer Laboratory Services-ECD)

Appendix C: Additional Flow Rate Data

Table 26: Phase 3 Raw Data

BSF #:	Name:	Clan:	Date:	Day:	Time:	Flow L/min	Color:
13	Kingsley Kpadin, ZC	Nakpando	10-Oct	1	17:35	0.58	
13	Kingsley Kpadin	Nakpando	10-Oct	1	17:36	0.59	
13	Kingsley Kpadin	Nakpando	17-Oct	8	14:03	0.5	
13	Kingsley Kpadin	Nakpando	17-Oct	8	14:05	0.5	
13	Kingsley Kpadin	Nakpando	17-Oct	8	14:08	0.5	
13	Kingsley Kpadin	Nakpando	20-Oct	11	11:20	0.46	Improved
13	Kingsley Kpadin	Nakpando	20-Oct	11	11:23	0.46	Improved
13	Kingsley Kpadin	Nakpando	20-Oct	11	11:25	0.45	Improved
14	Nborbi Nwaki, CBS	Bissagmam	10-Oct	1	11:40	1.11	
14	Nborbi Nwaki	Bissagmam	10-Oct	1	11:45	1.15	
14	Nborbi Nwaki	Bissagmam	17-Oct	8	12:04	0.64	
14	Nborbi Nwaki	Bissagmam	17-Oct	8	12:06	0.63	
14	Nborbi Nwaki	Bissagmam	17-Oct	8	12:09	0.63	
15	Nborbi Uwuborlamaa	Bissagmam	10-Oct	1	12:17	1.5	
15	Nborbi Uwuborlamaa	Bissagmam	10-Oct	1	12:18	1.5	
15	*---Maintenance-------						
15	Nborbi Uwuborlamaa	Bissagmam	17-Oct	8	12:23	0.48	
15	Nborbi Uwuborlamaa	Bissagmam	17-Oct	8	12:24	0.48	
15	Nborbi Uwuborlamaa	Bissagmam	17-Oct	8	12:26	0.48	
16	Lifu Obori	Bissagmam	10-Oct	1	13:50	1	
16	Lifu Obori	Bissagmam	10-Oct	1	13:55	1.07	
16	Lifu Obori	Bissagmam	17-Oct	8	12:57	0.55	
16	*---Maintenance----						
16	Lifu Obori	Bissagmam	17-Oct	8	13:06	0.69	
16	Lifu Obori	Bissagmam	17-Oct	8	13:08	0.68	
17	Ngibiche Ngorba	Bikpalib	10-Oct	1	14:20	1.15	
17	Ngibiche Ngorba	Bikpalib	10-Oct	1	14:25	1.15	
17	Ngibiche Ngorba	Bikpalib	17-Oct	8	13:17	1.09	
17	Ngibiche Ngorba	Bikpalib	17-Oct	8	13:19	1.09	
17	Ngibiche Ngorba	Bikpalib	17-Oct	8	13:20	1.07	
18	Ama Kunjin, RCMC	Bekom East	10-Oct	1	12:14	0.91	
18	Ama Kunjin	Bekom East	10-Oct	1	12:15	0.94	
18	Ama Kunjin	Bekom East	17-Oct	8	13:25	0.97	
18	Ama Kunjin	Bekom East	17-Oct	8	13:26	0.91	
18	Ama Kunjin	Bekom East	17-Oct	8	13:28	0.91	
19	Bilil Komba	Bekom East	10-Oct	1	14:18	0.94	

19	Bilil Komba	Bekom East	10-Oct	1	14:19	0.91	
19	Bilil Komba	Bekom East	17-Oct	8	11:52	0.83	
19	Bilil Komba	Bekom East	17-Oct	8	11:53	0.81	
19	Bilil Komba	Bekom East	17-Oct	8	11:55	0.83	
20	Bintey	Basatib East	10-Oct	1	11:40	0.83	
20	Bintey	Basatib East	10-Oct	1	11:41	0.83	
21	Waja Jayim	Bichako	10-Oct	1	11:00	0.86	
21	Waja Jayim	Bichako	10-Oct	1	11:02	0.86	
21	Waja Jayim	Bichako	17-Oct	8	13:39	0.83	
21	Waja Jayim	Bichako	17-Oct	8	13:42	0.83	
21	Waja Jayim	Bichako	17-Oct	8	13:44	0.83	
22	Rose Talafor, RCMC	Kpajotib	10-Oct	1	15:07	1.03	
22	Rose Talafor	Kpajotib	10-Oct	1	15:09	1.03	
22	Rose Talafor	Kpajotib	17-Oct	8	12:30	0.63	
22	Rose Talafor	Kpajotib	17-Oct	8	12:31	0.63	
22	Rose Talafor	Kpajotib	17-Oct	8	12:32	0.59	
23	Zaccheus, CBS	Kpajotib	10-Oct	1	14:14	0.91	
23	Zaccheus	Kpajotib	10-Oct	1	14:15	0.9	
23	Zaccheus	Kpajotib	17-Oct	8	12:05	0.51	
23	Zaccheus	Kpajotib	17-Oct	8	12:06	0.5	
23	Zaccheus	Kpajotib	17-Oct	8	12:07	0.49	
24	Peace Biwumbu	Basatib West	10-Oct	1	15:36	0.79	
24	Peace Biwumbu	Basatib West	10-Oct	1	15:38	0.77	
24	Peace Biwumbu	Basatib West	17-Oct	8	12:55	0.43	
24	Peace Biwumbu	Basatib West	17-Oct	8	12:57	0.41	
24	Peace Biwumbu	Basatib West	17-Oct	8	12:59	0.41	
25	Kpachi Mensah,	Basatib West	10-Oct	1	12:49	0.86	
25	Kpachi Mensah	Basatib West	10-Oct	1	12:51	0.83	
25	Kpachi Mensah	Basatib West	17-Oct	8	11:51	0.7	
25	Kpachi Mensah	Basatib West	17-Oct	8	11:52	0.68	
25	Kpachi Mensah	Basatib West	17-Oct	8	11:53	0.68	
26	Joseph Niliyon, CBS	Bigbem	11-Oct	1	11:50	1.5	
26	Joseph Niliyon	Bigbem	11-Oct	1	11:52	1.2	
26	Joseph Niliyon	Bigbem	18-Oct	8	8:21	1.02	
26	Joseph Niliyon	Bigbem	18-Oct	8	8:23	1.03	
26	Joseph Niliyon	Bigbem	18-Oct	8	8:25	1.02	
27	Ndilinge Sunkpin	Bigbem	11-Oct	1	12:10	1.2	
27	Ndilinge Sunkpin	Bigbem	11-Oct	1	12:12	1.25	
27	Ndilinge Sunkpin	Bigbem	18-Oct	8	8:35	1	Very Clear
27	Ndilinge Sunkpin	Bigbem	18-Oct	8	8:37	1	Very Clear
27	Ndilinge Sunkpin	Bigbem	18-Oct	8	8:38	1	Very Clear
28	Tiada Timajah	Bigbem	11-Oct	1	12:35	1.15	
28	Tiada Timajah	Bigbem	11-Oct	1	12:38	1.25	

28	Tiada Timajah	Bigbem	18-Oct	8	9:25	1.25	Very Clear
28	Tiada Timajah	Bigbem	18-Oct	8	9:27	1.22	Very Clear
28	Tiada Timajah	Bigbem	18-Oct	8	9:28	1.22	Very Clear
29	Kudjo Dordoe	Bigbem	11-Oct	1	11:25	1	
29	Kudjo Dordoe	Bigbem	11-Oct	1	11:27	1.11	
29	Kudjo Dordoe	Bigbem	18-Oct	8	8:45	0.58	Very Clear
29	*---Maintenance----						
29	Kudjo Dordoe	Bigbem	18-Oct	8	8:56	0.6	Very Clear
29	Kudjo Dordoe	Bigbem	18-Oct	8	8:58	0.6	Very Clear
30	Attah Njomaya	Bigbem	11-Oct	1	12:50	1	
30	Attah Njomaya	Bigbem	11-Oct	1	12:52	1.36	
30	Attah Njomaya	Bigbem	18-Oct	8	9:09	1.15	Very Clear
30	Attah Njomaya	Bigbem	18-Oct	8	9:11	1.13	Very Clear
30	Attah Njomaya	Bigbem	18-Oct	8	9:13	1.15	Very Clear
31	Emmanuel Namey,	Binajub	11-Oct	1	12:56	0.92	
31	Emmanuel Namey	Binajub	11-Oct	1	12:58	0.94	
31	Emmanuel Namey	Binajub	18-Oct	8	10:18	0.62	NAC
31	Emmanuel Namey	Binajub	18-Oct	8	10:20	0.61	NAC
31	Emmanuel Namey	Binajub	18-Oct	8	10:23	0.6	NAC
32	Wunya Sei, RCMC	Binajub	11-Oct	1	14:21	1	
32	Wunya Sei	Binajub	11-Oct	1	14:22	0.98	
32	Wunya Sei	Binajub	18-Oct	8	10:31	0.41	
32	*---Maintenance----						
32	Wunya Sei	Binajub	18-Oct	8	10:48	0.71	
32	Wunya Sei	Binajub	18-Oct	8	10:49	0.71	
32	Wunya Sei	Binajub	18-Oct	8	10:50	0.71	
33	Ndati Kudjo, RCMC	Binajub	11-Oct	1	13:28	0.92	
33	Ndati Kudjo	Binajub	11-Oct	1	13:30	0.91	
33	Ndati Kudjo	Binajub	18-Oct	8	10:07	0.6	Very Clear
33	Ndati Kudjo	Binajub	18-Oct	8	10:09	0.61	Very Clear
33	Ndati Kudjo	Binajub	18-Oct	8	10:10	0.61	Very Clear
34	Samson Bijabi	Binajub	11-Oct	1	14:42	0.88	
34	Samson Bijabi	Binajub	11-Oct	1	14:43	0.88	
34	*---Maintenance---						
34	Samson Bijabi	Binajub	18-Oct	8	9:56	0.63	NAC
34	Samson Bijabi	Binajub	18-Oct	8	9:58	0.63	NAC
34	Samson Bijabi	Binajub	18-Oct	8	10:00	0.63	NAC
35	Ama Nyagme, RCMC	Kochatib	11-Oct	1	12:35	0.88	
35	Ama Nyagme	Kochatib	11-Oct	1	12:37	0.88	
35	Ama Nyagme	Kochatib	18-Oct	8	12:27	0.5	
35	Ama Nyagme	Kochatib	18-Oct	8	12:31	0.48	
35	Ama Nyagme	Kochatib	18-Oct	8	12:35	0.48	
36	Nyagnaso Okya	Kochatib	11-Oct	1	12:15	0.91	

36	Nyagnaso Okya	Kochatib	11-Oct	1	12:18	0.91	
36	Nyagnaso Okya	Kochatib	18-Oct	8	11:54	0.27	
36	*---Maintenance---						
36	Nyagnaso Okya	Kochatib	18-Oct	8	12:17	0.55	
36	Nyagnaso Okya	Kochatib	18-Oct	8	12:19	0.55	
36	Nyagnaso Okya	Kochatib	18-Oct	8	12:21	0.55	
37	Lasim Gabuja, RCMC	Kochatib	11-Oct	1	13:04	0.91	
37	Lasim Gabuja	Kochatib	11-Oct	1	13:07	0.91	
38	Jakodo Gayem	Kochatib	11-Oct	1	13:31	0.94	
38	Jakodo Gayem	Kochatib	11-Oct	1	13:33	0.97	
38	Jakodo Gayem	Kochatib	18-Oct	8	12:45	0.74	Clear
38	Jakodo Gayem	Kochatib	18-Oct	8	12:47	0.75	Clear
38	Jakodo Gayem	Kochatib	18-Oct	8	12:49	0.75	Clear
39	Okapi Bamon	Bemuabolb	12-Oct	1	10:10	0.86	
39	Okapi Bamon	Bemuabolb	12-Oct	1	10:11	0.87	
39	Okapi Bamon	Bemuabolb	20-Oct	9	13:09	0.94	Very Clear
39	Okapi Bamon	Bemuabolb	20-Oct	9	13:10	0.95	Very Clear
39	Okapi Bamon	Bemuabolb	20-Oct	9	13:11	0.94	Very Clear
40	Mercy Matipa	Nakpando	12-Oct	1	10:33	1.2	
40	Mercy Matipa	Nakpando	12-Oct	1	10:34	1.2	
40	Mercy Matipa	Nakpando	20-Oct	9	13:00	1.3	Very
40	Mercy Matipa	Nakpando	20-Oct	9	13:01	1.33	Very
40	Mercy Matipa	Nakpando	20-Oct	9	13:02	1.33	Very
41	Bijisun Nyape	Nakpando	12-Oct	1	*Installe		
41	*---Maintenance---						
41	Bijisun Nyape	Nakpando	13-Oct	2	10:32	1.28	
41	Bijisun Nyape	Nakpando	13-Oct	2	*Installe		
41	Bijisun Nyape	Nakpando	13-Oct	2	10:48	0.79	
41	Bijisun Nyape	Nakpando	13-Oct	2	10:50	0.79	
41	Bijisun Nyape	Nakpando	20-Oct	9	12:33	0.67	Improved
41	Bijisun Nyape	Nakpando	20-Oct	9	12:36	0.68	Improved
41	Bijisun Nyape	Nakpando	20-Oct	9	12:39	0.68	Improved
42	Waja Kokunja	Nakpando	12-Oct	1	11:00	1.3	
42	Waja Kokunja	Nakpando	12-Oct	1	11:01	1.3	
42	Waja Kokunja	Nakpando	20-Oct	9	11:56	1	Improved
42	Waja Kokunja	Nakpando	20-Oct	9	11:57	0.98	Improved
42	Waja Kokunja	Nakpando	20-Oct	9	11:58	0.98	Improved
43	Yao Waja	Nakpando	12-Oct	1	*Installe		
43	*---Maintenance---						
43	Yao Waja	Nakpando	13-Oct	2	11:12	0.77	
43	Yao Waja	Nakpando	13-Oct	2	11:14	0.77	
43	*--Removed 1/2 of 3rd						
43	Yao Waja	Nakpando	13-Oct	2	11:55	1.5	

43	Yao Waja	Nakpando	13-Oct	2	*Installe		
43	Yao Waja	Nakpando	13-Oct	2	12:08	0.71	
43	Yao Waja	Nakpando	13-Oct	2	12:10	0.71	
43	Yao Waja	Nakpando	20-Oct	9	12:21	0.61	NAC
43	Yao Waja	Nakpando	20-Oct	9	12:23	0.61	NAC
43	Yao Waja	Nakpando	20-Oct	9	12:25	0.61	NAC
44	Kwabena Kpadin,	Nakpando	12-Oct	1	8:40	0.75	
44	Kwabena Kpadin	Nakpando	12-Oct	1	8:42	0.79	
44	Kwabena Kpadin	Nakpando	20-Oct	9	11:03	0.65	NAC
44	Kwabena Kpadin	Nakpando	20-Oct	9	11:04	0.65	NAC
44	Kwabena Kpadin	Nakpando	20-Oct	9	11:05	0.65	NAC
45	Bebey Kpadin, RCMC	Nakpando	12-Oct	1	9:02	0.75	
45	Bebey Kpadin	Nakpando	12-Oct	1	9:04	0.75	
45	Bebey Kpadin	Nakpando	17-Oct	6	11:00	0.37	
45	Bebey Kpadin	Nakpando	20-Oct	9	11:11	0.2	Very Clear
46	Mamumbe Yawan,	Nakpando	12-Oct	1	11:09	0.86	
46	Mamumbe Yawan	Nakpando	12-Oct	1	11:12	0.83	
46	Mamumbe Yawan	Nakpando	20-Oct	9	11:43	0.56	Improved
46	Mamumbe Yawan	Nakpando	20-Oct	9	11:44	0.55	Improved
46	Mamumbe Yawan	Nakpando	20-Oct	9	11:46	0.54	Improved
47	Manyabiche Waja,	Kotolitib	12-Oct	1	*Installe		
47	Manyabiche Waja	Kotolitib	12-Oct	1	12:04	1.15	
47	Manyabiche Waja	Kotolitib	12-Oct	1	12:05	1.15	
47	Manyabiche Waja	Kotolitib	15-Oct	4	6:56	0.95	
47	Manyabiche Waja	Kotolitib	15-Oct	4	6:58	0.95	
47	Manyabiche Waja	Kotolitib	15-Oct	4	*Installe		
47	Manyabiche Waja	Kotolitib	15-Oct	4	7:13	0.72	
47	Manyabiche Waja	Kotolitib	15-Oct	4	7:16	0.72	
47	Manyabiche Waja	Kotolitib	20-Oct	9	11:33	0.71	NAC
47	Manyabiche Waja	Kotolitib	20-Oct	9	11:35	0.7	NAC
47	Manyabiche Waja	Kotolitib	20-Oct	9	11:37	0.7	NAC
48	Mawan Tibindan	Kotolitib	12-Oct	1	*Installe		
48	Mawan Tibindan	Kotolitib	12-Oct	1	11:17	1.67	
48	Mawan Tibindan	Kotolitib	12-Oct	1	11:19	1.67	
48	Mawan Tibindan	Kotolitib	15-Oct	4	7:35	1.62	
48	Mawan Tibindan	Kotolitib	15-Oct	4	*Installe		
48	Mawan Tibindan	Kotolitib	15-Oct	4	7:51	0.64	
48	Mawan Tibindan	Kotolitib	15-Oct	4	7:53	0.62	
48	Mawan Tibindan	Kotolitib	20-Oct	9	12:46	0.63	Improved
48	Mawan Tibindan	Kotolitib	20-Oct	9	12:48	0.63	Improved
48	Mawan Tibindan	Kotolitib	20-Oct	9	12:50	0.64	Improved
49	Koln Nanya	W. Bemuabolb	12-Oct	1	10:07	0.65	
49	Koln Nanya	W. Bemuabolb	12-Oct	1	10:08	0.64	

49	Koln Nanya	W. Bemuabolb	20-Oct	9	14:06	0.32	Improved
49	Koln Nanya	W. Bemuabolb	20-Oct	9	14:09	0.32	Improved
49	Koln Nanya	W. Bemuabolb	20-Oct	9	14:12	0.32	Improved
50	Mapula Nyilinge,	W. Bemuabolb	12-Oct	1	10:47	0.86	
50	Mapula Nyilinge	W. Bemuabolb	12-Oct	1	10:48	0.86	
50	Mapula Nyilinge	W. Bemuabolb	20-Oct	9	14:17	0.4	NAC
50	Mapula Nyilinge	W. Bemuabolb	20-Oct	9	14:19	0.4	NAC
50	Mapula Nyilinge	W. Bemuabolb	20-Oct	9	14:20	0.4	NAC
51	Gmamon	Bekom West	12-Oct	1	*Installe		
51	Gmamon	Bekom West	12-Oct	1	12:04	1.43	
51	Gmamon	Bekom West	12-Oct	1	12:05	1.43	
51	Gmamon	Bekom West	17-Oct	6	*Installe		
51	Gmamon	Bekom West	17-Oct	6	10:40	0.79	
51	Gmamon	Bekom West	17-Oct	6	10:42	0.78	
51	Gmamon	Bekom West	20-Oct	9	13:45	0.76	Very Clear
51	Gmamon	Bekom West	20-Oct	9	13:46	0.76	Very Clear
51	Gmamon	Bekom West	20-Oct	9	13:47	0.76	Very Clear
52	Benoin Wajimba	Wayutib East	12-Oct	1	*Installe		
52	Benoin Wajimba	Wayutib East	12-Oct	1	11:41	1.43	
52	Benoin Wajimba	Wayutib East	12-Oct	1	11:43	1.36	
52	Benoin Wajimba	Wayutib East	17-Oct	6	*Installe		
52	Benoin Wajimba	Wayutib East	17-Oct	6	10:05	0.65	
52	Benoin Wajimba	Wayutib East	17-Oct	6	10:07	0.67	
52	Benoin Wajimba	Wayutib East	20-Oct	9	13:34	0.43	Very Clear
52	Benoin Wajimba	Wayutib East	20-Oct	9	13:37	0.42	Very Clear
52	Benoin Wajimba	Wayutib East	20-Oct	9	13:39	0.42	Very Clear
53	Mana Naboer	Wayutib West	12-Oct	1	*Installe		
53	Mana Naboer	Wayutib West	12-Oct	1	11:21	1.11	
53	Mana Naboer	Wayutib West	12-Oct	1	11:23	1.11	
53	Mana Naboer	Wayutib West	15-Oct	4	8:22	0.91	
53	Mana Naboer	Wayutib West	15-Oct	4	8:24	0.92	
53	Mana Naboer	Wayutib West	15-Oct	4	*Installe		
53	Mana Naboer	Wayutib West	15-Oct	4	8:38	0.61	
53	Mana Naboer	Wayutib West	15-Oct	4	8:40	0.61	
53	Mana Naboer	Wayutib West	20-Oct	9	13:55	0.57	Improved
53	Mana Naboer	Wayutib West	20-Oct	9	13:57	0.57	Improved
53	Mana Naboer	Wayutib West	20-Oct	9	13:59	0.57	Improved

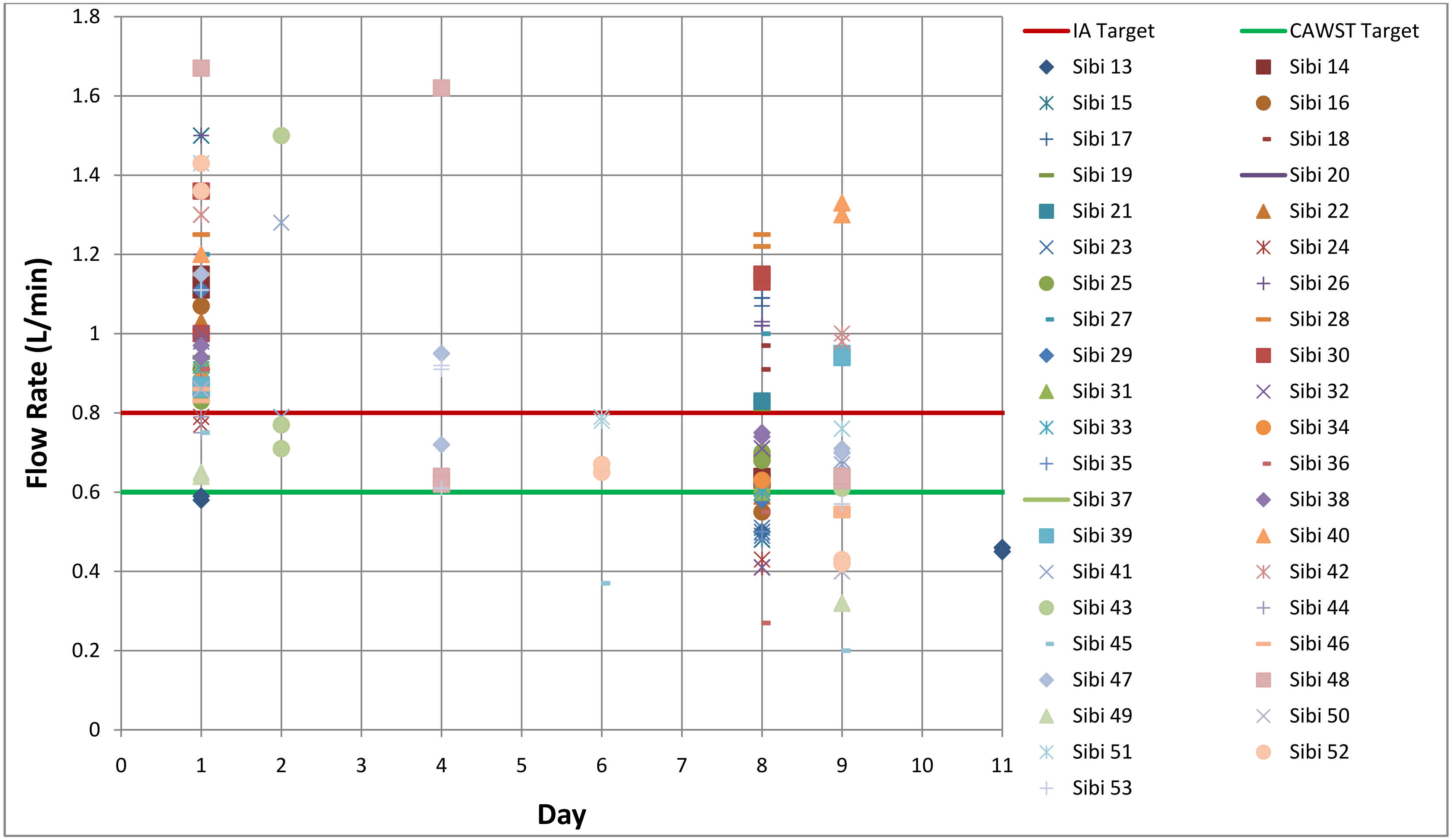

Figure 91: Phase 3 – All Flow Rate Measurements for HydrAid™ BioSand Filters Sibi 13-53. Recommended flow rates by the Center for Affordable Water and Sanitation Technology (CAWST) and International Aid (IA) are also graphed at 0.6 L/min and 0.8 L/min, respectively. A general range of acceptable flow rates is from a maximum of 1 L/min to a minimum that is determined by the user to be the lowest acceptable flow rate (e.g. 0.4 L/min).

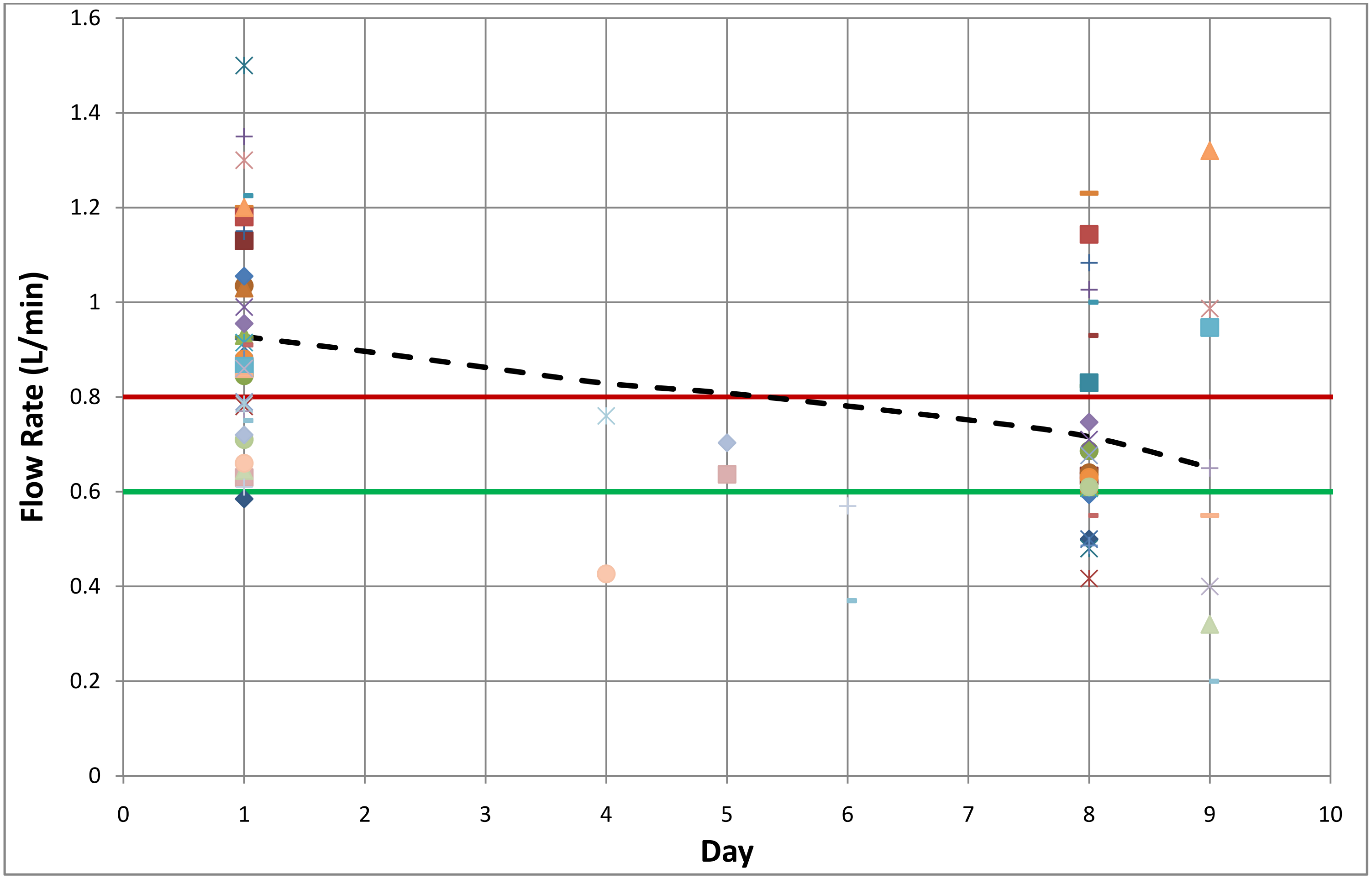

Figure 92: Phase 3 – Adjusted-average flow rate measurements for HydrAid™ BioSand Filters Sibi 13-53. The trend line demonstrates the general decrease in flow rates over time. Recommended flow rates by the Center for Affordable Water and Sanitation Technology (CAWST) and International Aid (IA) are also graphed at 0.6 L/min and 0.8 L/min, respectively. A general range of acceptable flow rates is from a maximum of 1 L/min to a minimum that is determined by the user to be the lowest acceptable flow rate (e.g. 0.4 L/min).

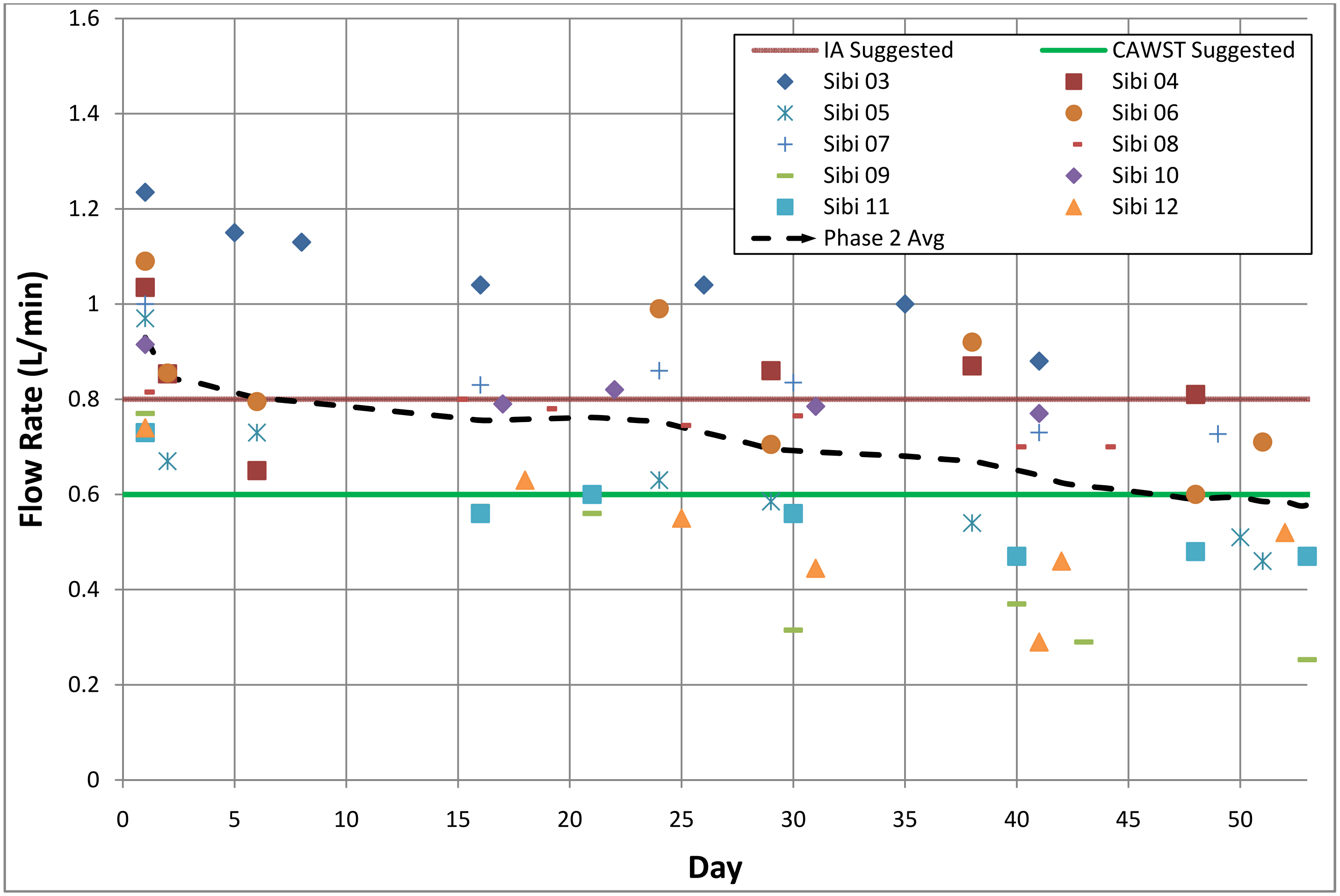

Figure 93: Phase 2 – Adjusted-average flow rate measurements for HydrAid™ BioSand Filters Sibi 03-12. The trend line demonstrates the general decrease in flow rates over time. Recommended flow rates by the Center for Affordable Water and Sanitation Technology (CAWST) and International Aid (IA) are also graphed at 0.6 L/min and 0.8 L/min, respectively. A general range of acceptable flow rates is from a maximum of 1 L/min to a minimum that is determined by the user to be the lowest acceptable flow rate (e.g. 0.4 L/min).

Appendix D: Other Information

BSF Sibi 01 – Household Interview (July 2007):

Name: Yao Donkor

Occupation: Farmer

People in Household: 14

Use of Filtered Water: Drinking and cooking

Use Pattern: 4 out of 7 days

Source Water: Sibi stream, off the main road

Do you drink any other water? Borehole water

How is the flow rate? Fast when full and slows when emptying

Is it difficult to operate? No

Maintenance Frequency: None yet

Water Color: Influent is red. Effluent is like well water

Taste: Prefers the filtered water; it tastes like well water

Odor: Influent has a smell like rotting leaves. Effluent has no odor.

Problems: Slow flow and leakage. The household would need two filters to supply enough drinking water to everyone in the household.

Durability: All is strong except the cracked piece

How much would you pay for the BSF? GH¢2 is fair. (~US$2.17)

Illnesses in the household since using the BSF: None

Storage container used: Clay pot with a cover that is cleaned regularly

BSF Sibi 02 – Household Interview (July 2007):

Name: Kwasi Wumbe

Occupation: Farmer

People in Household: 3

Use of Filtered Water: Drinking and cooking

Use Pattern: Daily, ~40 L/day

Source Water: Sibi stream - far upstream from the community, close to Merimeri

Do you drink any other water? No

How is the flow rate? It is faster when full and then slows when the water level drops

Is it difficult to operate? No

Maintenance Frequency: Daily

Water Color: Improved, much clearer

Taste: Tastes like pipe water, prefers it to the taste of the stream water

Odor: The filter removes the mineral smell

Problems: The filter is leaking and the flow is slow

Durability: Shell is strong, inlet PVC connector has cracked

How much would you pay for the BSF? GH¢2 (~US$2.17)

Illnesses in the household since using the BSF: None

Storage container used: Jeri can that is cleaned daily

Nkwanta District Map

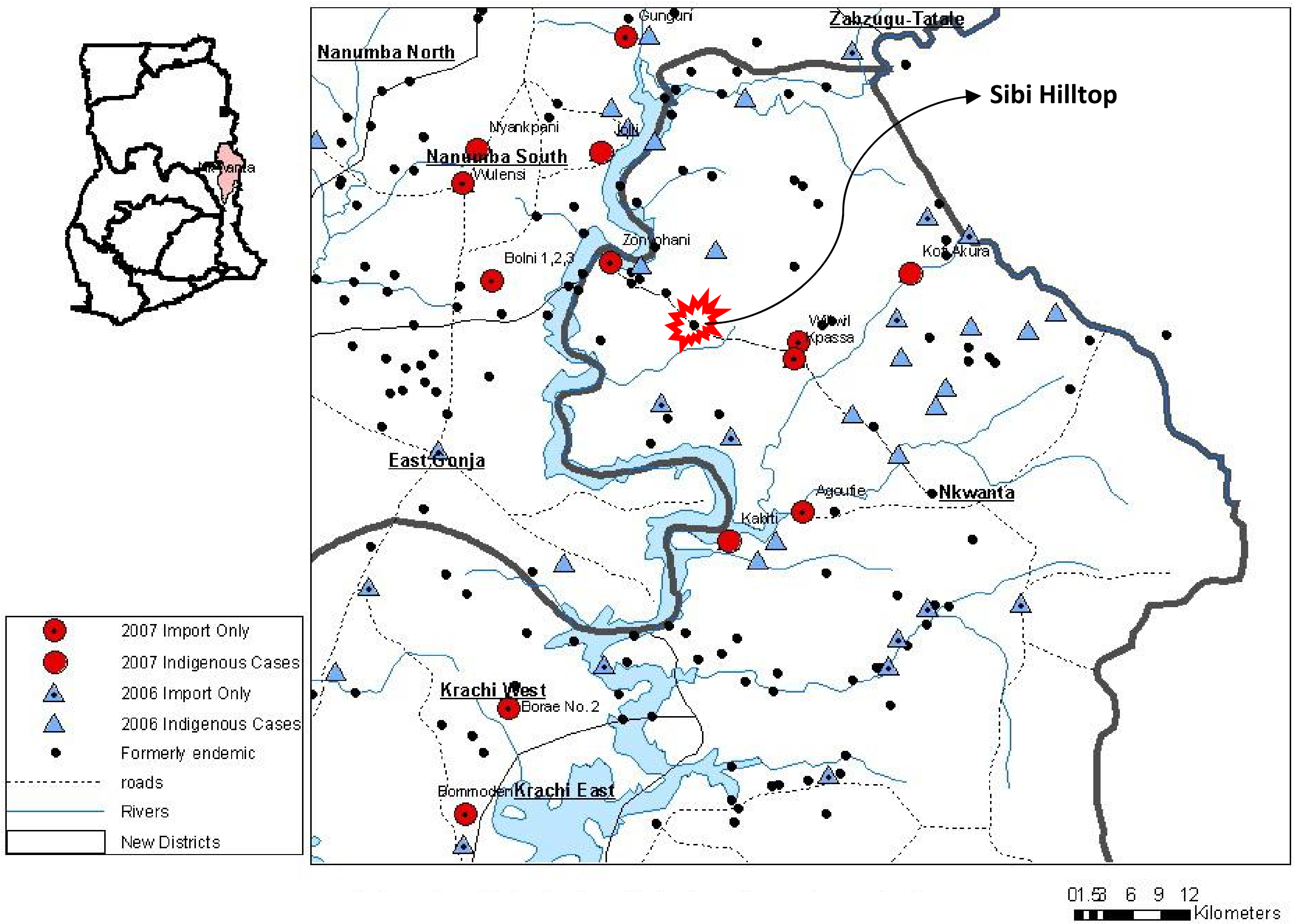

Figure 94: Nkwanta District Map showing location of Sibi Hilltop and strategic communities for the Guinea Worm Eradication Program (Adapted from Stewart 2007)

Compiled Survey Results

Table 27: Compiled household survey results for Sibi 01 through 12 (interviewed from October 22-25, 2007).

Question:	01	02	03	04	05	06	07	08	09	10	11	12	TOTALS:
1. Name:	Yao Donkor (M)	Kwasi Wumbe (M)	Abraham Tabanti (M)	Joseph Osei (M)	Akua Yimbidan (F)	Afia Yiyal (F)	Mborja Batigna (F)	Obori Gmanja Lalir (M)	Attah K John (M)	Adam Chanuri (M)	Stephen Agba (M)	John Naboer (M)	9 Males, 3 Females
2. BSF#:	Sibi 01	Sibi 02	Sibi 03	Sibi 04	Sibi 05	Sibi 06	Sibi 07	Sibi 08	Sibi 09	Sibi 10	Sibi 11	Sibi 12	Twelve
3. Clan:	Binajub	Binajub	Binajub	Bigbem	Kpajotib	Bekom	Kochatib	Nakpand	Basatib	Bigbem	Bissagma	Wayutib	8 clans represented
4. Age:	54	39	34	32	30	42	45	43	24	49	29	27	37
5. Profession:	Farmer	Farmer	Farmer, Assembly	Carpenter Petrol	Farmer, Trader	Farmer, Trader	Farmer, Trader	Farmer, Chief	Farmer, Teacher	Farmer, Youth	Farmer	Farmer	7 different professions
6. # in HH:	17	3	7	7	21	13	14	8	17	22	16	4	12.42
7. # using	12	3	7	7	21	13	14	8	17	22	16	4	12
8. Location of BSF:	verandah	thatched alcove	verandah	inside room	inside room	inside room	inside room	verandah	verandah	inside room	inside extended	inside enclosed	7 inside, 5 outside
9. RWH potential:	good	very poor	excellent	excellent	very poor	good	excellent	good	very poor	excellent	excellent	very poor	4 Very Poor, 3 Good, 5 Excellent
10. Ease of Operation:	easy	easy	easy	easy	easy	easy	easy	easy	easy	easy	easy	easy	12 easy
11. Who Operates:	Husband & Wife	Kwasi & daughter	his wife	his wife	Akua & 4 women	Afia	Mborja	his wife	John & 3 women	his 3 wives	Stephen, his wife	Jon, his wife	5 Males, 19 Females
12. Source H2O:	Sibi Stream; bridge	kabunbuk stream	Sibi Stream; bridge	Kabunbuk stream	Sibi Stream, Madane	Sibi Stream at the Top	Sibi Stream; bridge	kabunbuk stream	Sibi Stream, bridge	Sibi Stream	Sibi Stream, top	kabunbok stream	8 Sibi, 4 Kabunbok
13. Is BSF durable?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	12 Yes
14. Strength comparison	Not Sure	Not Sure	Plastic	Not sure	Plastic	Concrete	Not Sure	Concrete	Concrete	Concrete	Not sure	Plastic	3 Plastic, 4 Concrete, 5 Unsure

15. Market buy?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	12 Yes
16. Highest Price, GHC:	over 10.00	over 10.00	over 10.00	over 10.00	over 10.00	5-7.5	over 10.00	over 10.00	over 10.00	7.5-10.00	over 10.00	over 10.00	10 (10.00+), 1 (5-7.5), 1 (7.5-10)
17. More 4 concrete?	No	No	Yes	No	No	Yes	No	Yes	Yes	Yes	No	No	7 No, 5 Yes
18. Price 4 concrete, GHC:	5-7.5	Over 10.00	Over 10.00	5-7.50 (7.00)	0-5.00	over 10.00	7.5-10.00	over 10.00	over 10.00	over 10.00	5-7.50	over 10.00	7 (over 10), 1(0-5), 3(5-7.5), 1(7.5-10)
19. Problems:	None	None	None	None	None	None	None	None	Yes, flow rate	None	None	None	11 None, 1 Flow too slow
20. Use frequency:	2x/d	2x/d	2x/d	1x/d	~11x/wk	~10x/wk	3x/d	~8x/wk	3x/d	~6x/wk	2x/d	1x/d	12.25x/wk
21. Volume per use:	20 L	20 L	20 L	20 L	20 L	20 L	20 L	20 L	20 L	20 L	20 L	20 L	12 = (20 L)
22. Use of effluent:	drinking, cooking	drinking, cooking	drinking	drinking	drinking, cooking	drinking cooking	drinking	drinking, cooking	drinking, cooking	drinking only	drinking only	drinking, cooking	5 drinking only, 7 drinking /cooking
23. Drink other H_2O?	No	No	Yes, RW	Unless he travels	Yes, SW at farm	No	No	Yes, RW & BH	No	No	Yes, SW at farm	Yes, SW at farm	5 Yes, 7 No
24. Q-rate fine?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	12 Yes
25. Taste Preference:	effluent	effluent	effluent	effluent	effluent	effluent	effluent	effluent	effluent	effluent	effluent	effluent	12 effluent
26. Color Preference:	effluent	effluent	effluent	effluent	effluent	effluent	effluent	effluent	effluent	effluent	effluent	effluent	12 effluent
27. Odor Preference:	effluent	effluent	effluent	effluent	effluent	effluent	effluent	effluent	effluent	effluent	effluent	effluent	12 effluent
28. Effluent collection:	different pans	jerry can	diff head pans	large metal pot	plastic bucket	plastic bucket	small head	clay pot	rubber bucket	different head	clay pot	large head pan	varies
29. Wash frequency:	every time before use	rinses w/ water daily	every time before use	unknown	daily	daily; before use	Daily before use w/ soap and	twice per week	daily	before use	every 3 days	daily	varies
30. Cover container?	No	Yes	No	No	No	No	No	Yes	Yes	No	No	Yes	4 Yes, 8 No

31. transfer effluent?	Yes, clay pot	No	Yes, clay pot w/ lid	Yes, 2 clay pots	No	Yes	Yes, 2 clay pots	No	No	Yes, Clay pots	No	No	6 No, 6 Yes
32. Wash frequency:	daily	n/a	every 3 days	daily	n/a	every 3 days	Almost daily	n/a	n/a	2-3x/wk	n/a	n/a	varies
33. Why want BSF?	To prevent sickness from water	Because of sickness	It gives us clean water.	To prevent illness	To prevent GW	Because of GW prevent'n	To prevent illnesses	For getting clean water.	To prevent disease	Because of germs in the water	It saves me from drinking bad water	To filter water for drinking and cooking	12 - prevent waterborne disease
34. Perform "swirl-and-dump"	Yes	Yes	No	No	Yes	Yes	No	No	Yes	No	No	No	5 Yes, 7 No
35. Maint. frequency:	monthly	Daily	n/a	n/a	weekly	weekly	n/a	n/a	daily-weekly	n/a	n/a	n/a	3 weekly, 1 daily, 1 monthly
36. Ease of maint.:	Easy	Easy	n/a	n/a	Easy	Easy	n/a	n/a	moderate	n/a	n/a	n/a	4 easy, 1 moderate
37. Higher flow after:	Yes	Yes	n/a	n/a	Yes	Yes	n/a	n/a	Yes	n/a	n/a	n/a	5 yes
38. Taste change?	No	No	n/a	n/a	No	Yes	n/a	n/a	No	n/a	n/a	n/a	4 no, 1 yes
39. Clean exterior?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	12 yes
40. # in HH (0-5 yrs):	2	0	1	2	3	2	3	2	5	4	4	2	2.5
# in HH (6-12 yrs):	3	1	0	1	5	4	2	1	1	5	4	0	2.25
# in HH (13-18 yrs):	2	1	1	1	7	1	2	2	2	6	0	0	2.08
# in HH +18:	5	1	5	3	6	6	7	3	9	7	8	2	5.17
41. Pre BSF D #s (0-5):	0	0	0	0	0	1	0	0	0	2	0	0	0.25
Pre BSF D #s (6-12):	0	0	0	0	0	2	0	0	0	0	0	0	0.17
Pre BSF D #s (13-18):	0	0	0	0	0	0	0	0	0	0	0	0	0

Pre BSF D #s +18	0	0	0	0	2	0	0	0	0	2	0	0	0.33
42. Post BSF D #s (0-5 yrs)	2	0	0	0	0	0	1	0	0	1	0	0	0.33
Post BSF D #s (6-12)	0	0	0	0	0	0	0	0	0	0	0	0	0
Post BSF D #s (13-18)	0	0	0	0	0	0	0	0	0	0	0	0	0
Post BSF D #s +18	0	0	0	0	0	0	0	0	0	1	0	0	0.08
43. Source H_2O last yr:	stream water	stream water	stream water	stream water	stream water	stream water	stream water	Stream and borehole water	stream water	stream water	stream water	stream water	12 SW, 1 BH water
44. Treated source?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	12 Yes
How?	GW filter	GW filter	GW filter	GW filter	GW filter	GW filter	GW filter	GW filter	GW filter	GW filter	GW filter	GW filter	12 GW filter
45. BSF improves family health?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	12 Yes