SUSTAINABILITY ASSESSMENT OF THE BIOSAND FILTER IN BONAO, DOMINICAN REPUBLIC

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Abstract

Benjamin A. Aiken: SUSTAINABILITY ASSESSMENT OF THE BIOSAND FILTER
IN BONAO, DOMINICAN REPUBLIC
(Under the direction of Mark D. Sobsey)

Access to clean drinking water is not a reality for approximately 1.1 billion people in the world, leading to approximately 1.6 million children dying each year due to diarrheal diseases linked to unsafe drinking water. Household water treatment at the point-of-use (POU) has proven effective in improving microbiological water quality and reducing diarrheal disease among users in both laboratory and field studies. The Biosand filter (BSF), an intermittently operated, slow sand filter, is a promising POU technology, although little follow-up of the initial positive study and trial results has occurred to assess BSF sustainability. The purpose of this study was to assess the sustainability of previously implemented BSFs in and around Bonao, Dominican Republic (DR) through two approaches: 1) cross-sectional analysis of continued use, performance effectiveness, and sustained water quality improvement, and 2) longitudinal analysis of sustained health impact, measured as diarrheal disease, and sustained water quality improvement. Over 90% of the BSFs were found still in use after an average of one year since installation. Incidence rates of diarrheal disease were reduced by 61% for BSF intervention households in comparison with non-BSF control households. Water quality improvement, as measured by reduction of fecal indicator bacteria, was found to be low (84 to 88%) in comparison to reductions seen in the laboratory but comparable to analogous rates seen for the BSF in other field assessments. Together, the results suggest the BSF is a highly sustainable POU water treatment technology.

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Abbreviations

BSF – Biosand filter

CI – Confidence interval

DBP – Disinfection by-product

DR – Dominican Republic

EC – *E. coli*

IRR – Incidence rate ratio

LRV – Log reduction value

MDG – Millenium Development Goals

MPN – Most probable number

NGO – Non-governmental organization

NTU – Nephelometric turbidity unit

OR – Odds ratio

POU – Point of use

RCT – Randomized controlled trial

SSF – Slow sand filtration

TC – Total coliforms

UNICEF – United Nations International Children's Fund

WHO – World Health Organization

Chapter 1: Introduction

1.1 Introduction

Access to clean drinking water is not a reality for approximately 1.1 billion people in the world (WHO/UNICEF, 2000). This lack of access places a significant health and economic burden on these people in the form of diarrheal disease, time away from productive enterprise, costs of medical treatment, and decrements in child development. The burden disproportionately impacts children, with approximately 1.6 million children dying each year due to diarrheal diseases linked to unsafe drinking water and many more suffering from disease and developmental deficiencies (WHO, 2008).

Household water treatment at the point-of-use (POU) holds great potential in providing clean, safe drinking water to those lacking it. It is particularly attractive in locations where access to traditional large-scale water treatment systems and safe wells is not realistic due to inadequacies of water sources, high costs of alternative safe drinking water (e.g., safe bottled water), and lack of quality control in water treatment and distribution. In both laboratory and field studies, POU technologies have proven effective in improving microbiological water quality and reducing diarrheal disease among users. Meta-analyses of multiple household-level interventions with POU technologies found average reductions in diarrheal disease of 35 to 51% among users, and epidemiological, microbial reduction, and other scientific evidence of the effectiveness of POU water treatment technologies is growing as new studies are reported (Fewtrell et al., 2005; Clasen et al., 2007; Sobsey, 2002).

Building on the growing evidence of the effectiveness of POU water treatment, the parameters of sustainability, cost effectiveness, and scalability become critical as researchers, policy-makers, and implementers move forward (Sobsey, 2002). Though some measures of user compliance in performing POU treatment have been assessed (Rose et al, 2006; Rainey & Harding, 2005; Ram et al, 2007; MacGregor-Skinner et al, 2004; Brown, 2003), little follow-up of the initial positive results seen in the randomized controlled trials and other implementation studies has occurred. As a result, little robust evidence exists of the sustainability of POU technology, as measured by continued use, consistent water quality improvement, and sustained health impact. Of the existing evidence, continued use and sustained impact based on improved water quality are shown mostly to decrease over time, whether due to the difficulty of affecting human behavior change, physical breakage of the treatment technology, or lack of physical or economic access to resupply and replacement parts (MacGregor-Skinner et al, 2004; Brown, Sobsey, & Proum 2007; Arnold & Colford 2007). Given that sustainability is one of the primary performance criteria for recommended POU technologies, further assessment of sustainability will be critical evidence of long-term POU effectiveness (Sobsey, 2002; Sobsey et al., 2008).

The Biosand filter (BSF) is a promising POU technology with increasing evidence of effectiveness in both laboratory and field studies (Palmateer et al., 1999; Lee, 2001; Elliot et al., 2006; Stauber, 2007; Liang, 2007). The BSF is an intermittently operated, slow sand filter based on the design and operational principles of traditional large-scale slow sand filtration. By developing and maintaining a biologically active surface layer or schmutzdecke, the filter functions by biological predation, natural death, adsorption, and mechanical trapping of potentially harmful pathogens.

Laboratory studies document the BSF reducing indicators of fecal contamination by approximately 90-99% for bacteria, 90% for viruses, and >99.9% for protozoan parasites (Stauber et al., 2006). Initial field studies also show effective reductions of fecal bacteria in water and a positive health impact, measured as reduced burdens of household diarrheal disease. BSFs in Nicaragua were found to reduce bacterial indicators of fecal contamination by 99.1% (Manz & Buzunis, 1995). BSFs in six different countries showed an average reduction of 93% of fecal indicator bacteria (Kaiser et al., 2002). BSFs in the Dominican Republic were found to reduce diarrheal disease by 47% in BSF households compared to control households in a randomized controlled trial (Stauber, 2007).

Some evidence of BSF continued use has been documented, though few, if any, rigorous field studies have been conducted to assess sustainability and longitudinal effective use. Among 107 households in Haiti in which the BSF had been implemented for more than two years, all households were found to still be using the filter and average reduction of *E. coli* was determined to be 98.5% (Duke et al, 2006). Among 57 households in Ethiopia surveyed five years after BSF implementation, 70.2% were found to still be using the filter, and average reduction of *E. coli* was determined to be 87.9% (Earwaker, 2006).

The purpose of this study was to assess the overall sustainability of previously implemented BSFs in and around Bonao, Dominican Republic (DR) through two approaches:

1) Cross-sectional analysis of continued use, performance effectiveness, and sustained water quality improvement

2) Longitudinal analysis of sustained health impact, measured as diarrheal disease, and sustained water quality improvement.

The DR served as an appropriate and attractive location for conducting this sustainability assessment for the following reasons: (1) over eight years of BSF implementation, (2) relatively high reported background rates of diarrheal disease, with 14% and 20% two-week point prevalence nationally and in the study province of Monseñor Noeul, respectively, (3) availability of trained and experienced field staff, (4) detailed background information on participating households of the previous BSF RCT, and (5) sufficient infrastructure and local resources for a field study and needed laboratory analysis of water quality (USAID, 2003).

1.2 Objectives

1. Determine the sustainability of the Biosand filter (BSF) after an average of one year since installation in Bonao, Dominican Republic, as measured by continued use and performance effectiveness in a cross-sectional assessment.
2. Determine the ability of the Biosand filter (BSF) to have a sustained health impact on reduction of household diarrheal disease incidence rates for BSF intervention households as compared to non-BSF control households in a prospective cohort study in Bonao, Dominican Republic.
3. Determine the ability of the Biosand filter (BSF) to have sustained water quality improvements by reducing concentrations of *E. coli* and total coliforms, as well as turbidity, in both a cross-sectional assessment and a longitudinal prospective cohort study in Bonao, Dominican Republic.

Chapter 2: Literature Review

2.1 The Global Burden of Diarrheal Disease

Approximately 1.1 billion people in the world lack access to improved sources of drinking water, placing a significant burden on these people in the form of diarrheal disease. Unfortunately, an improved source of drinking water (Table 2.1) does not necessarily equate with safe drinking water. As a result, the global burden of diarrheal disease is impacting possibly more people than estimated.

Table 2.1 – Improved and Unimproved Sources of Drinking Water

IMPROVED SOURCES OF DRINKING WATER	UNIMPROVED SOURCES OF DRINKING WATER
- Piped water into dwelling, yard or plot - Public taps/standpipe - Tubewell/borehole - Protected dug well - Protected spring - Rainwater collection - Bottled water	- Unprotected dug well - Unprotected spring - Vendor-provided water - Tanker truck water - Surface water (river, stream, dam, lake, pond, canal, irrigation channel)

(WHO/UNICEF, 2005)

Diarrheal disease is caused by infectious organisms, including bacteria, viruses, protozoa, and helminthes, that are transmitted via the fecal-oral route. Six categories of water-related diseases have been established to outline the various ways that water, sanitation, and hygiene influence the incidence of diarrhea (Table 2.2). The health impacts of diarrheal disease include dehydration, malabsorption of nutrients, and intestinal damage, which range in severity from minor ailments to causing death. (Keusch et al., 2006)

Table 2.2 – "Categories of water-, sanitation- and hygiene-related diseases"

CATEGORY	DESCRIPTION
Waterborne	"Caused by the ingestion of water contaminated by human or animal excreta or urine containing pathogenic bacteria or viruses."
Water-based	"Caused by parasites found in intermediate organisms living in water."
Water-related	"Caused by microorganisms with life cycles associated with insects that live or breed in water."
Excreta-related	"Caused by direct or indirect contact with pathogens associated with excreta and/or vectors breeding in excreta."
Water collection and storage	"Caused by contamination that occurs during or after collection, often because of poorly designed, open containers and improper hygiene and handling."
Toxin-related	"Caused by toxic bacteria, such as cyanobacteria, which are linked to eutrophication of surface-water bodies."

(Montgomery & Elimelech, 2007)

Although diarrheal disease impacts all ages and can be particularly threatening to people aged 60 and over or immunocompromised individuals, the global burden, estimated at 4 billion cases of diarrhea each year, disproportionately impacts children under the age of five (WHO/UNICEF, 2000). Specifically, children less than five years old experience over 90% of the deaths in the developing world attributable to diarrheal disease, and diarrheal diseases are the third leading cause (17%) of death for these children (WHO/UNICEF, 2005). These percentages result in an estimated 1.6 million children dying each year from diarrheal diseases linked to unsafe drinking water (WHO, 2008).

Childhood diarrhea, particularly for those less than 2 years of age, is of great concern due to its potential and increasingly studied role in physical and cognitive development (Keusch et al., 2006). Though more research must be conducted to solidify the long-term importance of diarrheal disease in children, results already highlight this likelihood. A study in Brazil found a significant inverse relationship between diarrheal disease and test scores measuring intellectual capacity and concentration (Keusch et al., 2006), and childhood malnutrition, a direct result of poorly managed cases of diarrheal disease, has been linked to lower levels of physical fitness and productive work among adults (Dobbing, 1990).

Given the large number of people affected by the diarrheal disease burden and the immediate and long-term impacts it can have, significant amounts of work must be done. Despite these challenges, decreases in the global health burden, as measured by mortality, suggest that substantial progress has been made. Estimated number of deaths from diarrheal disease fell from 4.6 million per year before 1980 to 3.0 million per year between 1980 and 1990 to 2.6 million per year between 1990 and 2000 (Keusch et al., 2006). Further, the population with access to improved drinking water sources increased from 77% coverage in 1990 to 83% coverage in 2002, with 42% of those with access having access to a household or yard tap (WHO/UNICEF, 2005).

Estimates of the global burden of diarrheal disease based on morbidity, however, do not suggest substantial improvement in the past two decades. Diarrheal disease incidence was estimated at 3.2 episodes per child per year in 2003, down only from 3.5 episodes per child per year in 1993 (Keusch et al., 2006). Given the impact of diarrhea on the growth and proper maturation of children, especially those less than 5 years of age, this relatively stable incidence is of great concern (Kosek, Bern, & Geurrant, 2003). Further, given the increasing population growth seen in the poorest regions of the world, which are affected disproportionately by diarrheal disease, decreasing morbidity associated with diarrheal disease becomes more difficult.

International entities and organizations have responded to the water challenge with various incentives and directives, including the adoption of water as a human right by the United Nations (UN) Committee on Economic, Social and Cultural Rights in November 2002 (UN, 2003). Underlying all movements was the UN Millenium Declaration in 2000, from which eight specific Millenium Development Goals (MDGs) were developed. One aspect of the 7th MDG (to ensure environmental sustainability) is to "reduce by half the proportion of people without sustainable access to safe drinking water and basic sanitation" (UN, 2008). To further motivate progress toward this MDG, the UN proclaimed 2005 to 2015 as the International Decade for Action Water for Life (WHO/UNICEF, 2005).

Dedication to human dignity and equality serve as the central directives for the MDGs and the associated movements supported by the major international development players. It is important, however, to highlight the added economic incentives for focusing on decreasing the number of people lacking access to safe drinking water. Investments of US$1 in water supply, sanitation, and drinking water quality are estimated to give a regional dependent economic return of US$5 to US$60 (WHO, 2004). As a result, yearly costs for achieving the MDG for water and sanitation (US$11.3 billion) are estimated to provide a yearly economic return of US$84 billion. These savings, all due to decreases in diarrheal diseases, result from reduction of health care costs for agencies and individuals, gaining of productive days for the workforce population, higher attendance at school, time savings, and averted deaths (Table 2.3). (WHO/UNICEF, 2005)

Table 2.3 – Economic Benefits of Investing in Drinking Water and Sanitation

TYPES OF ESTIMATED ECONOMIC BENEFITS
1. “Health care savings of US$7 billion a year for health agencies and US$340 million for individuals.”
2. “320 million productive days gained each year in the 15-59 year age group, an extra 272 million school attendance days a year, and an added 1.5 billion healthy days for children under 5 years of age, together representing productivity gains of US$9.9 billion a year.”
3. “Time savings resulting from more convenient drinking water and sanitation services totaling 20 billion working days a year, giving a productivity payback of some US$63 billion a year.”
4. “Value of deaths averted, based on discounted future earnings, amounting to US$3.6 billion a year.”

(WHO/UNICEF, 2005; WHO, 2004)

2.2 Household Water Treatment

The traditional approaches to improving health and decreasing diarrheal disease associated with water, sanitation, and hygiene focus on water supply, sanitation, and hygiene. These approaches, with average estimated reductions of 25%, 32%, and 45%, respectively, in diarrheal disease morbidity, remain important in making progress (Fewtrell et al., 2005).

The traditional viewpoint associated with these approaches, however, held that household level water treatment or point-of-use (POU) water treatment would not lead to the same levels of reduction. Specifically, the median reduction in diarrheal disease prevalence due to water quality interventions was estimated at 17%, which is lower than each of the other options (Esrey et al., 1991). Further, the many causes of diarrhea led researchers to suggest that minimal health impact would result from water quality improvements when high levels of fecal contamination were present (Esrey et al., 1991).

Due to numerous recent studies of household water treatment at the point-of-use, the formerly dominant paradigm has shifted. Meta-analyses of multiple household-level interventions with POU technologies found average reductions in diarrheal disease of 35 to 51% among users, which are higher average levels of improvement than for water supply or sanitation interventions and comparable to hygiene interventions (Fewtrell et al., 2005; Clasen et al., 2007). In addition, epidemiological, microbial reduction, and other scientific evidence of the effectiveness of POU water treatment technologies is growing as new studies are reported (Sobsey, 2002).

Many POU technologies are already in use throughout the world, and several more are in development. Robust scientific evidence of efficacy, however, as measured by positive health impact, microbiological water quality improvement, and sustained use, only exists for five principal POU technologies (Table 2.4) (Sobsey et al., 2008). Each of

Table 2.4 – Five principal POU technologies

TECHNOLOGY	DESCRIPTION*
Chlorination with safe storage (CDC Safe Water System)	Application of dilute sodium hypochlorite to inactivate pathogens in water and storage of treated water in safe container.
Combined coagulant-chlorine disinfection systems (Proctor & Gamble PuR$^{®}$)	Application of a chemical-coagulant to flocculate particles and inactivate pathogens in water, followed by straining through cloth to remove coagulated particles.
SODIS (Solar disinfection)	Transparent plastic (PET or PETE) bottles are filled with water, shaken to aerate, and exposed to sun (UV/heat energy inactivates pathogens) for 6 (sunny) to 48 hours (cloudy).
Ceramic filter	Water is passed through fired porous ceramic media (pot and candle designs) that removes pathogens from water and inactivates pathogens if impregnated with colloidal silver, before collecting into base of filter module.
Biosand filter	Water is passed through an intermittently operated, slow sand filter based on large scale slow sand filtration, where biologically active layer and sand media remove pathogens.

(Lantagne, Quick, & Mintz, 2007; Sobsey et al., 2008)

* Descriptions are intended to be basic and general and as a result, do not adequately describe the detail or possible variations of each technology.

these technologies has shown positive results in the field for both water quality improvements and health impact (Lantagne, Quick, & Mintz, 2007). As policy makers, researchers, and implementers recognize these benefits and the potential drawbacks (Table 2.5), the parameters of sustainability, cost effectiveness, and scalability become critical as these parties move forward.

Table 2.5 – Benefits and drawbacks of five principal POU technologies

TECHNOLOGY	BENEFITS	DRAWBACKS
Chlorination with safe storage (CDC Safe Water System)	Reduction of bacteria/viruses, residual protection, easy to use, documented health impact, scalable, low cost.	Low parasite reduction, less effective in turbid water and water with organic material, taste and odor, potential disinfection by-products (DBPs), low post-implementation compliance.
Combined coagulant-chlorine disinfection systems (Proctor & Gamble PuR®)	Removal/inactivation of bacteria/viruses/parasites/heavy metals/pesticides, residual protection, documented health impact, visual improvement of water, scalable, little DBP concern.	Multi-step process, time consuming, material and resupply requirements, high relative cost, low post-implementation compliance.
SODIS (Solar disinfection)	Reduction of bacteria/viruses/ protozoa, documented health impact, easy to use, low cost, minimal taste change, low recontamination threat.	Needs low turbidity water, low volume output, time consuming, material requirements, low post-implementation compliance.
Ceramic filter	Reduction of bacteria/protozoa, ease of use, documented health impact, low recontamination threat, long life potential, high continued use if unbroken, low cost, locally producible.	Variable virus reduction, no residual protection, user education required, low flow rate/volume output, breakable.
Biosand filter	Reduction of bacteria/protozoa, documented health impact, ease of use, visual and taste improvement of water, locally producible, low maintenance, long life, high continued use.	Low virus reduction, no residual protection, difficult to transport, high initial cost, scalability unknown.

Adapted from: (Lantagne, Quick, & Mintz, 2007; Sobsey et al., 2008)

2.3 The Biosand Filter

The Biosand filter (BSF) is based on slow sand filtration technology, which dates back to the early 20th century in the United States (Cutler & Miller, 2005). As a household version of a large-scale slow sand filter with a biologically active surface layer or schmutzdecke, the BSF functions by several mechanisms: biological predation on pathogens by organisms that develop in the schmutzdecke with the inflow of organic nutrients and diffusion of oxygen; natural death of pathogens trapped over time in the filter; adsorption of pathogens and suspended particles to sand grains in the filter bed; and mechanical trapping of potentially harmful pathogens and suspended particles in the pore spaces between sand grains (Palmateer, Manz, & Jurkovic, 1999; Duke et al. 2006).

Though analogous in theory, there are some differences between the BSF and a slow sand filter (Table 2.6). The principal difference is that the BSF maintains a 5 cm resting water layer above the top surface of the sand (Haarhoff & Cleasby, 1991). As a result, the BSF can be intermittently operated. The 5 cm distance was researched to be the most effective head height in regard to decreasing disturbance of sand layer while

Table 2.6 – "Differences between BSF and slow sand filter"

PARAMETER	BIOSAND FILTER	SLOW SAND FILTER
Filtration rate	0.6 m/h	0.1 m/h
Resting water above top of sand	0.05 m	1.5 m
Sand depth	0.46 m	0.8 m
Size	Height: 0.9 m Width: 0.3 m	Height: 3-5 m Width: 4-15 m
Raw water quality	Max. Turbidity: > 100 NTU[a]	Max. Turbidity: < 20 NTU

a. Nephelometric Turbidity Unit

Adapted from: (Lee, 2001; Haarhoff & Cleasby) allowing for maximum oxygen (Ritenour, 1998). In addition, the presence of a diffuser plate above the resting water level serves to distribute the inflow water evenly to prevent disturbance of the sensitive biological layer or schmutzdecke (Lee, 2001).

Dr. David Manz at the University of Calgary in Alberta, Canada developed the BSF in the early 1990's. The current concrete BSF (Figure 2.1) is the principal version in use around the world, having been tested in both laboratory and field studies for its effectiveness in improving water quality and improving health outcomes as measured by diarrheal disease. A plastic BSF is being implemented and promoted as well in several countries, with ongoing studies being conducted to measure its effectiveness in the field (International Aid, 2008). In sum, it is estimated that over 200,000 BSFs are in use in over 70 countries (Manz, 2008).

Figure 2.1 – Diagram of concrete Biosand filter

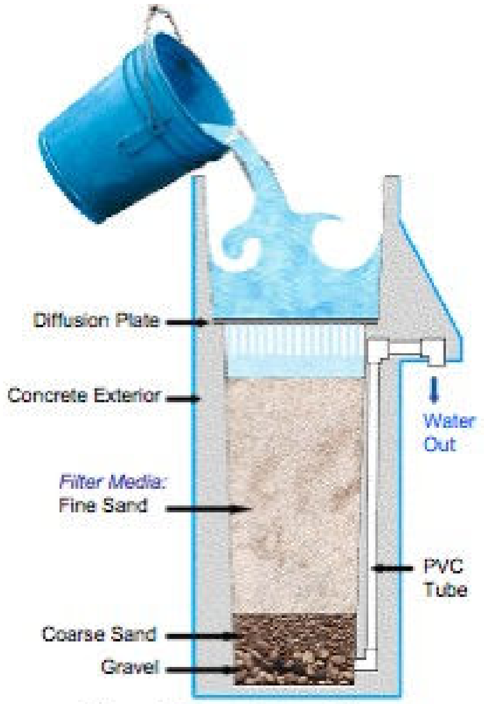


Figure 1: Manz BioSand filter.

(Duke et al., 2006)

Figure 2.2 – Biosand filter in Dominican Republic home

Laboratory studies document the BSF reducing indicators of fecal contamination by approximately 90-99% for bacteria, 90% for viruses, and >99.9% for protozoan parasites (Stauber et al., 2006). Initial field studies also show effective reductions of fecal bacteria in water and a positive health impact, measured as reduced burdens of household diarrheal disease. BSFs in Nicaragua were found to reduce bacterial indicators of fecal contamination by 99.1% (Manz & Buzunis, 1995). BSFs in six different countries showed an average reduction of 93% of fecal indicator bacteria (Kaiser et al., 2001). BSFs in the Dominican Republic were found to reduce diarrheal disease by 47% in BSF households compared to control households in a randomized controlled trial (Stauber, 2007).

Some evidence of BSF continued use has been documented, though few, if any, rigorous field studies have been conducted to assess longitudinal effective use and sustainability. Among 107 households in Haiti in which the BSF had been implemented for more than two years, all households were found to still be using the filter and average reduction of *E. coli* was determined to be 98.5% (Duke et al, 2006). Among 57 households in Ethiopia surveyed five years after BSF implementation, 70.2% were found to still be using the filter, and average reduction of *E. coli* was determined to be 87.9% (Earwaker, 2006).

2.4 Biosand Filtration in the Dominican Republic

The BSF has been in use in the Dominican Republic since 2000, when the non-governmental organization (NGO) Add Your Light promoted an initial technician training program along with the Canadian Embassy and the Rotary Club of Calgary Chinook. Subsidized and unsubsidized implementation programs have made and installed thousands of filters since then, distributing them throughout the country.

Estimates in 2002 suggested 98% of the urban population and 85% of the rural population had access to improved drinking water, though only 37% and 31% of the access, respectively, were household connections (WHO/UNICEF, 2004). More recent estimates suggest maintained urban levels of coverage (97%) and improvement in rural levels of coverage (91%) (UNICEF, 2008). Nonetheless, the household connections are recognized to be unreliable and of poor water quality. Of the other forms of improved drinking water sources, a significant portion is likely from bottled water (Stauber, 2007), and no estimates exist as to what percentage of the improvements are the result of POU implementation programs.

Demographic surveys found an estimated 14% of all children suffering from diarrheal disease over a two-week period, with this estimated percentage increasing to over 20% for children between 6 and 24 months old. The diarrheal disease burden estimate for Monsenor Noeul, the province in which this study and the previous RCT took place, was above average at 22%. (USAID, 2003)

Previous research conducted in the Dominican Republic includes a study on diarrheal disease prevention practices (McLennan, 2000) and the previous RCT conducted in Bonao (Stauber, 2007). The high level of BSF implementation in and around Bonao, Dominican Republic, in combination with the high prevalence of diarrheal disease and the low level of follow-up of previously implemented BSFs, make the region an attractive location for continued assessment of the BSF. Further, the availability of trained and experienced field staff, the detailed background information on participating households from the previous BSF RCT, and sufficient infrastructure and local resources for a field study and needed laboratory analysis of water quality make possible the opportunity for advanced research of the BSF.

Chapter 3: Sustainability Assessment of the Biosand Filter

3.1 Introduction

Access to clean drinking water is not a reality for approximately 1.1 billion people in the world (WHO/UNICEF, 2000). This lack of access places a significant health and economic burden on these people in the form of diarrheal disease and time away from productive enterprise. The burden disproportionately impacts children, with approximately 1.6 million children dying each year due to diarrheal diseases linked to unsafe drinking water (WHO, 2008).

Household water treatment at the point-of-use (POU) holds great potential in providing clean drinking water to those lacking it, particularly in locations where access to traditional large-scale water treatment systems is not realistic due to cost and lack of quality control. POU technologies have been proven to be effective in both laboratory and field studies at improving microbiological water quality as well as reducing diarrheal disease among users (Sobsey, 2002). Meta-analyses of multiple household-level interventions with POU technologies found average reductions in diarrheal disease of 35 to 51% among users, and epidemiological, microbial reduction, and other scientific evidence of the effectiveness of POU water treatment technologies is growing (Fewtrell et al., 2005; Clasen et al., 2007; Sobsey, 2002).

Building on the growing evidence of the effectiveness of POU water treatment, the parameters of sustainability, cost effectiveness, and scalability become critical as researchers, policy-makers, and implementers move forward (Sobsey, 2002). Though measures of compliance have been assessed (Rose et al, 2006; Rainey & Harding, 2005; Ram et al, 2007; MacGregor-Skinner et al, 2004; Brown, 2003), little long-term follow-up of the initial positive results seen in the randomized controlled trials and other implementation studies has occurred. As a result, little robust evidence exists of the sustainability of POU technology, as measured by continued use, sustained water quality improvement, and sustained health impact. Of the existing evidence, continued use and sustained impact are shown mostly to decrease over time, whether due to the difficulty of impacting human behavior change, physical breakage of the treatment technology, or lack of physical or economic access to resupply and replacement parts (MacGregor-Skinner et al, 2004; Brown, 2007; Arnold & Colford 2007). Given that sustainability is one of the primary performance criteria for the most promising POU technologies, further assessment of sustainability is critical in documenting the growing evidence of the effectiveness of POU water treatment (Sobsey, 2002).

The Biosand filter (BSF) is a promising POU technology with increasing evidence of effectiveness in both laboratory and field studies (Palmateer et al., 1999; Lee, 2001; Elliot et al., 2006; Stauber, 2007). The BSF is an intermittently operated, slow sand filter based on traditional large-scale slow sand filtration. With a biologically active surface layer or schmutzdecke, the filter functions by biological predation, natural death, adsorption, and mechanical trapping of potentially harmful pathogens.

Laboratory studies document the BSF reducing indicators of fecal contamination by approximately 90-99% for bacteria, 90% for viruses, and >99.9% for protozoan parasites (Stauber et al., 2006). Initial field studies, as well, show effective reductions of fecal contamination and a positive health impact. BSFs in Nicaragua were found to reduce bacterial indicators of fecal contamination by 99.1% (Manz & Buzunis, 1995). BSFs in six different countries showed an average reduction of 93% of fecal indicator bacteria (Kaiser et al., 2002). BSFs in the Dominican Republic were found to reduce diarrheal disease by 47% in BSF households compared to control households in a randomized controlled trial (Stauber, 2007).

Some evidence of BSF continued use has been documented, though few, if any, rigorous field studies have been conducted to assess sustainability. Among 107 households in Haiti in which the BSF had been implemented for an average of two years, all households were found to still be using the filter, and average reduction of *E. coli* was determined to be 98.5% (Duke et al, 2006). Among 57 households in Ethiopia surveyed five years after BSF implementation, 70.2% were found to still be using the filter, and average reduction of *E. coli* was determined to be 87.9% (Earwaker, 2006).

The purpose of this study was to assess the sustainability of previously implemented BSFs in and around Bonao, Dominican Republic (DR) through analysis of continued use, performance effectiveness, and sustained water quality improvement. The DR served as an appropriate and attractive location for conducting the sustainability assessment for the following reasons: (1) over eight years of BSF implementation, (2) relatively high reported rates of diarrheal disease, with 14% and 20% two-week point prevalence nationally and in the study province of Monseñor Noeul, respectively, (3) trained and experienced field staff, (4) detailed background information on participating households, and (5) local resources for field study logistics and needed laboratory analysis capability (USAID, 2003).

3.2 Methods

The study design focused on assessing the sustainability of the Biosand filter (BSF) through cross-sectional, follow-up interviews of BSF households on-site, inspection of the BSF, and analysis of household water quality.

3.2.1 Study Site

Ten communities were included in the assessment, each located near the city of Bonao, the capital of the province of Monseñor Nouel. Two of these communities, Jayaco and Brisas del Yuna, were the study sites for a BSF randomized controlled trial (RCT) completed in fall 2006. These communities will be referred to as the RCT communities. The remaining eight communities, Arroyo Toro, El Chispero, Ingenio, Jima, Los Quemados, Masipedro, Palmarito, and Sabana, are communities in which Rotary Club Bonao is actively engaged in BSF implementation. These communities will be referred to as the non-RCT communities.

Jayaco is a semi-rural, agricultural community located eight miles north of Bonao. The community consists of approximately 800 households divided among six principal areas. Five of these areas, Jayaco Arriba, Majaguay, KM 100, KM 101, and KM 103, along with another community, Brisas del Yuna, all of which were in the previous RCT, were selected for this assessment. Drinking water sources within Jayaco included piped water conveyed from an upland source, wells, unprotected springs, river water, and collected rainwater. The National Institute for Aqueducts and Potable Water (Instituto Nacional de Agua Potable y Aqueductos – INAPA) operates aqueducts and water supply networks throughout the country, including the piped water sources in Jayaco and the other communities in this study (INAPA, 2008). Primary health care services in Jayaco are provided by a local clinic, which is located in Jayaco Central, an area between Jayaco Arriba and Majaguay.

Brisas del Yuna is an urban community within the city of Bonao located along the Yuna River. This marginalized community consists of approximately 200 households, and drinking water sources include piped water, wells, unprotected springs, and river water. A local clinic provides primary health care services in the community.

Arroyo Toro, El Chispero, Ingenio, Jima, Los Quemados, Masipedro, and Sabana, are semi-rural communities located within approximately 20 miles of Bonao, while Palmarito is a semi-urban community adjacent to the municipality. Drinking water sources for these communities include piped water, wells, and unprotected springs. The local Rotary Club of Bonao invited the University of North Carolina to help them assess filter use and water quality in these eight communities. Because these communities were not the subject of the previous RCT, data were not available on total number of households or health care services in the community.

Together, these ten communities represented a population of diverse socioeconomic status, level of education, and access to services.

3.2.2 Prior BSF Intervention

The prior intervention in each household consisted of the installation of a concrete BSF, initial education of BSF use and maintenance, and provision of a 5-gallon narrow mouth water storage vessel and stand for the vessel. A local filter technician, in accordance with the standard guidelines for such processes, conducted the installation and education components. For all communities, an instructional pamphlet also was provided to household members for future reference.

BSF installations in Jayaco and Brisas del Yuna were done during the randomized controlled trial (RCT) conducted in 2006, with approximately 50% of households receiving BSFs in February 2006 and 50% receiving BSFs in August 2006. For all the non-RCT communities, except Ingenio, the BSF installations occurred between September and November 2006. The BSF installations in Ingenio were conducted in October 2005.

3.2.3 Study Participants

All RCT households were asked to participate in the follow-up study. Before conducting the follow-up assessment and water sampling, study details were provided to each contacted household, and informed consent was obtained. All 153 contacted households agreed to participate. In the case of a BSF having been moved to another accessible household, an additional interview was conducted with the new household when possible.

Members of the Rotary Club of Bonao and non-RCT community representatives aided in the process of identifying households with BSFs. Prior to interview, details of the study were provided to all contacted households, and the Rotary Club obtained informed consent from all participating households. Out of 247 households where BSFs were previously installed, 176 households were contacted, enrolled, and interviewed in these communities.

3.2.4 Sustainability

In June 2007, cross-sectional surveys were conducted to assess the sustainability of the BSF. Interviews lasted between fifteen and twenty minutes for households where the BSF was in use. The interviews, which were structured, translated, back-translated, and pre-tested in country for cultural appropriateness, were comprised of questions regarding demographics, continued use patterns and habits, and reported perceptions of BSF. For households not using their BSF, interviews focused specifically on reasons for disuse and lasted only five minutes. The reported head of the household, typically female, provided the responses when possible. In the absence of the head of the household, other knowledgeable household members completed the interview when appropriate. Trained local staff conducted all interviews in Spanish, the local language.

3.2.5 Water Quality Analysis

Water samples for laboratory analysis were taken from all RCT households when possible. Due to project budget limitations, only 31% of non-RCT households were asked to provide samples in order to decrease costs. The first household interviewed in each set of four households interviewed was systematically selected and asked to provide the following water samples if they were available: unfiltered drinking water, drinking water taken directly from the BSF outlet, filtered and stored drinking water, filtered water receiving additional treatment, and unfiltered water receiving treatment other than BSF treatment.

Water samples of approximately 500 mL were collected and sealed in 500 mL sterile Whirlpak® bags and immediately stored in ice-cooled containers. The microbiological analysis was conducted within twenty-four hours of sample collection, with the majority of samples processed within six hours of collection. The samples were maintained in ice-cooled containers for transport from the field to Dr. Mirna Peña’s Clinical Laboratory in Bonao, where they were analyzed for *E. coli* and total coliforms using the IDEXX Colilert® Quanti-Tray system (IDEXX, Laboratories, Westbrook, ME). Using 120 mL reagent bottles containing sodium thiosulfate to neutralize chlorine, each 100 mL sample of water was combined with one packet of Colilert® test reagent media and gently swirled until the media was completely dissolved. Each sample was then poured into an IDEXX Quanti-Tray/2000, the liquid was distributed uniformly among the wells by agitation, and then the Quanti-Tray was passed through a Quanti-Tray® Sealer, to seal the tray. The trays were incubated for twenty to twenty-four hours at 35°C (± 1), and then read visually to score the number of small and large yellow wells when exposed to visible light and the number of small and large fluorescing wells when exposed to long wavelength UV light. Yellow wells were summed to determine the most probable number (MPN) values for total coliforms, while fluorescing wells were summed to determine the MPN values for *E. coli*. The most probable number values were calculated according to an MPN table provided with the IDEXX Colilert® Quanti-Tray system.

Water samples also were analyzed for turbidity, pH, and free and total chlorine. Turbidity was measured with a Hach 2100P Portable Turbidimeter, pH was measured with a Hach sensION1 Portable pH Meter, and free and total chlorine were measured with a Hach Pocket Colorimeter II Test Kit.

3.2.6 Data Analysis

All data from cross-sectional, follow-up interviews were single-entered into specified data forms in EpiInfo™ (CDC) before being transferred into and analyzed using Intercooled Stata 8.0 (StataCorp., College Station, TX). Stratified analysis was conducted to assess for correlation between filter disuse and demographic, geographic, socioeconomic, and health-related factors. Univariate and multivariate analysis were conducted through ordinary logistic regression to test for and control for time in use and community as potential confounders. The two covariates were included in the model individually and together only if there was greater than a 10% a priori change in the outcome coefficient. For households using filters, analysis of continued use patterns and habits also was conducted.

Water sample data was single-entered into an Excel spreadsheet, and analysis was conducted in both Microsoft Excel and Intercooled Stata 8.0. Total coliform, *E. coli*, and turbidity measures were $\log_{10}$ transformed, and comparisons were made between arithmetic mean concentrations, geometric mean concentrations, and percent reductions (calculated with the equation, $(1 - 10^{-\text{average log reduction}})*100$, where average log reduction equals BSF treated water or BSF treated stored water minus untreated influent water). Stratified analysis also was conducted to assess for differences in key exposure and outcome variables by community and installation date.

3.3 Results

3.3.1 Study Participants

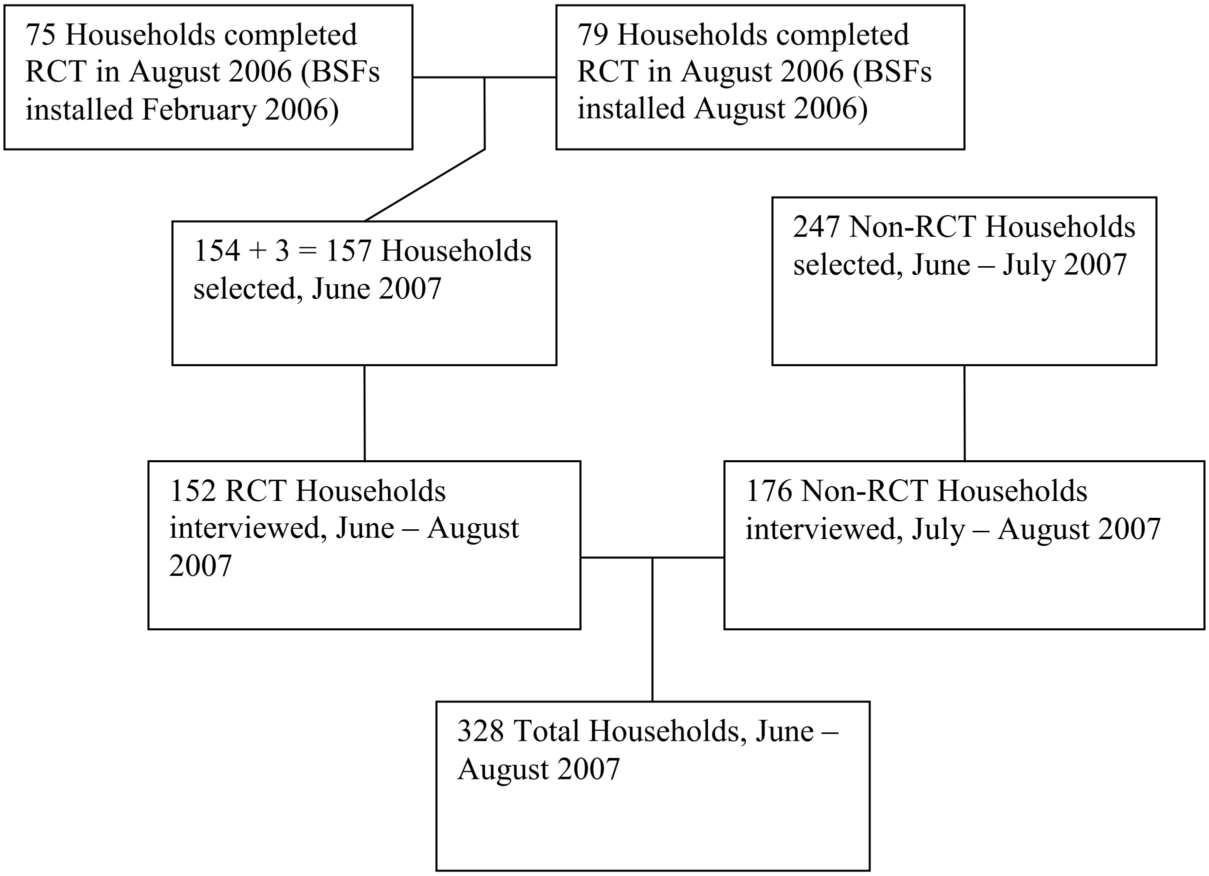
The study population totaled 1,670 persons in 328 households, as detailed in Table 3.1. Five households from the RCT group were not available for interview, although they were visited on multiple occasions. These households had either moved or were unable to be contacted due to incompatible schedules of householders and interviewers. Seventy-one out of 247 non-RCT households were unable to be interviewed on the day of the community visit and no repeat attempts were made to conduct these interviews, due to time and budget limitations. The average number of people per interviewed household was 5.1. A diagram of household data collection is provided in

Figure 3.1. This figure, in addition, provides the general timeline for the sustainability assessment.

Table 3.1 – RCT and Non-RCT Household numbers and totals

HOUSEHOLD DATA	RCT	Non-RCT	All
# of Households (sought for interview)	157	247	404
# of Households (interviewed)	152	176	328
# of People (interviewed households)	839	831	1,670
Average # of People per Interviewed Household	5.5	4.7	5.1

Figure 3.1 – Household enrollment and participation schedule



3.3.2 Sustainability – Filters Not in Use and Factors Associated with Continued Use

Approximately 10% of BSFs were found not in use among the 328 surveyed households (Table 3.2). For the RCT households, the five that could not be contacted for an interview were grouped with those households where filters were not in use, as a conservative assumption. However, confirmation and reasons for disuse were not able to be determined. The non-interviewed, non-RCT households were not included in the calculations because the household visit was attempted only once.

Table 3.2 – Filter use/disuse, as number (%) of households

USE DATA AT FOLLOW UP	RCT	Non-RCT	All
Using BSF	143 (91.1%)	158 (89.8%)	301 (90.4%)
Not Using BSF	9	18	27
Not-Found/Assumed Not Using BSF	5	n/a	5
Total Not Using BSF	14 (8.9%)	18 (10.2%)	32 (9.6%)

Primary reasons for BSF disuse reported by households (n = 27) and obtained via questionnaire, as detailed in Table 3.3, were:

1) Filter broken or not working (11%)

2) Perception or dislike of filter (63%)

3) Filter given away (7%)

4) Other reasons (19%)

Responses in the "other" category included using a neighbor's BSF, being away from the house due to health reasons, not currently residing in this home, and presence of ants in the filter. These reasons were reported as mutually exclusive, though all households not using their BSFs were given the opportunity to provide all reasons for disuse. Figures 3.2 and 3.3 graphically present reasons for disuse in RCT (n = 9) and non-RCT (n = 18) households, respectively.

Table 3.3 – Reported reasons for filter disuse

Reasons Given for Filter Disuse[a]	RCT (N=9) Number (%)	Non-RCT (N=18) Number (%)	All (N=27) Number (%)
Filter broken or not working	2 (22%)	1 (6%)	3 (11%)
Perception or dislike of filter[b]	3 (33%)	14 (78%)	17 (63%)
Filter given away	2 (22%)	0 (0%)	2 (7%)
Other[c]	2 (22%)	3 (17%)	5 (19%)

a. Responses are mutually exclusive.
b. Responses included in this category: do not like using filter, filtered water of poor quality, filtered water of bad odor, too much time to use, not necessary to use filter.
c. Other reasons given include: away from house due to operation, use of neighbors filter, not living or currently staying in house, and filter filled with ants.

Figure 3.2 – Histogram of reasons given for disuse (RCT households)

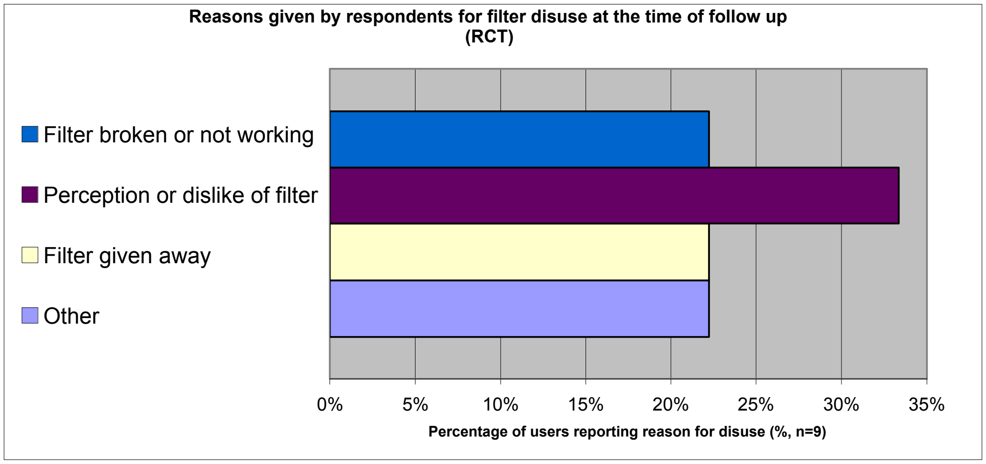
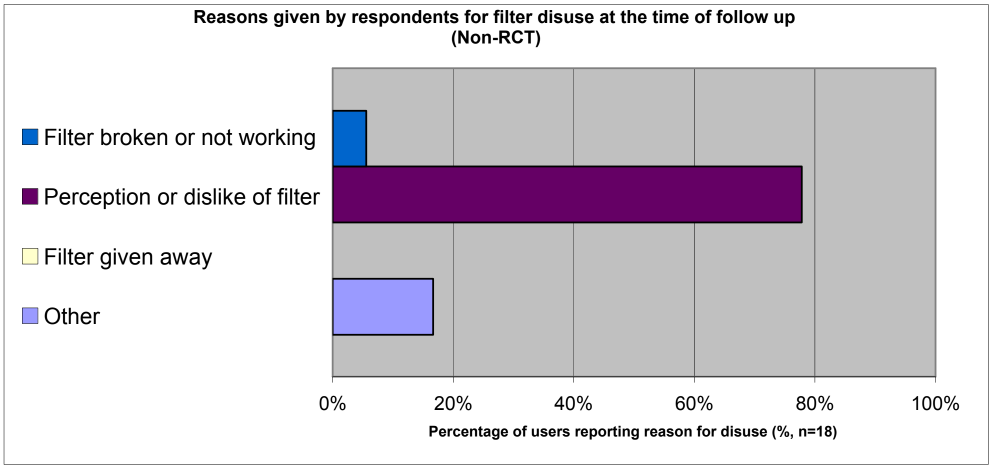


Figure 3.3 – Histogram of reasons given for disuse (non-RCT households)



Several selected factors were identified and analyzed as potential predictors of continued filter use. Positive association with continued filter use was determined by an odds ratio greater than one with a 95% confidence interval excluding the 1.00 null value. Negative association with continued filter use was determined by an odds ratio less than one with a 95% confidence interval excluding the 1.00 null value.

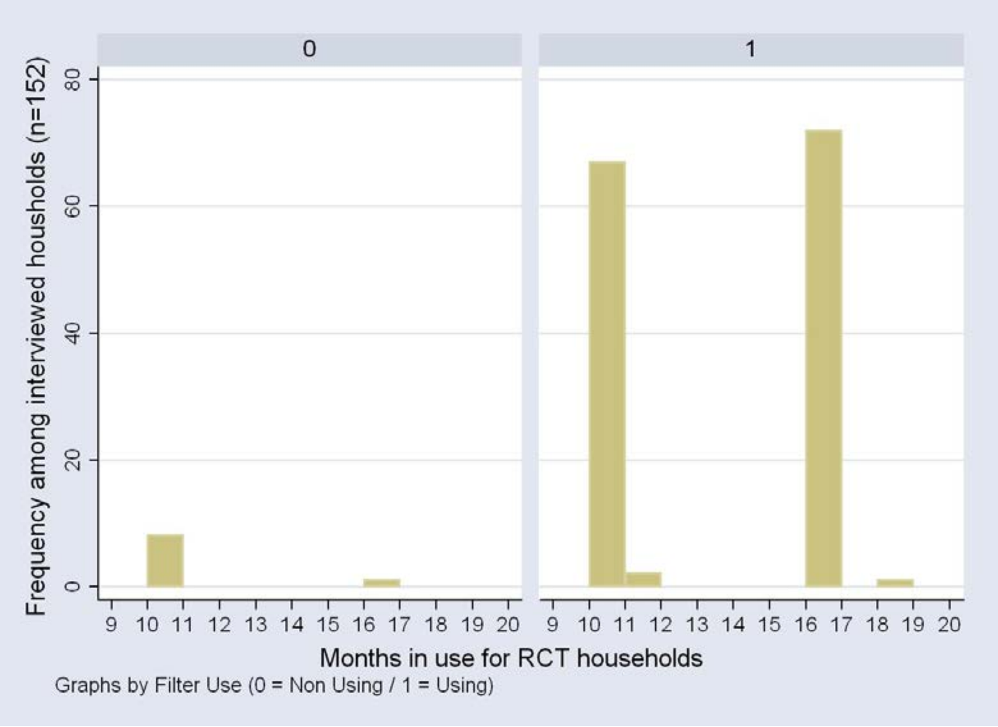
Initially, time since installation was found to be associated with continued filter use. For both RCT and non-RCT households, time since installation was analyzed using two implementation groups. For RCT households, one group included BSFs installed in February 2006 and the other group BSFs installed in August 2006. For non-RCT households, one group included BSFs installed in October 2005 and the other group BSFs installed in September through November 2006. Controlling for community as a confounder using logistic regression, only RCT households showed significant association between time since installation and continued use of BSF at follow-up, with more time since installation being positively associated with continued use. Specifically, BSFs installed in February 2006 were 9.90 (1.17-83.85, 95% Confidence Interval (CI)) times as likely to be in use as BSFs installed in August 2006, as detailed in Table 3.4 and graphically represented in Figure 3.4.

Table 3.4 – Time since installation analysis and estimated odds ratios for RCT and Non-RCT households

TIME SINCE INSTALLATION **- Controlling for Community**	**Using filter at time of follow up (143 RCT / 158 nRCT)**	**Not using filter at time of follow up (9 RCT / 18 nRCT)**	**OR (95% CI)[a] Adjusted[b] (*Significance)**
Implementation group (RCT)			
Installation 2/2006	73 (51.4%)	1 (11.1%)	9.90 (1.17-83.85)*
Installation 8/2006	69 (48.6%)	8 (88.9%)	Referent[d]
Implementation group (Non-RCT)			
Installation 10/2005	12 (7.6%)	5 (27.8%)	1.00 (0.23-4.37)
Installation 9-11/2006	146 (92.4%)	13 (72.2%)	Referent[d]

a. Odds ratios >1 show positive correlation with continued use, and odds ratios <1 show negative correlation with continued use.
b. Odds ratios estimates adjusted for community, coded as a categorical variable.
c. Time between interview date of this study and installation date from previous study.
d. The referent serves as the group to which the other groups are compared in calculating odds ratios.

Figure 3.4 – Histogram of filter time in use distribution for filters in use vs. filters not in use (RCT)



Due to the association seen between time since installation and continued use, all additional analysis of selected factors was conducted controlling for time since installation. These additional demographic and socio-cultural factors were selected for analysis due to their potential involvement in the complex process of accepting and using new technologies such as the BSF (Wellin, 1955; Rogers, 2003). Selected factors included in the analysis were: level of education, health education, number of assets, soap in the household, access to sanitation, safe storage practices, hand washing, drinking water source, payment for water, time to water source, and perception of the severity of diarrhea. This analysis was conducted only for RCT households, as this cross-sectional information was not available for non-RCT households. Controlling for time in use and community, no significant correlation was found between any of the factors and continued use of the BSF, as seen in Tables 3.5.A and 3.5.B and Figure 3.5.

Table 3.5.A – Selected factor analysis and estimated odds ratios for RCT households

RCT HOUSEHOLDS **- Selected Factor Analysis Controlling for Time in Use**	**Using filter at time of follow up (139 households)[a]**	**Not using filter at time of follow up (8 households)[b]**	**OR (95% CI)[c] Adjusted[d]**
Interviewee/spouse receiving any primary education[e]			
Yes	91 (65.5%)	5 (62.5%)	1.03 (0.22-4.67)
No	48 (34.5%)	3 (37.5%)	Referent[f]
Interviewee reported receiving health education[g]			
Yes	75 (54.0%)	3 (37.5%)	2.20 (0.48-10.00)
No	64 (46.0%)	5 (62.5%)	Referent[f]
Number of assets[h]			
0	3 (3.3%)	1 (14.3%)	Referent[f]
1-2	19 (20.9%)	6 (85.7%)	0.72 (0.06-8.46)
3-4	45 (49.5%)	0 (0.0%)	n/a[i]
5-6	24 (26.4%)	0 (0.0%)	n/a[i]

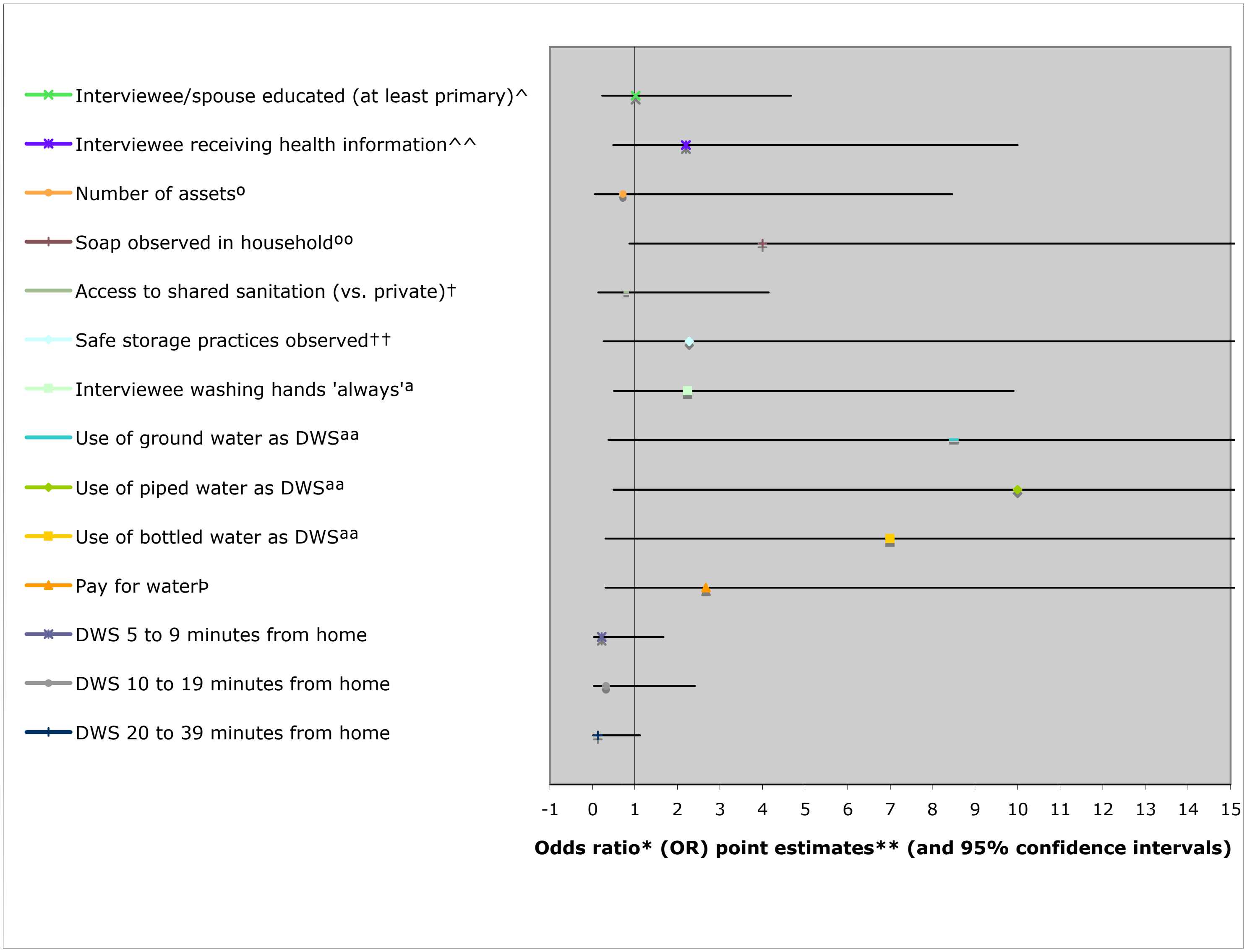
a. Total households do not total 143 here due to missing cross-sectional data for four using households.
b. Total households do not total 9 here due to missing cross-sectional data for one non-using households.
c. Odds ratios >1 show positive correlation with continued use, and odds ratios <1 show negative correlation with continued use.
d. Odds ratio estimates adjusted for time since implementation, coded as a four-group categorical variable: 10-, 11-, 16-, and 18-month.
e. Interviewee reported self and spouse having received any primary education.
f. The referent serves as the group to which the other groups are compared in calculating odds ratios.
g. Information about preventing or treating diarrhea from any source (friend, clinic, media, etc.).
h. Number of assets as categorical variable by sum of six household assets: motorcycle, refrigerator, television, washer, fan, cell phone.
i. N/A due to zero value in “Not using filter at time of follow up” category, which disallows odds ratio calculation.

Table 3.5.B – Selected factor analysis and estimated odds ratios for RCT households (Continued)

RCT HOUSEHOLDS **- Selected Factor Analysis Controlling for Time in Use**	**Using filter at time of follow up (139 households)**[a]	**Not using filter at time of follow up (8 households)**[b]	**OR (95% CI)**[c] **Adjusted**[d]
Soap observed in household[e]			
Yes	101 (72.7%)	4 (50.0%)	4.00 (0.88-18.17)
No	38 (27.3%)	4 (50.0%)	Referent[f]
Access to sanitation[g]			
Shared	31 (22.3%)	2 (25.0%)	0.75 (0.14-4.15)
Private	108 (77.7%)	6 (75.0%)	Referent[f]
Safe storage practices observed[h]			
Yes	30 (21.6%)	1 (12.5%)	2.29 (0.26-20.02)
No	109 (78.9%)	7 (87.5%)	Referent[f]
Interviewee reported washing hands “always”[i]			
Yes	89 (64.0%)	4 (50.0%)	2.25 (0.51-9.91)
No	50 (36.0%)	4 (50.0%)	Referent[f]
Reported drinking water sources during study[j]			
Surface water (river, canal)	3 (2.2%)	1 (12.5%)	Referent[f]
Groundwater (well, spring)	30 (21.7%)	2 (25.0%)	8.50 (0.37-195.45)
Rainwater	8 (5.8%)	0 (0.0%)	n/a[k]
Piped water (inside & outside)	66 (47.8%)	3 (37.5%)	10.00 (0.49-203.93)
Bottled water	31 (22.5%)	2 (25.0%)	7.00 (0.30-162.20)
Pay for water[l]			
Yes	38 (27.3%)	1 (12.5%)	2.68 (0.31-23.35)
No	101 (72.7%)	7 (87.5%)	Referent[f]
Time to water source (minutes)			
0-4	86 (62.3%)	2 (25.0%)	Referent[f]
5-9	15 (10.9%)	2 (25.0%)	0.21 (0.03-1.68)
10-19	20 (14.5%)	2 (25.0%)	0.31 (0.04-2.42)
20-39	15 (10.9%)	2 (25.0%)	0.13 (0.01-1.12)
>40	2 (1.5%)	0 (0.0%)	n/a[k]
Perception of diarrhea as serious illness[m]			
Yes	43 (30.7%)	0 (0.0%)	n/a[k]
No	97 (69.3%)	8 (100.0%)	

a. Total households do not total 143 here due to missing cross-sectional data for four using households.
b. Total households do not total 9 here due to missing cross-sectional data for one non-using households.
c. Odds ratios >1 show positive correlation with continued use, and odds ratios <1 show negative correlation with continued use.
d. Odds ratio estimates adjusted for time since implementation, coded as a four-group categorical variable: 10-, 11-, 16-, and 18-month.
e. Respondents were asked to demonstrate that soap was present in the household.
f. The referent serves as the group to which the other groups are compared in calculating odds ratios.
g. Shared latrine or toilet vs. Private latrine or toilet.
h. Safe storage defined as using a covered or narrow mouth water storage container.
i. Interviewee responds that family members wash hands “always” with soap and water after defecating.
j. Multiple answers possible and principal source not specified.
k. N/A due to zero value in “Not using filter at time of follow up” category, which disallows odds ratio calculation.
l. Any amount as reported by interviewee.
m. Interviewee reported belief in diarrhea as very easy or easy for children to get as well as an illness from which children can die.

Figure 3.5 – Associations between selected factors and continued BSF use (RCT households)



* Odds ratios >1 show positive correlation with continued use, and odds ratios <1 show negative correlation with continued use.
** Odds ratio estimates adjusted for time since implementation, coded as a four-group categorical variable: 10-, 11-, 16-, and 18-month.
^ Interviewee reported self and spouse having received any primary education.
^^ Information about preventing or treating diarrhea from any source (friend, clinic, media, etc.).
[o] Number of assets as categorical variable by sum of six household assets: motorcycle, refrigerator, television, washer, fan, cell phone.
[oo] Respondents were asked to demonstrate that soap was present in the household.
† Shared latrine or toilet in comparison to private latrine or toilet as the referent.
†† Safe storage defined as using a covered or narrow mouth water storage container.
[a] Interviewee responds that family members wash hands "always" with soap and water after defecating.
[aa] Multiple answers possible and principal source not specified.
˚ Any amount as reported by interviewee.

Assessment of community associations with continued filter use, in addition, was conducted using grouping based on observational and anecdotal information. For RCT households, the principle grouping was Brisas del Yuna, a semi-urban community, versus Jayaco, a semi-rural community. In addition, KM 103, the poorest and most rural area of the Jayaco community, was compared with the rest of Jayaco, and KM 103 and Brisas del Yuna, the poorest two areas/communities, were compared with the remaining areas in Jayaco. For non-RCT households, Palmarito, a semi-urban community, was compared with all other communities, which were semi-rural. No other groupings were analyzed for non-RCT households due to the lack of demographic and socioeconomic information for these communities.

Table 3.6 – Community analysis and adjusted odds ratios for RCT and non-RCT households

COMMUNITY COMPARISONS - Controlling for Time in Use	**Using filter at time of follow up (n=143,RCT / n=158,nRCT)**	**Not using filter at time of follow up (n=9,RCT / n=18,nRCT)**	**OR (95% CI)[a] Adjusted[b] (*Significance)**
Community[c]			
Brisas del Yuna	37 (25.9%)	3 (33.3%)	0.66 (0.15-2.86)
Jayaco	106 (74.1%)	6 (66.7%)	Referent[d]
Community[e]			
KM 103	27 (25.5%)	5 (83.3%)	0.06 (0.01-0.58)*
Rest of Jayaco	79 (74.5%)	1 (16.7%)	Referent[d]
Community[f]			
Brisas del Yuna & KM 103	64 (44.8%)	8 (88.9%)	0.09 (0.01-0.77)*
Other Communities	79 (55.2%)	1 (11.1%)	Referent[d]
Community[g]			
Palmarito	30 (19.0%)	1 (5.6%)	6.15 (0.73-51.92)
Other communities	128 (81.0%)	17 (94.4%)	Referent[d]

a. Odds ratios >1 show positive correlation with continued use, and odds ratios <1 show negative correlation with continued use as compared to referent group.
b. Odds ratio estimates adjusted for time since implementation, coded as a four-group categorical variable: 10-, 11-, 16-, and 18-month.
c. Comparison setup due to Brisas del Yuna as semi-urban and Jayaco as semi-rural.
d. The referent serves as the group to which the other groups are compared in calculating odds ratios.
e. Comparison setup based on anecdotal evidence that KM 103 is poorest and most rural area in Jayaco.
f. Comparison setup based on anecdotal evidence that KM 103 and Brisas del Yuna are the poorest areas/communities.
g. Comparison setup due to Palmarito as semi-urban and other communities as semi-rural.

Significant associations with continued filter use were found for two of the four community groupings, as detailed in Table 3.6: households in KM 103 were 0.06 (0.01-0.58, 95%CI) times as likely to still be using their BSF as households in Jayaco; and households in KM 103 and Brisas del Yuna were 0.09 (0.01-0.77, 95%CI) times as likely to still be using their BSF as households in the remaining Jayaco communities. Though the difference was not significant, households in Brisas del Yuna were 0.66 (0.15-2.86, 95% CI) times as likely to still be using their BSF as households in Jayaco, and households in Palmarito were 6.15 (0.73-51.92, 95%CI) times as likely to still be using their BSF as households in all other non-RCT communities.

3.3.3 Sustainability – Filters in Use

As previously noted, the overall percentage of BSFs in use at the time of follow-up was 91.1%, 89.8%, and 90.4% for RCT households, non-RCT households, and all households together, respectively (Table 3.2). Several additional questions related to sustainability were asked of households continuing to use their BSFs, including knowledge of filter cleaning process, cleaning of the filter outlet, amount and type of filter use, problems with the filter, and health benefits associated with the filter. Descriptive statistics for these results and comparative distributions for those variables with a value range are detailed in Tables 3.7.A and 3.7.B and Figures 3.6, 3.7, and 3.8.

Positive use and maintenance activities in the 301 households still using their BSF were reported as follows: cleaning filter outlet = 85.1% of RCT households and 84.8% of non-RCT households; always using the BSF for drinking water = 89.5% (RCT) and 98.7% (non-RCT); never having to clean the filter by the time of follow up = 79.0% (RCT) and 70.1% (non-RCT); using BSF water for additional purposes besides drinking

= 49.0% (RCT) and 57.6% (non-RCT); replacing another previously practiced treatment with BSF = 74.1% (RCT) and 47.5% (non-RCT); BSF providing sufficient water for daily needs = 95.1% (RCT) and 96.2% (non-RCT); and beneficial impact on health = 96.2% (RCT) and 100% (non-RCT) (e.g., preventing diarrheal, skin, and vaginal disease).

Table 3.7.A – Selected factors of BSF use for all households still using BSF

FACTORS[a] OF BSF USE FOR HOUSEHOLDS USING BSF	**RCT Households (N = 143)[b]**	**Non-RCT Households (N = 158)[c]** (*Significance)[d]
Knowledge of steps for cleaning BSF[e]		
Yes	56 (39.2%)	37 (23.4%)*
No	87 (60.8%)	121 (76.6%)
Number of times BSF cleaned[f]		
0	113 (79.0%)	110 (70.1%)*
1-2	19 (13.3%)	36 (22.9%)
3-4	3 (2.1%)	9 (5.7%)
5-6	6 (4.2%)	2 (1.3%)
7-8	0 (0.0%)	0 (0.0%)
9-10	2 (1.4%)	0 (0.0%)
Washing of the filter outlet[g]		
Yes	120 (85.1%)	134 (84.8%)
No	21 (14.9%)	24 (15.2%)
Number of times BSF used per week		
1-3	75 (53.2%)	55 (35.5%)*
4-6	16 (11.4%)	11 (7.1%)
7-13	45 (31.9%)	85 (54.8%)
>14	5 (3.6%)	4 (2.6%)
BSF water used for drinking water “always”		
Yes	128 (89.5%)	156 (98.7%)*
No	15 (10.5%)	2 (1.3%)
Using BSF water for other uses in addition to drinking water[h]		
Yes	70 (49.0%)	91 (57.6%)
No	73 (51.0%)	67 (42.4%)
BSF water sufficient for daily needs		
Yes	135 (95.1%)	151 (96.2%)
No	7 (4.9%)	6 (3.8%)

a. All characteristics reported as such by interviewee.
b. RCT households do not total 143 for all characteristics due to missing responses for certain households, and reported percentages may not add up to 100% due to rounding.
c. Non-RCT households do not total 158 for all characteristics due to missing responses for certain households, and reported percentages may not add up to 100% due to rounding.
d. Significant difference between groups as determined by chi-square test showing $p < 0.05$.
e. Includes knowledge of all or some of the steps.
f. Number of times cleaned since installation of filter.
g. Washing of any form, including with soap, chlorine, and/or water.
h. Other uses include washing hands, washing dishes, washing food, cooking, and bathing.

Table 3.7.B – Selected factors of BSF use for all households still using BSF (Continued)

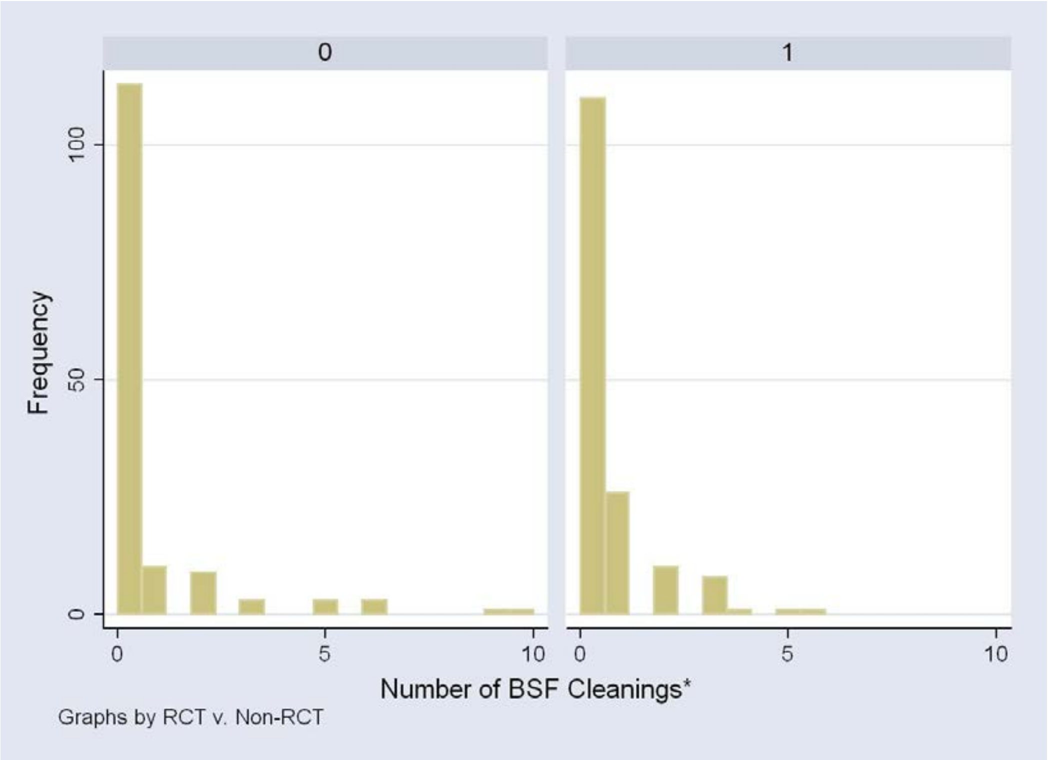
FACTORS[a] OF BSF USE FOR HOUSEHOLDS USING BSF (Continued)	**RCT Households (N = 143)[b]**	**Non-RCT Households (N = 158)[c]** (*Significance)[d]
Use of BSF replaced other treatment practice		
Yes	106 (74.1%)	75 (47.5%)*
No	37 (25.9%)	83 (52.5%)
Other treatments replaced:		
Boiling	22 (20.8%)	26 (35.1%)*
Chlorine	45 (42.5%)	19 (25.7%)
Purchasing bottled water	37 (34.9%)	21 (28.4%)
Straining water through cloth	2 (1.9%)	8 (10.8%)
Problems with the BSF		
Yes	12 (8.4%)	3 (1.9%)*
No	131 (91.6%)	155 (98.1%)
Reported Problems:		
Change or stop in flow	4 (36.4%)	0 (0.0%)
Lost or broken diffuser plate	1 (9.1%)	0 (0.0%)
Leakage via crack or fissure	0 (0.0%)	2 (66.7%)
Water is not clean or considered unusable	1 (9.1%)	0 (0.0%)
Other[e]	5 (45.5%)	1 (33.3%)
Knowledge of where to find or buy replacement parts		
Yes	7 (4.9%)	16 (10.3%)
No	135 (95.1%)	140 (89.7%)
BSF having beneficial impact on health[f]		
Yes	142 (99.3%)	158 (100.0%)
No	1 (0.7%)	0 (0.0%)

a. All characteristics reported as such by interviewee.
b. RCT households do not total 143 for all characteristics due to missing responses for certain households, and reported percentages may not add up to 100% due to rounding.
c. Non-RCT households do not total 158 for all characteristics due to missing responses for certain households, and reported percentages may not add up to 100% due to rounding.
d. Significant difference between groups as determined by chi-square test showing $p < 0.05$.
e. Other problems include presence of ants and breakage of outlet.
f. Includes cleaner water for the family and decrease or avoidance of diarrheal, skin, and/or vaginal illness.

The number of cleanings for those BSFs that were cleaned since installation ranged from 0 to 10 (Figure 3.6), additional uses of the BSF treated water included washing hands, washing dishes, washing food, cooking, and bathing, and replaced treatment practices included boiling, chlorination, use of bottled water, and straining water through cloth (Figure 3.7). The BSF was used between 1 and 20 times per week

(Figure 3.8), with 53.2% of RCT households using the filter 1 to 3 times per week and 54.8% of non-RCT households using the filter 7 to 13 times per week.

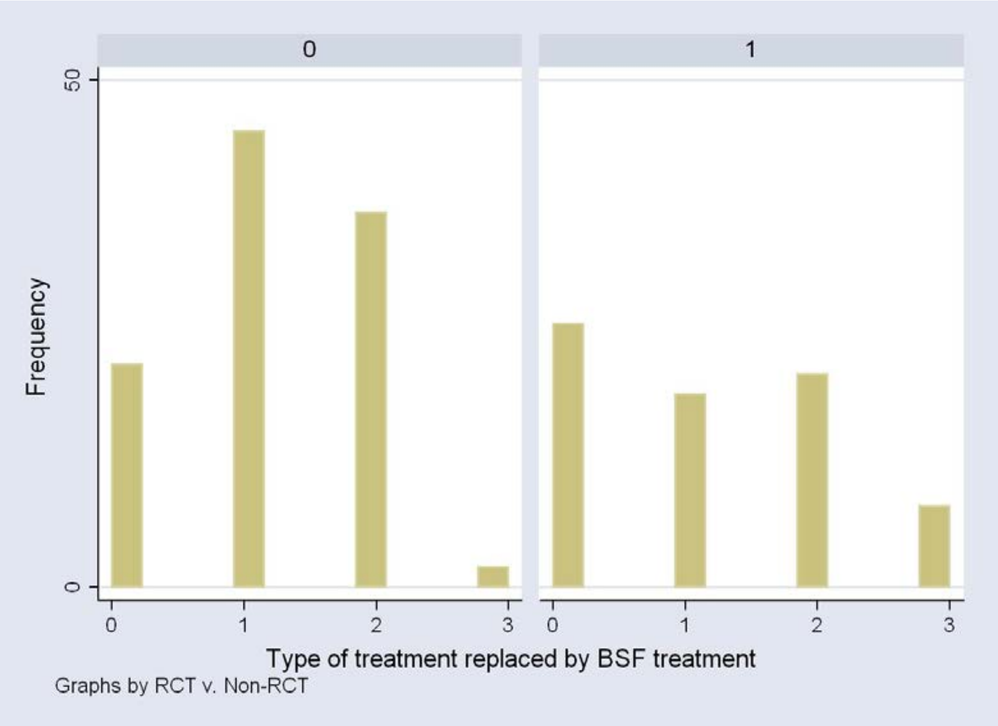
Figure 3.6 – Histogram of number of BSF cleanings for RCT and non-RCT households



Note: 0 = RCT and 1 = non-RCT / *Number of times cleaned since installation of filter.

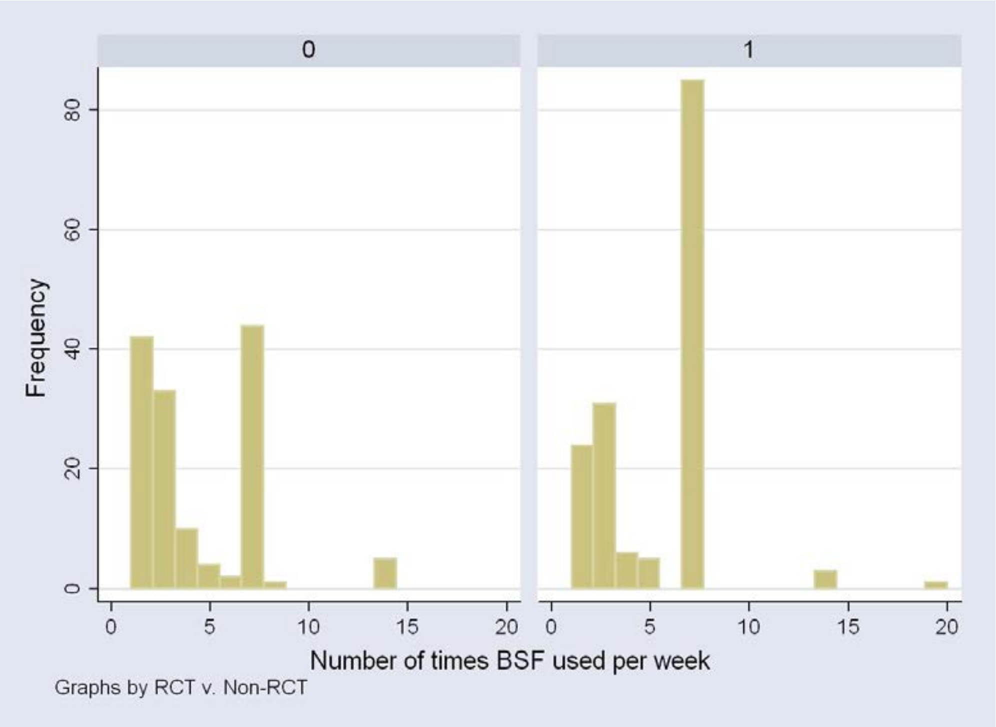
Negative indications of sustainability and BSF maintenance included the following: households knowing some or all principal steps in BSF cleaning = 39.2% RCT and 23.4% non-RCT; filter problems = 8.4% (RCT) and 1.9% (non-RCT); and knowledge of where to find or buy BSF replacement parts = 4.9% (RCT) and 10.3% (non-RCT). The principal reported problems included a change or stop in flow rate, a lost or broken diffuser plate, a leakage via crack or fissure, and unclean or unsuitable water.

Figure 3.7 – Histogram of type of treatment replaced by BSF for RCT and non-RCT households



Note: 0=RCT, 1=non-RCT (top) / 0=Boiling, 1=Chlorination, 2=Bottled Water, 3=Cloth Straining (bottom)

Figure 3.8 – Histogram of number of BSF uses per week for RCT and non-RCT households



Note: 0 = RCT and 1 = non-RCT

When comparing the indications seen in the RCT and non-RCT households, the differences were found to be significant for households knowing some or all principle steps in BSF cleaning, number of filter cleanings, number of times the BSF is used per week, always using the BSF for drinking water, BSF replacing another previously practiced treatment, type of previously practiced treatment replaced, and filter problems.

3.3.4 Water Quality Analysis

Water samples were analyzed for all RCT households continuing to use their BSF and for 31% of non-RCT households continuing to use their BSF. A total of 348 and 156 samples were analyzed for raw and treated water concentrations and corresponding calculated reductions of *E. coli*, total coliforms, and turbidity among RCT and non-RCT households, respectively, as detailed in Table 3.8. Intended observations included both untreated and BSF treated water samples taken during a sampling visit. For RCT households, there were 108 (76%) complete observations out of 143 interviews. For non-RCT households, there were 55 (35%) complete observations out of 158 interviews.

Concentrations of *E. coli* were categorized into decimal (order-of-magnitude) concentrations for both untreated and BSF treated water samples. Out of 167 untreated water samples for all communities, 55 (33%) had 10 or less *E. coli* MPN/100mL (Table 3.9). Out of 170 BSF treated water samples taken for all communities, 133 (75%) had 10 or less *E. coli* MPN/100mL (Table 3.10). The World Health Organization (WHO) considers water samples from 0 to 10 MPN/100mL to be in the "reasonable" range of water safety (WHO, 2004).

Table 3.8 – Water sample numbers and totals

TYPE OF WATER SAMPLE	**NUMBER (%)**
RCT Households – All	**N = 348**
- Untreated	111 (31.9%)
- BSF Treated	115 (33.0%)
- BSF Treated, Stored	114 (32.8%)
- BSF Treated, Boiled, Stored	8 (2.3%)
Non-RCT Households – All	**N = 156**
- Untreated	56 (35.9%)
- BSF Treated	55 (35.3%)
- BSF Treated, Stored	45 (28.8%)

Note: For reference, when both untreated and BSF treated water samples were taken during a sampling visit, it was considered a complete observation. For the RCT households, there were 108 complete observations. For the non-RCT households, there were 55 complete observations.

Table 3.9 – *E. coli* concentrations of untreated water samples

Number (percentage[a]) of all samples by decimal *E. coli* concentration ranges in untreated water[b]						
	<1 (MPN/100mL)	1-10 (MPN/100mL)	11-100 (MPN/100mL)	101-1000 (MPN/100mL)	1,001+ (MPN/100mL)	Total samples
All communities	19 (11%)	36 (22%)	63 (38%)	37 (22%)	12 (7%)	167
RCT	16 (14%)	21 (19%)	44 (40%)	21 (19%)	9 (8%)	111
Non-RCT	3 (5%)	15 (27%)	19 (34%)	16 (29%)	3 (5%)	56

a. Percentages with strata may not add up to 100% due to rounding.
b. Samples were filter influent in all households, taken at the time of visit (untreated water samples).

Table 3.10 – *E. coli* concentrations of BSF treated water samples

Number (percentage[a]) of all samples by *E. coli* decimal concentration ranges in treated household drinking water[b]						
	<1 (MPN/100mL)	1-10 (MPN/100mL)	11-100 (MPN/100mL)	101-1000 (MPN/100mL)	1,001+ (MPN/100mL)	Total samples
All communities	68 (40%)	65 (35%)	28 (16%)	7 (4%)	2 (1%)	170
RCT	45 (39%)	48 (42%)	17 (15%)	3 (3%)	2 (2%)	115
Non-RCT	23 (42%)	17 (50%)	11 (20%)	4 (7%)	0 (0%)	55

a. Percentages with strata may not add up to 100% due to rounding.
b. Samples were filter effluent in all households, taken directly at the time of visit (BSF treated water samples).

Geometric mean concentrations of *E. coli* and total coliforms and geometric mean value of turbidity, all presented in Table 3.11, were calculated and stratified by community. For RCT households, geometric mean *E. coli* MPN/100 mL was 25.3 and 3.2 for untreated and BSF treated water, respectively; geometric mean total coliform MPN/100mL was 1035 and 129 for untreated and BSF treated water, respectively; and geometric mean turbidity (NTU) was 1.2 and 0.6 for untreated and BSF treated water, respectively. For non-RCT households, geometric mean *E. coli* MPN/100 mL was 35.2

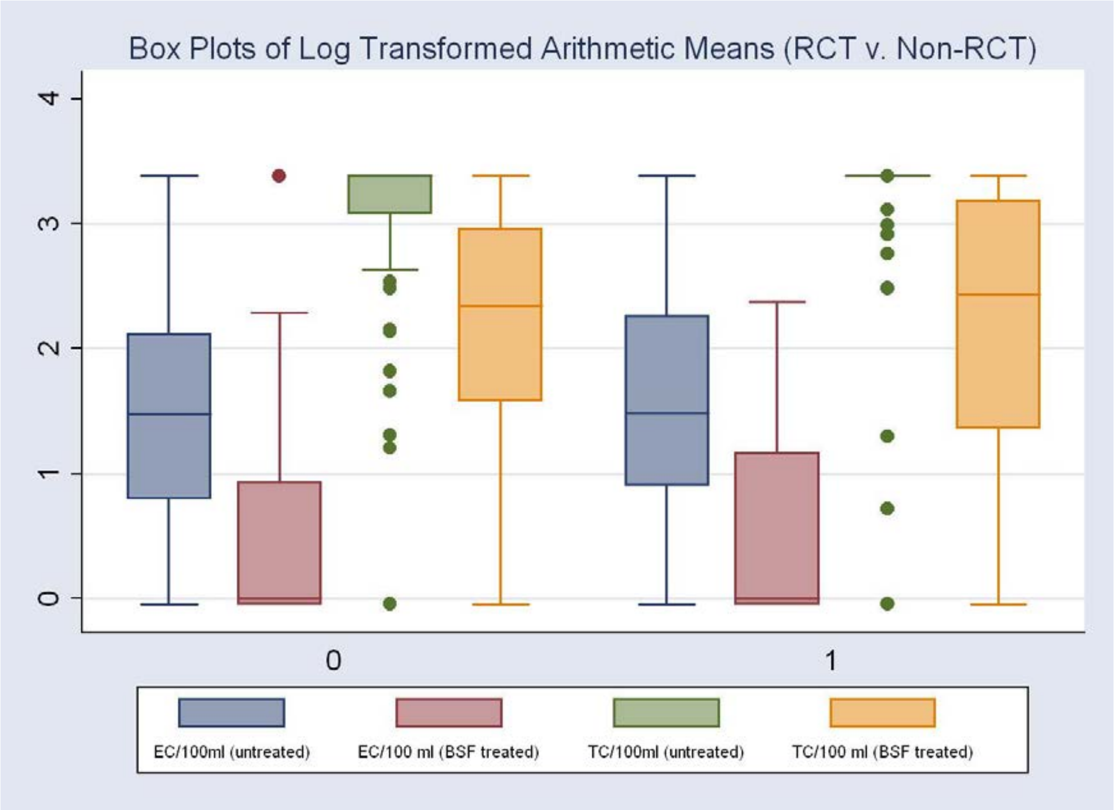
Table 3.11 – Geometric mean concentrations of *E. coli*, Total coliforms, and turbidity in untreated and BSF treated water samples

All Samples	Water quality data[a], geometric means (Untreated Water)			Water quality data[a], geometric means (BSF Treated Water)		
	E.coli/100 mL	TC/100mL	Turbidity (NTU)	*E.coli*/100 mL	TC/100mL	Turbidity (NTU)
All communities	28.3	1181	1.1	3.3	131	0.6
RCT	25.3	1035	1.2	3.2	129	0.6
Brisas del Yuna	21.1	482	1.0	3.3	137	0.7
Jayaco Arriba	66.7	2161	1.6	2.5	116	0.7
KM 100	17.0	1454	1.1	5.2	143	0.6
KM 101	54.3	2264	1.6	3.8	369	0.6
KM 103	7.7	326	1.1	2.4	32.1	0.8
Majaguay	16.6	1573	0.9	2.7	292	0.4
Non-RCT	35.2	1532	1.0	3.6	136	0.5
Arroyo Toro	51.5	2420	1.3	0.9	208	0.5
El Chispero	15.4	1864	0.9	3.2	94.1	0.6
Ingenio	47.9	2137	0.9	0.9	15.9	0.4
Jima	23.9	1924	0.9	6.2	210	0.5
Los Quemados	34.7	854	0.4	23.8	532	0.4
Masipedro	292	2420	2.5	4.9	583	0.5
Palmerito	24.1	594.3	1.4	3.5	197	0.6
Sabana del Puerto	45.4	2420	0.6	3.6	28.1	0.6

a. Data from filter households, untreated water and BSF treated water samples from 1 sustainability sampling round.

and 3.6 for untreated and BSF treated water, respectively; geometric mean total coliform MPN/100mL was 1532 and 136 for untreated and BSF treated water, respectively; and geometric mean turbidity (NTU) was 1.0 and 0.5 for untreated and BSF treated water, respectively. Box plots of log-transformed arithmetic mean concentrations of *E. coli* and total coliforms in RCT and non-RCT households are shown in Figure 3.9. In addition, further analysis and stratifications of the water sample data can be found in Appendix A, along with all of the additional data analysis for total coliforms equivalent to that presented here for *E. coli*.

Figure 3.9 – Box plots of arithmetic means of *E. coli* and total coliforms (RCT v. Non-RCT)



Note: RCT = 0, Non-RCT = 1 / EC – *E. coli*, TC – Total coliforms

Average percent reductions in *E. coli*, total coliforms, and turbidity are provided in Table 3.12. For RCT households, percent reductions based on concentration differences in untreated and BSF treated water were 87.7% for *E. coli*, 87.3% for total coliforms, and 32.4% for turbidity. For non-RCT households, these reductions were 89.8% for *E. coli*, 91.1% for total coliforms, and 23.8% for turbidity.

Table 3.12 – Percent reductions in water samples by *E. coli*, total coliforms, and turbidity

Percent reductions[a] in water samples by Total coliform, *E. coli*, and Turbidity

Measure:	***E. coli***		**Total Coliform**		**Turbidity**
Samples compared for reduction:	Untreated to BSF Treated	Untreated to BSF Treated & Stored	Untreated to BSF Treated	Untreated to BSF Treated & Stored	Untreated to BSF Treated
All communities	88.4%	50.6%	88.7%	15.4%	29.5%
RCT	87.7%	52.2%	87.3%	(1.1%)[b]	32.4%
Brisas del Yuna	84.4%	(9.9%)	70.5%	(41.5%)	0.9%
Jayaco Arriba	96.3%	82.8%	94.6%	0.8%	54.7%
KM 100	66.2%	(1.3%)	89.4%	10.5%	41.6%
KM 101	93.1%	68.9%	84.4%	33.2%	61.7%
KM 103	75.6%	70.5%	92.0%	(57.7%)	11.5%
Majaguay	80.7%	44.8%	80.4%	42.5%	32.2%
Non-RCT	89.8%	42.3%	91.1%	38.6%	23.8%
Arroyo Toro	98.2%	55.2%	91.4%	0.0%	56.4%
El Chispero	79.3%	26.2%	94.9%	18.8%	19.2%
Ingenio	98.1%	78.2%	99.3%	65.7%	42.7%
Jima	74.2%	48.3%	89.1%	59.9%	30.0%
Los Quemados	41.3%	63.2%	23.3%	79.5%	(7.0%)
Masipedro	98.3%	54.1%	75.9%	0.0%	79.0%
Palmerito	85.6%	66.5%	66.8%	39.3%	4.9%
Sabana del Puerto	92.1%	(543.6%)	98.8%	0.0%	(8.9%)

a. Percent reduction values are computed as $(1 - 10^{-\text{average log reduction}})*100$ for *E. coli* and total coliform measures and as ((influent – effluent)/influent)*100 for turbidity.
b. Negative reductions are indicated by ( ).

Average $\log_{10}$ reductions in *E. coli* and total coliforms ranged from less than 0 to as much as 3.38 (<0% to 99.96%), as determined by the magnitude and range of concentrations measured. Figures 3.10 (*E. coli*) and 3.11 (total coliforms) illustrate these distributions as histograms, which appear to be normally distributed except for the percentage of samples showing zero or negative $\log_{10}$ reductions. Figure 3.12 highlights these distributions as box plots. Based on decimal categories of $\log_{10}$ *E. coli* reductions (Table 3.13), 32% were between 1 and 1.99, 12% between 2 and 2.99 and 5% >3 $\log_{10}$. Of the samples in which there was 0 $\log_{10}$ *E. coli* reduction, 79% had <1 *E. coli* per 100 mL in the untreated water.

Figure 3.10 – Histogram of $\log_{10}$ reductions of *E. coli* (all samples)

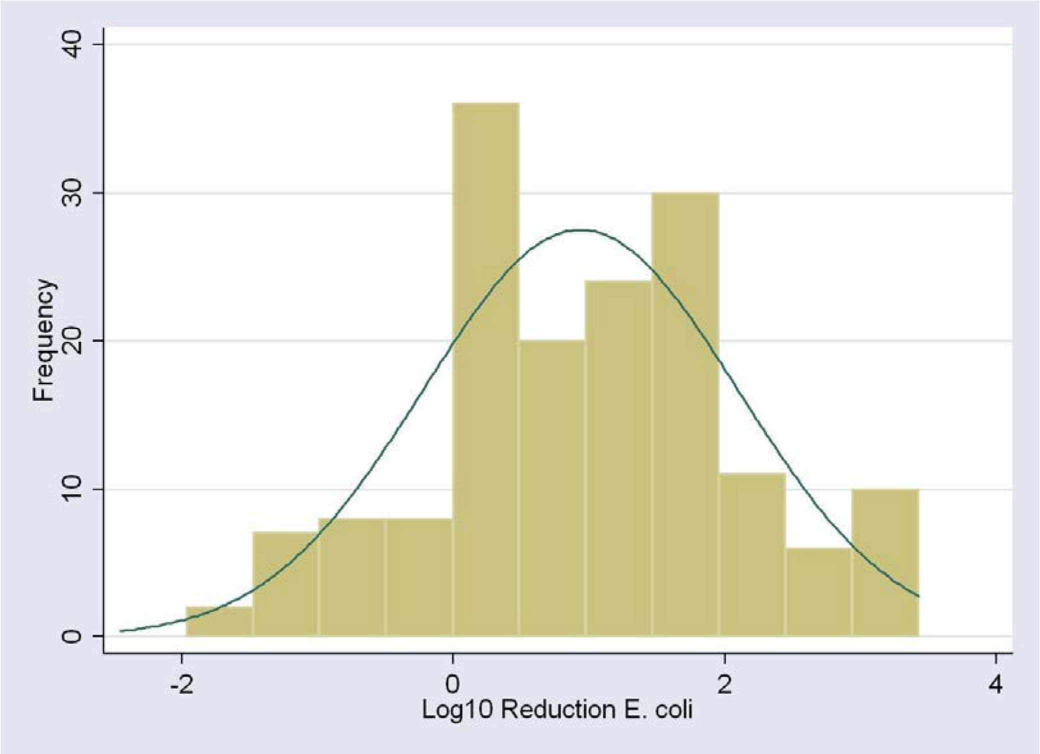


Figure 3.11 – Histogram of $\log_{10}$ reductions of total coliforms (all samples)

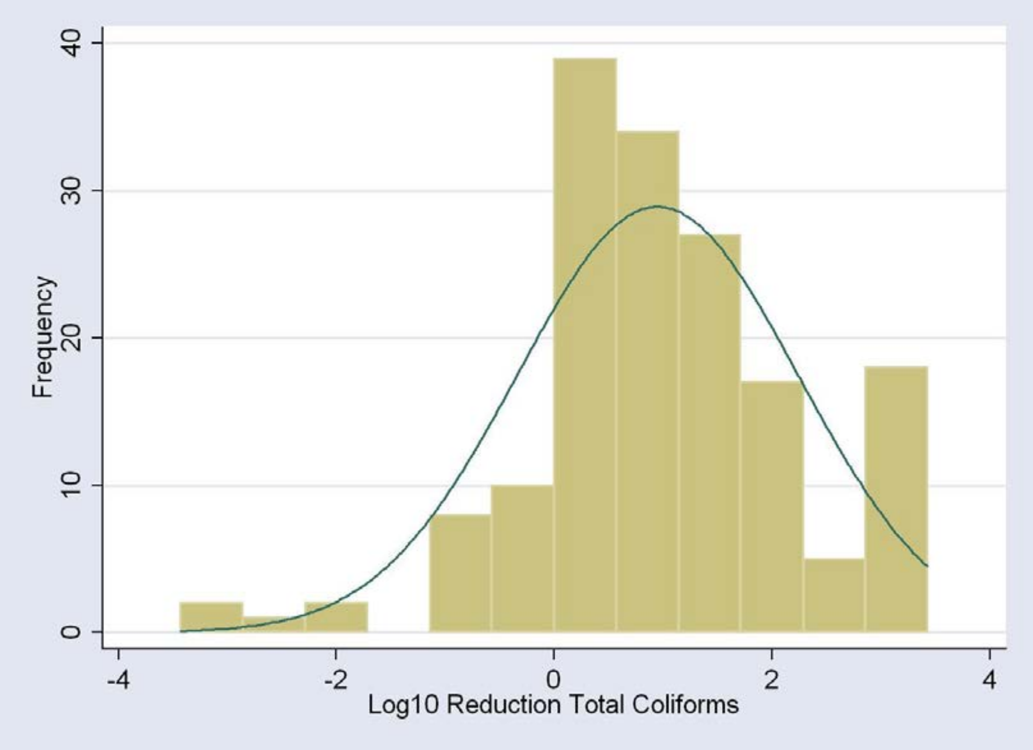


Figure 3.12 – Box plots of $\log_{10}$ reductions of total coliforms and *E. coli* (all samples)

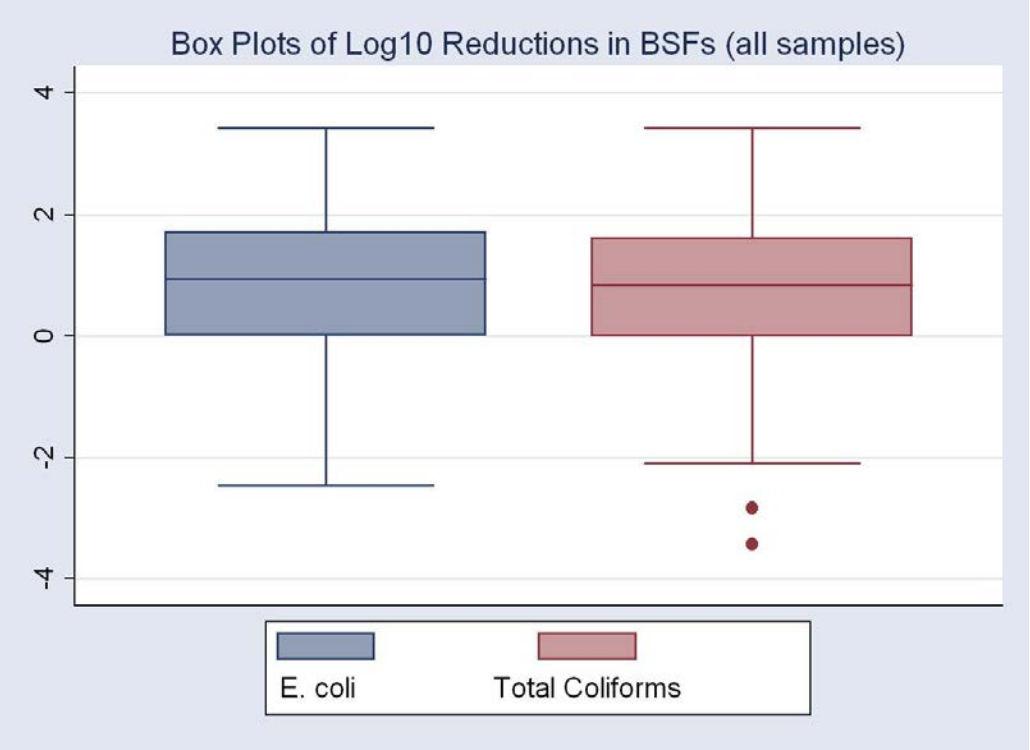


Table 3.13 – Categorical analysis of $\log_{10}$ reductions of *E. coli*

Percentage[a] of all filter samples by *E. coli* $\log_{10}$ reduction values[b] (LRV) (n=163[c])						
	<0[d]	0[e]	0.01-0.99	1-1.99	2-2.99	3-3.99
All communities	16%	9%	27%	32%	12%	5%
RCT	16%	12%	23%	33%	10%	6%
Non-RCT	16%	2%	35%	29%	15%	4%

a. Percentages may not add up to 100% due to rounding.
b. Log_{10} reduction values are computed as the $\log_{10}$(effluent/influent); 1 LRV=90% reduction, 2 LRV=99% reduction, and 3 LRV=99.9% reduction. Reduction is a function of influent water, however, and low LRV values do not necessarily indicate poor performance. In forty percent of samples (n=68), filters reduced product water to <1 *E. coli* per 100 mL, so reported LRVs are potential underestimates.
c. 163 (87%) sampling events (out of 188 total sampled one time each) yielded complete data to use in the LRV calculation.
d. Negative LRV values indicate that the effluent water contains more *E. coli* than the influent water.
e. In 79% of these samples the influent water contained <1 *E. coli* per 100 mL.

The negative $\log_{10}$ reductions seen in 16% of samples for *E. coli* correlate with increased concentrations of *E. coli* in the BSF treated water compared with the untreated water. These negative reductions can be the result of a filter not functioning properly, the flushing of organisms built up within the filter or in the exit orifice, or variations in source water quality, such that the bacteriological quality of water previously applied to the filter and now being pushed out of the filter bed is lower in quality than water delivered to the bed on the day of sampling.

3.4 Discussion

3.4.1 Study Participants

Participation in the sustainability assessment included two relatively distinct, yet important groups of households, where BSFs were installed between 8 and 22 months prior to interview. With the initial positive findings of various trials and intervention studies on BSFs and other POU technologies combined with the lack of specific follow-up to these trials and interventions, the opportunity to follow-up specifically with households previously the subject of an RCT was important (Fewtrell et al, 2005). Among three follow-up assessments cited in the meta-analysis of Fewtrell et al (2005), which assessed 38 studies overall, two were in response to health impact studies, with only one involving a POU technology (Hoque et al, 1996; Wilson & Chandler, 1993; Conroy et al, 1999).

On the other hand and in comparison, the non-RCT households included in the assessment provided insight into the sustainability of the BSF in households not involved in a research driven approach, therefore not subject to the repeated interviews and consistent oversight typical of a research study. Rather, these households, similar to others in programmatic settings, were exposed to a basic installation process with minimal follow-up. Given the growing prevalence of these "real-world" POU implementation programs not associated with advanced scientific research, the opportunity to include these non-RCT households also was important (Clasen et al, 2007; Lantagne, Quick, & Mintz, 2007).

3.4.2 Sustainability – Filters Not in Use and Factors Associated with Continued Use

Out of 328 interviewed households, 27 households were found not be using their BSF. Including an additional 5 non-interviewed households in the RCT group as a conservative measure, the overall percentage of households not using the filter was 9.6%, which breaks down into 8.9% disuse among RCT households and 10.2% disuse among non-RCT households. These filter disuse rates equate with continued use rates of 90.4% overall, 91.1% among RCT households, and 89.8% among non-RCT households.

These continued use rates are relatively high in comparison with those seen for other POU technologies. For ceramic filtration, continued use rates ranged from 67 to

73% up to one year post-implementation to 31% up to four years post-implementation, with 65% of discontinued use the due to filter breakage (Brown, Sobsey, & Proum, 2007; Clasen, Brown, & Collin, 2006; Lantagne, 2001). For chlorination, self-reported continued use ranged from 65 to 73% for intervention households up to one year post-introduction, with chlorine residual confirmed for 34 to 54% of these households (Colindres et al, 2007; Makutsa et al, 2001; Ram et al, 2007). For combined flocculation and disinfection, compliance during intervention ranged from 27 to 86% for the study population, with chlorine residual confirmed for 27 to 44% of these households and post-study compliance confirmed for 10% of one interviewed study population six months post-implementation (Crump et al, 2005; Macgregror-Skinner, 2004; Reller et al, 2003). For solar disinfection (SODIS), compliance ranged from 9 to 78% during study periods of approximately 6 months (Rose et al, 2006; Rainey & Harding, 2005).

Further, the continued use rates seen for the BSF in this study support those measured during other BSF interventions and studies. For 107 BSF households assessed in Haiti after 2.5 years average use, 96.3% of the filters were found to be working properly upon the first visit (Duke et al., 2006). For 336 BSF households assessed in Cambodia after up to 8 years of use, 87.5% of the filters were found to be in regular use (Liang, 2007). For 137 BSF households assessed in Honduras after up to 5 years of use, 71.7% of the filters were found to be in regular use (Miller, 2007). For 57 BSF households assessed in Ethiopia after at least five years of use, 70.2% of the filters were found to be in regular use (Earwaker, 2006). For 51 BSF households assessed in Kenya after 4 years of use, 98.0% of the filters were found to be in regular use (Fewster, Mol, & Wiessent-Brandsma, 2004).

Together, the high continued use rates in comparison with those seen for other POU technologies and the consistent continued use rates seen across BSF studies and intervention are a strong positive indicator of the sustainability of the BSF. High continued use rates specifically among our participants in Bonao further support that the concrete BSF is sustainable, with the rates being as high or higher than those found in Cambodia and Ethiopia.

The principle reason provided for discontinued use of the BSF was not that the filter was broken or not functioning but rather due to perception or dislike of the filter, with 63% of responding households stating this as the reason. In contrast, when looking at the ceramic water filter, a comparable yet different POU technology, a highly reported reason for disuse is breakage. In Cambodia, the breakage rate post-implementation was approximately 2% per month (Brown, Sobsey, & Proum, 2007); in Bolivia, 25% of households reported that breakage prevented regular use of their ceramic filter (Clasen, Brown, & Collin, 2006); and in Nicaragua, 66% of households not using their filter reported breakage as the reason for discontinued use (Lantagne, 2001).

Breakage or lack of proper function was reported by only 11% of households not using their BSF, which is low in comparison to the reported values for just breakage seen with the ceramic filter. In Honduras and Cambodia, respectively, 5% and 29% of non-using BSF households cited inability to fix a problem or lack or proper function as the reason for disuse (Miller, 2007; Liang, 2007). The latter is somewhat high, but they both still support the BSF as a positive indicator of sustainability. In Ethiopia, however, breakage or lack of proper function was reported by 86% of households not using their BSF, which suggests additional studies are necessary to solidify the ability of the BSF to withstand breakage over the long-term (Earwaker, 2006). In considering all of the reasons for disuse, it is important to note that these percentages represent relatively or very small sample sizes, such that general continued use rates may be a more adequate and representative indicator of sustainability.

It is also interesting to note the distinction between RCT and non-RCT households in regard to reported reasons for discontinued use. For RCT households, 33% reported perception or dislike of the filter as the reason for disuse, while 78% of non-RCT households reported this reason. The close and consistent contact afforded the RCT group over a period of many months provides one explanation for the apparent difference in perception of the BSF from the non-RCT group.

Looking specifically at time in use as an important factor for continued use of the BSF, a distinct pattern was seen only for RCT households, where time in use was positively correlated with continued use. In effect, the BSFs installed the longest were 9.90 (1.17-83.85) times as likely to in use as those installed more recently, which is counter-intuitive for a product requiring maintenance and constructed with breakable parts. Though the wide confidence interval suggests uncertainty, the higher continued use rates seen with BSFs in use longer are likely related to the structure of the RCT. For the households receiving BSFs in February 2006, interviews were conducted on a weekly basis for the next six months, and keeping the filter was contingent upon continued use of the filter as a study participant. In comparison, the filters installed in August 2006 were simply installed alongside of initial basic education and not followed over any period of time post implementation. Given this information, it is not surprising that time in use was positively associated with continued use among RCT households.

The lack of association seen with time since installation among non-RCT BSFs when controlling for community is likely limited by the presence of only one community in the group receiving the filters almost two years prior to follow-up verses the multiple communities that make up the comparison group. Further, this result is comparable to the lack of a strong association between filter disuse and time in use found for BSFs in Cambodia that had been in use for up to 8 years (Liang, 2007).

Selected factor analysis found positive associations with continued filter use for households that reported receiving health education, having soap in the household, practicing safe storage of filtered water, washing hands “always”, paying for water, having access to private verses shared latrines, and using ground, piped, or bottled versus surface water. These factors are potentially involved in the uptake of the BSF technology (Wellin, 1955; Rogers, 2003), but none of these associations, however, were found to be statistically significant. In addition, though certain conclusions can be made with the community analysis results, this study is particularly limited in its ability to analyze the impact of wealth or poverty on continued use of the BSF, and additional research into the influence of socioeconomic factors is necessary in future assessments.

Using observational and anecdotal evidence, the groupings used to compare communities were based on geographical and socioeconomic factors. Therefore, the results should be interpreted with caution. Further, considering the factors associated with continued filter use, it is important to highlight that the small numbers of interviewed households not using the filter (9 RCT and 18 non-RCT) make difficult the ability to establish significance and challenge the robustness of significance when found. Nonetheless, the differences are worth detailing, as they both show significant associations with BSF disuse for the two poorest RCT communities. Brisas del Yuna and KM 103 together were found to be 0.09 (0.01-0.77) times as likely to be using the filter as the other communities, while KM 103 was found to be 0.06 (0.01-0.58) times as likely to be using the filter as the remaining communities in Jayaco specifically.

3.4.3 Sustainability – Filters in Use

Strong positive indicators for sustainability and acceptability of the BSF were the high percentage (~85%) of users cleaning the filter outlet, the BSF providing sufficient water the daily needs for approximately 95% of users, and the beneficial health impact reported by almost all (96-100%) users. Given the BSF does not provide a consistent mechanism for protecting against recontamination of filtered water, the cleaning of the filter outlet serves as an identifiable step in preventing recontamination. Though practice of this cleaning step previously has been found to be inadequate, the high reported percentage for this study suggests that proper filter training can stimulate appropriate and adequate cleaning of the filter outlet (Earwaker, 2006).

Provision of sufficient water for daily needs is a comparable standard when considering POU technologies, and the ability of the BSF, flowing up to 1 L per minute, to provide sufficient water for a household's daily needs is a strength. Both the BSF and chlorination, with one dose or unit, are capable of producing 20 L of water over a period of 4 hours, a standard based on the minimum World Health Organization (WHO) suggested quantity of water for domestic use during emergencies and a conservative measure for regular household use (WHO, 2005). In contrast, ceramic filtration, combined coagulation and disinfection, and solar disinfection (SODIS) do not meet the standard of this indicator of sustainability (Sobsey et al, 2008).

Additional uses of the BSF may serve as additional incentive to continue using the filter, and reported additional uses included washing hands, washing dishes, washing food, cooking, and bathing. Further, 74.1% of RCT households and 47.5% of non-RCT households reported the BSF as replacing another form of treatment. For boiling, chlorination, and purchase of bottled water, using the BSF in place of such practices can reduce both costs and use of resources among households. Due to the high percentage of households not knowing the steps to cleaning the filter, the high percentage of households not having cleaned the filter does not necessarily support the BSF as a low maintenance POU technology. In looking toward sustainable use of the BSF in the future, it will be especially important to ensure users have access to information of how to properly clean the filter or to a technician that can assist them in the cleaning process, particularly given that the flow rate can be easily restored with proper cleaning.

Each of the positive and negative indications for BSF sustainability was assessed for the 301 households still using their BSFs. All of these selected factors were self-reported, so it is possible, particularly among the positive indicators, that they are overestimates, as filter users may be prone to giving positive responses if such responses are thought to be the desirable outcome of the intervention or in hopes of receiving additional health-related interventions in the future (Manun'Ebo et al, 1997).

3.4.4 Water Quality Analysis

Analysis of the microbiological water quality related to use of the BSF revealed both low levels of improvement and relatively low levels of fecal contamination of influent waters. When comparing untreated water samples to BSF treated water samples, the average reduction was 88.4% for *E. coli*. Among these samples, 47% showed greater than 1 $\log_{10}$ reduction (>90%), with a maximum 3.38 $\log_{10}$ reduction (99.96%).

In comparison to the average reductions of 79% for *E. coli* seen in Stauber's RCT in 2006, these reductions values are actually an improvement and support the BSF as a sustainable POU technology. Further, they are comparable to those seen in an analogous study in Ethiopia, where 87.9% reduction of *E. coli* was seen with 39 BSFs in use for at least 5 years (Earwaker, 2006), and with 75% of BSF treated water samples achieving less than 10 *E. coli* MPN/100 mL, they are an improvement on analogous measures of 70.5% and 55% seen in studies conducted in Kenya and Cambodia, respectively (Fewster, Mol, & Wiesent-Brandsma, 2004; Liang et al, 2007).

Nonetheless, these levels of reduction are low in comparison to laboratory results for the BSF, where it has been shown to reduce bacterial indicators of fecal contamination by 90 to 99% (Stauber et al., 2006). They are also low in comparison reduction rates seen in other analogous studies: 98.5% reduction of *E. coli* for 107 BSFs assessed in Haiti that had been in use an average of 2.5 years (Duke et al, 2006); 95% reduction of *E. coli* for 104 BSFs in use for up to 8 years (Liang et al, 2007); and 93.0% reduction of *E. coli* for approximately 600 BSFs in 6 countries across 3 continents (Kaiser et al, 2002).

This result could be related to the relatively low contamination levels seen in the influent or untreated water samples. For *E. coli*, 71% of the untreated water samples were less than 100 MPN/100 mL, with a geometric mean of 28.3 MPN/100 mL. With low initial concentrations of indicators and the given detection limits of <1 MPN/100 mL to

>2419.6 MPN/100 mL, the $\log_{10}$ reduction values calculated may be underestimates of those actually achieved by the BSF.

Negative $\log_{10}$ reductions in *E. coli* were found in 16% of the water samples, which is concerning. These negative reductions signified an increase in *E. coli* concentration in BSF treated water samples as compared to untreated water samples. As highlighted in the results, these negative reductions can be the result of a filter not functioning properly, the flushing of organisms built up within the filter, or variations in source water quality. A possible explanation for such negative reductions is that the water stored within the filter bed was of less quality than the source water being poured into the filter. Further, concentrations of *E. coli* have the propensity to change over time.

The geometric mean for *E. coli* among BSF treated water samples was 3.3 MPN/100 mL, which is within the “reasonable” range of water safety (0-10 MPN/100 mL), according to WHO definitions (WHO, 2004). The geometric mean for total coliforms, on the other hand, among BSF treated water samples was 131.1, which falls into the “dangerous” range of water safety (100-1000 MPN/100 mL), according to WHO definitions (WHO, 2004). High coliform values observed in effluent or BSF treated water, in addition to being influenced by relatively low contamination levels in influent water, can result from growth and survival of total coliforms within in the filter or on the filter outlet. Previous research in the United States found significant increases in the presence of coliforms above temperatures of 15ºC (LeChevallier, Welch, & Smith, 1996). With average temperatures ranging from 23 to 32ºC in the Dominican Republic, the environment is potentially enhancing for coliform growth (Presidencia, 2008).

Average turbidity reductions seen between untreated water and BSF treated water were low at 29.5%. Similar to the reductions discussed above, the low turbidity levels (1.1 NTU average) seen in the untreated water samples provide an explanation for the low reductions. Further, the average turbidity level of the BSF treated water (0.6 NTU) falls below the United States Environmental Protection Agency (EPA) standard of 1 NTU, and the average turbidity level of the untreated water (1.1 NTU) adheres to the WHO standard of less than 5 NTU (WHO, 2004).

Chapter 4: Sustained Health Impact of the Biosand Filter In Household Use

4.1 Introduction

Access to clean drinking water is not a reality for approximately 1.1 billion people in the world (WHO/UNICEF, 2000). This lack of access places a significant health and economic burden on these people in the form of diarrheal disease, time away from productive enterprise, costs of medical treatment, and decrements in child development. The burden disproportionately impacts children, with approximately 1.6 million children dying each year due to diarrheal diseases linked to unsafe drinking water and many more suffering from disease and developmental deficiencies (WHO, 2008).

Household water treatment at the point-of-use (POU) holds great potential in providing clean, safe drinking water to those lacking it. It is particularly attractive in locations where access to traditional large-scale water treatment systems and safe wells is not realistic due to inadequacies of water sources, high costs of alternative safe drinking water (e.g., bottled water), and lack of quality control in water treatment and distribution. In both laboratory and field studies, POU technologies have proven effective in improving microbiological water quality and reducing diarrheal disease among users. Meta-analyses of multiple household-level interventions with POU technologies found average reductions in diarrheal disease of 35 to 51% among users, and epidemiological, microbial reduction, and other scientific evidence of the effectiveness of POU water treatment technologies is growing as new studies are reported (Fewtrell et al., 2005; Clasen et al., 2007; Sobsey, 2002).

Building on the growing evidence of the effectiveness of POU water treatment, the parameters of sustainability, cost effectiveness, and scalability become critical as researchers, policy-makers, and implementers move forward (Sobsey, 2002). Though some measures of user compliance in performing POU treatment have been assessed (Rose et al, 2006; Rainey & Harding, 2005; Ram et al, 2007; MacGregor-Skinner et al, 2004; Brown, 2003), little follow-up of the initial positive results seen in the randomized controlled trials and other implementation studies has occurred. As a result, little robust evidence exists of the sustainability of POU technology, as measured by continued use, consistent water quality improvement, and sustained health impact. Of the existing evidence, continued use and sustained impact based on improved water quality are shown mostly to decrease over time, whether due to the difficulty of affecting human behavior change, physical breakage of the treatment technology, or lack of physical or economic access to resupply and replacement parts (MacGregor-Skinner et al, 2004; Brown, Sobsey, & Proum, 2007; Arnold & Colford, 2007). Given that sustainability is one of the primary performance criteria for recommended POU technologies, further assessment of sustainability will be critical evidence of long-term POU effectiveness (Sobsey, 2002; Sobsey et al., 2008).

The Biosand filter (BSF) is a promising POU technology with increasing evidence of effectiveness in both laboratory and field studies (Palmateer et al., 1999; Lee, 2001; Elliot et al., 2006; Stauber, 2007; Liang, 2007). The BSF is an intermittently operated, slow sand filter based on the design and operational principles of traditional large-scale slow sand filtration. By developing and maintaining a biologically active surface layer or schmutzdecke, the filter functions by biological predation, natural death, adsorption, and mechanical trapping of potentially harmful pathogens.

Laboratory studies document the BSF reducing indicators of fecal contamination by approximately 90-99% for bacteria, 90% for viruses, and >99.9% for protozoan parasites (Stauber et al., 2006). Initial field studies also show effective reductions of fecal bacteria in water and a positive health impact, measured as reduced burdens of household diarrheal disease. BSFs in Nicaragua were found to reduce bacterial indicators of fecal contamination by 99.1% (Manz & Buzunis, 1995). BSFs in six different countries showed an average reduction of 93% of fecal indicator bacteria (Kaiser et al., 2002). BSFs in the Dominican Republic were found to reduce diarrheal disease by 47% in BSF households compared to control households in a randomized controlled trial (Stauber, 2007).

Some evidence of BSF continued use has been documented, though few, if any, rigorous field studies have been conducted to assess longitudinal effective use and sustainability. Among 107 households in Haiti in which the BSF had been implemented for more than two years, all households were found to still be using the filter and average reduction of *E. coli* was determined to be 98.5% (Duke et al, 2006). Among 57 households in Ethiopia surveyed five years after BSF implementation, 70.2% were found to still be using the filter, and average reduction of *E. coli* was determined to be 87.9% (Earwaker, 2006).

The purpose of this study was to assess the continued use, performance, and overall sustainability of previously implemented BSFs in and around Bonao, Dominican Republic (DR) through longitudinal analysis of sustained health impact, measured as diarrheal disease, and sustained water quality improvement. The DR served as an appropriate and attractive location for conducting this sustainability assessment for the following reasons: (1) over eight years of BSF implementation, (2) relatively high reported background rates of diarrheal disease, with 14% and 20% two-week point prevalence nationally and in the study province of Monseñor Noeul, respectively, (3) availability of trained and experienced field staff, (4) detailed background information on participating households of the previous BSF RCT, and (5) sufficient infrastructure and local resources for a field study and needed laboratory analysis of water quality (USAID, 2003).

4.2 Methods

This prospective cohort study focused on assessing the sustained use, improvement of water quality, and health impact (reduced risk of diarrheal disease) of the Biosand filter (BSF) through a series of longitudinal household interviews of BSF intervention and control households and analysis of household water quality. Specifically, the study compared households that had a BSF with matched households that did not have a BSF. A placebo BSF was not used for the control households due to technical and ethical limitations.

4.2.1 Study Site

Two communities, Jayaco and Brisas del Yuna, were included in the assessment, each located near the city of Bonao, the capital of the province of Monseñor Nouel. These communities previously were the study sites for a BSF randomized controlled trial (RCT) completed in fall 2006 (Stauber, 2007).

Jayaco is a semi-rural, agricultural community located eight miles north of Bonao. The community consists of approximately 800 households divided among six principal areas. Five of these areas, specifically Jayaco Arriba, Majaguay, KM 100, KM 101, and

KM 103, along with another community, Brisas del Yuna, served as the focus of the previous RCT. For this reason, they were selected for this assessment. Drinking water sources within Jayaco include piped water conveyed from an upland source, wells, unprotected springs, river water, and collected rainwater. The National Institute for Aqueducts and Potable Water (Instituto Nacional de Agua Potable y Aqueductos – INAPA) operates aqueducts and water supply networks throughout the country, including the piped water sources in Jayaco and Brisas del Yuna (INAPA, 2008). Primary health care services in Jayaco are provided by a local clinic, which is located in Jayaco Central, an area between Jayaco Arriba and Majaguay.

Brisas del Yuna is an urban community within the city of Bonao located along the Yuna River. This marginalized community consists of approximately 200 households, and drinking water sources include piped water, wells, unprotected springs, and river water. Similar to Jayaco, a local clinic provides primary health care services in the community.

4.2.2 Prior BSF Intervention

The previous RCT intervention in each household consisted of the installation of a concrete BSF, initial education of BSF use and maintenance, and provision of a 5-gallon narrow mouth water storage vessel and stand for the vessel. A local filter technician, in accordance with the standard guidelines for such processes, conducted the installation and education components. For all communities, an instructional pamphlet containing pictures and text also was provided to household members for future reference. The BSF installations occurred during the RCT conducted in 2006, with approximately 50% of households receiving BSFs in February 2006 (study intervention households) and 50% receiving BSFs in August 2006 (study control households).

4.2.3 Study Participants

An initial cross-sectional survey was conducted in February 2007 in Brisas del Yuna and Jayaco to assess basic demographics, drinking water treatment practices, and baseline diarrheal disease prevalence in the households associated with the RCT as well as 181 households without a BSF. The latter households served as the source of possible controls for the prospective cohort study and initially included the communities El Llano, Peñalo, San Isidro, and Jayaco Central, in addition to the six RCT communities. To prevent potential difficulties in comparability, it was determined that these four additional communities, with no BSF households, would not be included in the prospective cohort study. As a result, 98 potential control households were identified as available in Brisas del Yuna and Jayaco.

Based on the data from this initial cross-sectional survey and the results from the RCT in 2006, the risk ratio for diarrheal disease necessary for an effective study with respect to detecting reduced diarrheal disease risk was estimated to be 0.80. This ratio equated to a targeted minimum detectable diarrheal disease reduction of at least 20% for those having and using the BSF in comparison with those not having or using the BSF. Using a power of 80% and α of 0.05 and taking potential clustering of observations among participants into consideration, conservative targets of 70 households per cohort and a study period of 8 weeks (8 visits) were established. Despite the relatively short length of the study, these targets were set conservatively above the calculated results, which are detailed in Appendix B, to take into account a potential household attrition rate of 10%.

Households were recruited into the prospective cohort study to be part of the intervention group (household with BSF) or control group (household without BSF and practicing normal water management practices). In order to be included in the intervention group for the study, households were required to meet certain criteria: previously installed BSF in the household and in use, at least one child under five years of age, and willingness to participate as given by written consent. In order to be included in the control group for the study, households also were required to meet certain criteria: no BSF ever in the household, at least one child under five years of age, and willingness to participate as given by written consent.

Upon obtaining informed consent, in-depth cross-sectional interviews were conducted with all newly recruited control households in June 2007 before beginning the longitudinal component of the study. These interviews sought to assess demographic, socioeconomic, diarrheal disease, and sanitation information for each household, as was previously collected for the majority of intervention households in preparation for the prior RCT study in June through August 2005. Along with the resulting community proportions of control households identified in the cross-sectional survey, possible RCT households with BSFs were identified and randomly selected to participate using the random number generator function in Microsoft Excel. The goal was to have equal numbers of households from each of the six communities in each of the two cohorts.

Both BSF intervention and non-BSF control households were informed of the prospective cohort study details and their role in the study. Control households were informed that by participating in the entire length of the study, they would receive a BSF at the end of the study period. Due to the short length of the study, three or more missed interviews led to removal of a participant from the study, as was explained during the informed consent process.

4.2.4 Sustained Health Impact Based on Diarrheal Disease Incidence

In July through August 2007, eights weeks of interviews were conducted to assess the sustained health impact of the BSF, as measured by comparing diarrheal disease incidence in BSF and non-BSF households. Interviews lasted approximately five minutes for both households with and without a BSF. They were structured, translated, back-translated, and pre-tested in country for cultural appropriateness and sought information on weekly drinking water and filter use habits and occurrence of diarrheal disease. The reported head of the household or primary caregiver, typically female, provided the responses when possible. In the absence of the head of the household, other knowledgeable household members completed the interview when appropriate. Trained local staff conducted all interviews in Spanish, the local language.

Interviews were conducted at 7-day intervals when possible. When a case of diarrheal disease was reported, the interviewee was asked for additional information regarding the diarrhea: the date the case began, the frequency of the evacuations, duration, and a description of stool consistency, including the presence of blood in stools. Ongoing cases were measured the following week and during ensuing household visits until the case subsided.

4.2.5 Water Quality Analysis

Water samples for laboratory analysis were taken from all study households at two-week intervals when possible, for a total of four rounds of samples. Each intervention household was asked to provide the following water samples if they were available: unfiltered drinking source water, drinking water taken directly from the BSF outlet, filtered and stored drinking water, filtered water receiving additional treatment, and unfiltered water receiving non-filter treatment of some other kind. Each control household was asked to provide the following water samples if they were available: drinking source water and drinking source water receiving additional treatment.

Water samples of approximately 500 mL were collected and sealed in 500 mL sterile Whirlpak® bags and immediately stored in ice-cooled containers. The ensuing microbiological analysis was conducted within twenty-four hours of sample collection, with the majority of samples processed within six hours of collection. The samples were maintained in ice-cooled containers for transport from the field to Dr. Mirna Peña's Clinical Laboratory, in Bonao, where they were analyzed for *E. coli* and total coliforms using the IDEXX Colilert™ Quanti-Tray system (IDEXX, Laboratories, Westbrook, ME). In a 120 mL reagent bottle containing sodium thiosulfate to neutralize chlorine, each 100 mL sample of water was combined with one packet of Colilert™ test reagent media and gently swirled until the media was completely dissolved. Each sample was then poured into an IDEXX Quanti-Tray/2000 unit, the liquid was distributed uniformly among the wells by agitation, and then the Quanti-Tray was passed through a Quanti-Tray® Sealer to seal the tray. The trays were incubated for twenty to twenty-four hours at 35°C (± 1), and then read visually to score the number of small and large yellow wells when exposed to visible light and the number of small and large fluorescing wells when exposed to long wavelength UV light. Yellow wells were summed to determine the most probable number (MPN) per 100 mL for total coliforms, while fluorescing wells were summed to determine the MPN per 100 mL for *E. coli*. The MPN were calculated according to an MPN table provided with the IDEXX Colilert™ Quanti-Tray system.

Water samples also were analyzed for turbidity and pH. Turbidity was measured with a Hach 2100P Portable Turbidimeter, and pH was measured with a Hach sensION1 Portable pH Meter.

4.2.6 Data Analysis

All longitudinal data were single-entered into specified data forms in EpiInfo™ (CDC) before being transferred into and analyzed using Intercooled Stata 8.0 software (StataCorp., College Station, TX). Data analysis focused on comparing incidence rates of diarrheal disease for BSF users and BSF non-users, where a case of diarrhea was defined as the passage of three or more loose or watery evacuations in a 24-hour period or one or more evacuation containing blood in it in a 24-hour period. Ongoing cases were followed up during ensuing household visits, with a preceding period of at least three successive days free of diarrheal disease required before a new incident case was assigned. Further, when ongoing cases continued from one period of 7-day recall into the ensuing 7-day period, the individual was removed from the overall pool of individuals contributing person-weeks for the latter period.

Stratified analysis was conducted to assess for potentially confounding differences between intervention and control cohorts, including demographic, geographic, and health-related factors. Univariate and multivariate analysis were conducted through ordinary logistic regression to test and control for several cofactors as potential confounders. The cofactors were added individually to the model, with an a priori change in the outcome coefficient of greater than or equal to 10% determining inclusion of the covariate in the model. The cofactors and the coding schemes used in the analysis are listed in Appendix D.

Water sample data was single-entered into an Excel spreadsheet, and analysis was conducted in both Microsoft Excel and Intercooled Stata 8.0. Total coliform, *E. coli*, and turbidity measures were $\log_{10}$ transformed, and comparisons were made between arithmetic mean concentrations, geometric mean concentrations, and percent reductions (calculated with the equation, $(1 - 10^{-\text{average log reduction}})*100$, where average log reduction equals BSF treated water or BSF treated stored water minus untreated influent water). Stratified analysis also was conducted to assess for differences in key exposure and outcome variables by community and week.

4.3 Results

4.3.1 – Study Participants and Comparability of Cohorts

Participation was initially sought from 138 households total, 68 for the intervention group and 70 for the control group. Of these, 135 households began the study, with one BSF intervention household and four non-BSF control households dropping out during the study due to lack of availability for interviews or loss to follow-up. The prospective cohort study population, therefore, totaled 648 persons in 130 households, as detailed in Table 4.1. The principal reason for loss to follow-up was incompatible schedules of householders and interviewers, and repeat visits for these households were conducted when available.

The intervention group totaled 369 persons in 65 households, while the control group totaled 279 persons in 65 households. For the intervention cohort, the average number of people per household was 5.68. For the control cohort, the average number of people per household was 4.29. A diagram of household data collection and the general study timeline are provided in Figure 4.1.

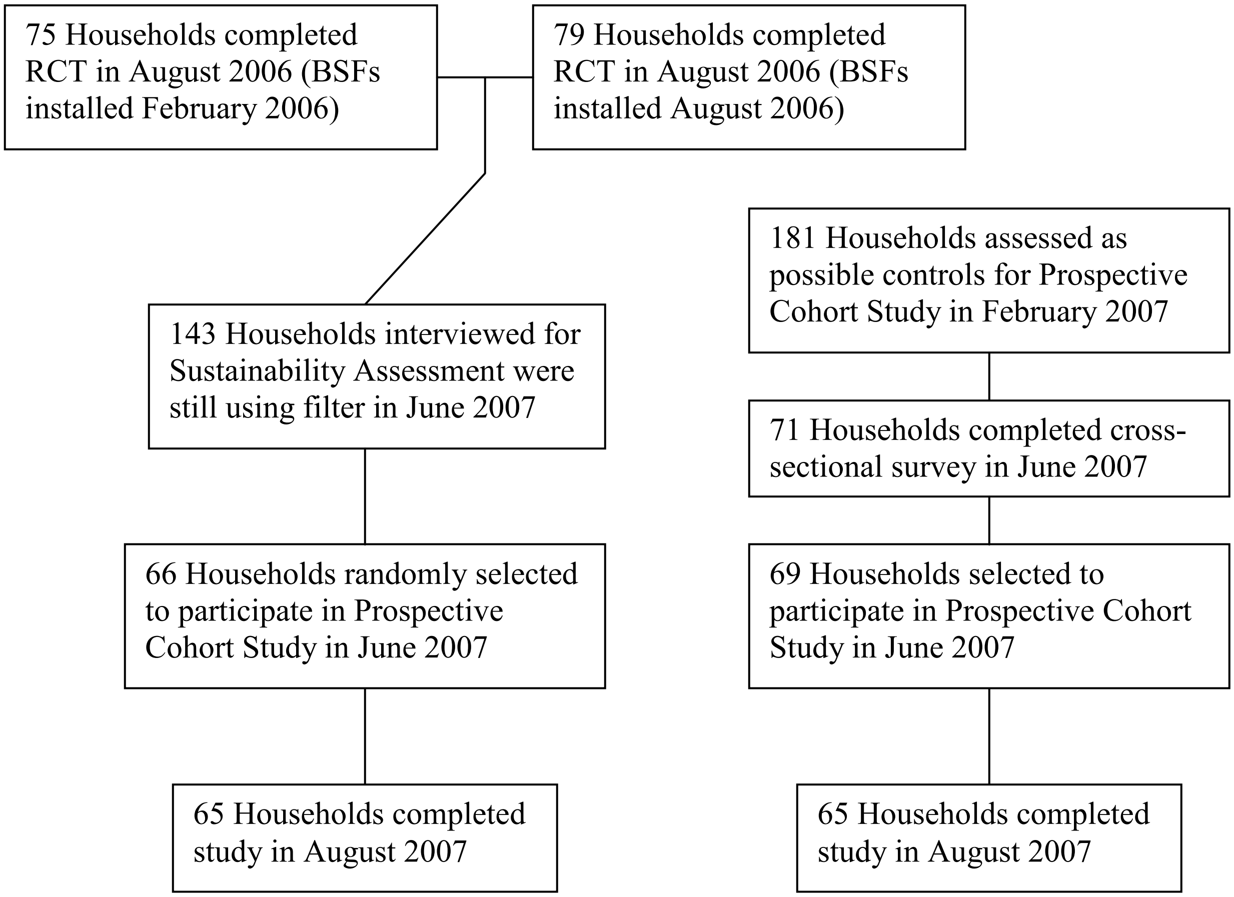
Table 4.1 – Intervention (BSF) and control (non-BSF) total household numbers

HOUSEHOLD DATA	Intervention	Control	All
# of Households (beginning study)	66	69	135
# of Households (completing study)	65	65	130
# of People (interviewed households)	369	279	648
Average # of People per Interviewed Household	5.7	4.3	5.0

Comparability analysis of intervention and control cohorts was conducted by community and for number, gender, and age, as listed in Table 4.2. Brisas del Yuna contributed the largest number of households (48) and people (231) and Majaguay the least (8 households and 48 people). There were ninety more people in the intervention cohort than in the control cohort, which was determined to be a significant difference. Differences between cohorts were assessed using a chi-square test or a t-test, with a significant difference when p-values were found to be less than 0.05.

Significant differences between cohorts were also found for number of people in KM 101 (40 intervention vs. 14 control), average number of members per household (5.68 intervention vs. 4.29 control), and the average age of participants less than 5 years of age (2.6 intervention vs. 1.8 control). The intervention and control groups were 53.1% and 50.5% females, respectively, and 23.7% and 28.3% children aged less than 5 years, respectively.

Figure 4.1 – Household enrollment and participation schedule



In addition, comparability analysis of intervention and control cohorts was conducted for several selected demographic, socioeconomic, and socio-cultural factors, with the results provided in detail in Table 4.3. Each of these factors potentially is involved in health behavior and susceptibility to disease (Wellin, 1955; Rogers, 2003), and as a result, differences between cohorts for these factors could skew the comparison between cohorts for the key exposure variables and outcome measures.

Significant differences were found for the following: primary and secondary education level of the interviewee, paying for water, and those in the 0 to 4 minute category for time to water source. Specifically, less control than intervention households reported having received primary education (38.5% vs. 64.5%), but more control than intervention households reported having received secondary (43.1% vs. 21.0%) education. Further, although not significant ($p > 0.05$), more control than intervention households reported having received university (13.9% vs. 4.8%) education. For the other

Table 4.2 – Cohort comparability analysis by community, number, gender, and age

CHARACTERISTIC	**Intervention group (65 households)**	**Control group (65 households)** (*Significance)[a]
Number (percent) of households by community		
Brisas del Yuna	22 (33.9%)[b]	26 (40.0%)[b]
Jayaco Arriba	17 (26.2%)	16 (24.6%)
KM 100	9 (13.9%)	10 (15.4%)
KM 101	7 (10.8%)	4 (6.2%)
KM 103	6 (9.2%)	5 (7.7%)
Majaguay	4 (6.2%)	4 (6.2%)
Number (percent) of people by community		
Brisas del Yuna	125 (33.9%)[b]	106 (38.0%)
Jayaco Arriba	95 (25.7%)	72 (25.8%)
KM 100	51 (13.8%)	41 (14.7%)
KM 101	40 (10.8%)	14 (5.0%)*
KM 103	28 (7.6%)	28 (10.0%)
Majaguay	30 (8.1%)	18 (6.5%)
Total number of people in cohort	369	279*
Mean number of individuals per household	5.68	4.29*
Gender		
Number (percent) female ≥ 5 years of age	151 (41.1%)[bc]	101 (36.2%)
Number (percent) female < 5 years of age	44 (12.0%)	40 (14.3%)
Number (percent) male ≥ 5 years of age	129 (35.1%)	99 (35.5%)
Number (percent) male < 5 years of age	43 (11.7%)	39 (14.0%)
Age		
Number (percent) ≥ 5 years of age	280 (76.3%)[c]	200 (71.7%)
Number (percent) < 5 years of age	87 (23.7%)	79 (28.3%)
Mean age of participants ≥ 5 years of age	24.7	26.4
Mean age of participants < 5 years of age	2.6	1.8*

a. Significant difference between groups as determined by chi-square test or t-test, based on $p < 0.05$.
b. Percentages do not add up to 100% due to rounding.
c. Total people do not total 369 here due to missing age data for two people from two intervention households.

Table 4.3 – Cohort comparability analysis of selected factors

CHARACTERISTIC	Intervention group (62 households)[a]	Control group (65 households) (*Significance)[b]
Formal education level of interviewee		
Some or all primary school	40 (64.5%)[c]	25 (38.5%)[d]*
Some or all secondary school	13 (21.0%)	28 (43.1%)*
More than secondary	3 (4.8%)	9 (13.9%)
Interviewee reported receiving health education[e]		
Yes	30 (48.4%)	32 (49.2%)
No	32 (51.6%)	33 (50.8%)
Soap observed in household[f]		
Yes	43 (69.4%)	49 (75.4%)
No	19 (30.6%)	16 (24.6%)
Access to sanitation[g]		
Shared	15 (24.2%)	23 (35.4%)
Private	47 (75.8%)	42 (64.6%)
Safe storage practices observed[h]		
Yes	9 (14.5%)	6 (9.2%)
No	53 (85.5%)	59 (90.8%)
Interviewee reported washing hands "always"[i]		
Yes	50 (80.7%)[j]	50 (76.9%)
No	12 (19.4%)	15 (23.1%)
Reported drinking water sources during study[k]		
Surface water (river, canal)	7 (11.3%)[l]	3 (4.6%)[l]
Groundwater (well, spring)	25 (40.3%)	30 (46.2%)
Rainwater	5 (8.1%)	1 (1.5%)
Piped water (inside & outside)	41 (66.1%)	42 (64.6%)
Bottled water	14 (22.6%)	9 (13.8%)
Pay for water[m]		
Yes	17 (27.4%)	8 (12.3%)*
No	45 (72.6%)	57 (87.7%)
Time to water source (minutes)		
0-4	44 (72.1%)[ln]	34 (54.8%)*
5-9	5 (8.2%)	11 (17.7%)
10-19	8 (13.1%)	9 (14.5%)
20-39	3 (4.9%)	4 (6.5%)
>40	1 (1.6%)	4 (6.5%)

a. Households do not total 65 here due to missing cross-sectional data for three intervention households.
b. Significant difference between groups as determined by chi-square test showing $p < 0.05$.
c. Households do not total 62 here and percentages do not total 100 due to some households receiving no formal education.
d. Households do not total 65 here and percentages do not total 100 due to some households receiving no formal education.
e. Information about preventing or treating diarrhea from any source (friend, clinic, media, etc.).
f. Respondents were asked to demonstrate that soap was present in the household.
g. Shared latrine or toilet vs. Private latrine or toilet.
h. Safe storage defined as using a covered or narrow mouth water storage container.
i. Interviewee responds that family members wash hands "always" with soap and water after defecating.
j. Percentages do not add up to 100% due to rounding.
k. Multiple answers possible and principal source not specified.
l. Percentages do not add up to 100% due to multiple responses reported by households.
m. Any amount as reported by interviewee.
n. Households do not total 62 here due to lack of time to source reported for four intervention households.
o. Households do not total 65 here due to lack of time to source reported for three control households.

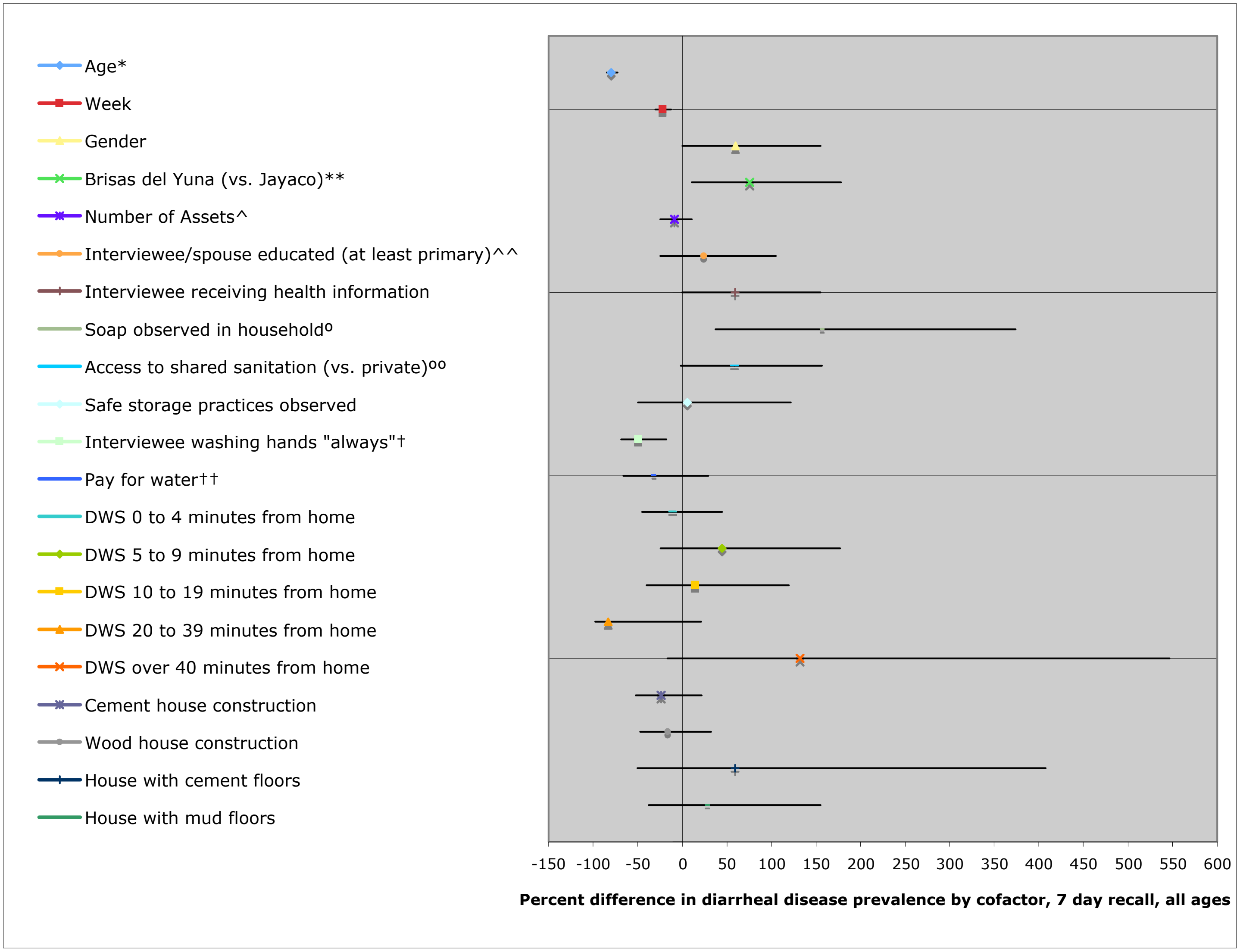
two factors showing significant differences, more intervention than control households reported paying for their water (27.4% vs. 12.3%) and having a water source less than five minutes from the home (72.1% vs. 54.8%).

Although none of the differences were found to be significant, there were greater percentages among intervention households for the following factors: having access to a private latrine or toilet (75.8% vs. 64.6%), using a covered or narrow mouth container to store water (14.5% vs. 9.2%), reporting that family members always wash their hands with soap and water after defecating (80.7% vs. 76.9%), and using surface water, rainwater, piped water, and bottled water as drinking water sources (11.3% vs. 4.6%, 8.1% vs. 1.5%, 66.1% vs. 64.6%, and 22.6% vs. 13.8%, respectively). There were greater but non-significant percentages among control households for the following factors: having received health information about preventing or treating diarrhea from any source (49.2% vs. 48.4%), having soap in the household (75.4% vs. 69.4%), having access to a shared latrine or toilet (35.4% vs. 24.2%), using groundwater (46.2% vs. 40.3%) as a drinking water source, and having water sources greater than or equal to 5 minutes from the home (45.2% vs. 27.9%).

4.3.2 – Sustained Health Impact Based on Diarrheal Disease Incidence

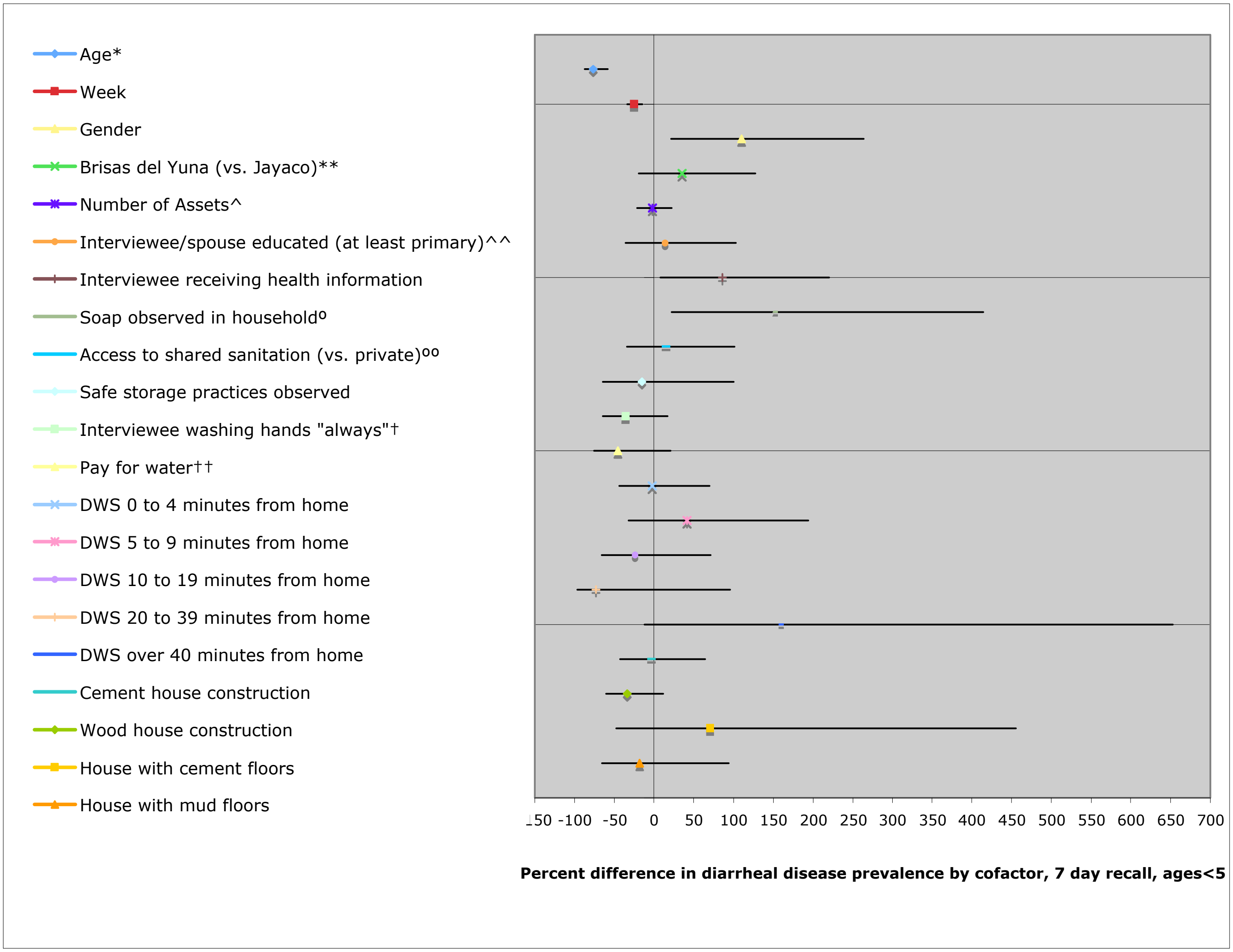
Prior to examining the influence of the BSF and study cohort on the incidence of diarrheal disease, independent associations between diarrheal disease and selected factors were analyzed using odds ratios. These factors were identified and analyzed due to their potential association with diarrheal disease. Positive association with continued filter use was determined by an odds ratio greater than one with a 95% confidence interval excluding the 1.00 null value. Negative association with continued filter use was determined by an odds ratio less than one with a 95% confidence interval excluding the 1.00 null value. The results for participants of all ages are presented in Figure 4.2, and the results for participants under the age of five are presented in Figure 4.3.

Figure 4.2 – Independent associations between selected cofactors and diarrheal disease (all ages)



* Age as an ordinal variable classified into three age groups: <2 years, 2 to 4 years, >5 years.
** Jayaco is the referent, serving as the group to which the other group(s) is(are) compared in calculating odds ratios.
^ Number of assets as ordinal variable by sum of six household assets: motorcycle, refrigerator, television, washer, fan, cell phone.
^^ Interviewee reported self and spouse having received at least primary education.
º Respondents were asked to demonstrate that soap was present in the household.
ºº Shared latrine or toilet in comparison to private latrine or toilet as the referent.
† Interviewee responds that family members wash hands "always" with soap and water after defecating.†† Any amount as reported by interviewee.

Figure 4.3 – Independent associations between selected cofactors and diarrheal disease (ages < 5)



* Age as an ordinal variable classified into two age groups: <2 years and 2 to 4 years.
** Jayaco is the referent, serving as the group to which the other group(s) is(are) compared in calculating odds ratios.
^ Number of assets as ordinal variable by sum of six household assets: motorcycle, refrigerator, television, washer, fan, cell phone.
^^ Interviewee reported self and spouse having received at least primary education.
º Respondents were asked to demonstrate that soap was present in the household.
ºº Shared latrine or toilet in comparison to private latrine or toilet as the referent.
† Interviewee responds that family members wash hands "always" with soap and water after defecating.
†† Any amount as reported by interviewee.

Significant positive associations with diarrheal disease for all ages were found for the following selected factors: being male, living in Brisas del Yuna, and having soap in the household. Significant negative associations with diarrheal disease for all ages were found for the following selected factors: increasing age as an ordinal variable classified into three groups, week in the study, and reporting by interviewee of washing hands “always” with soap and water after defecating.

Significant positive associations with diarrheal disease for participants under the age of five were found for the following selected factors: being male, head of the household or primary caregiver having received health information about preventing or treating diarrhea from any source, and having soap in the household. Significant negative associations with diarrheal disease for participants under the age of five were found for the following selected factors: increasing age as an ordinal variable classified into two groups and week in the study.

Having assessed the independent associations of the selected factors with diarrheal disease incidence, analysis was then done for diarrheal incidence of intervention versus control groups. The BSF intervention households experienced a 74% lower incidence rate of diarrheal disease as compared to control households for all participants of the prospective cohort study. The incidence rate and incidence rate ratio were calculated overall as well as for age, week, gender, and community stratifications, with the results given in Table 4.4. Of the total diarrheal disease burden, the intervention group contributed 2,970 person-weeks, while the control group contributed 2,251 person-weeks.

When assessing age group, participants less than 2 years of age, between 2 and 4 years of age, and greater than 5 years of age in BSF households experienced a 41%, 59%, and 88% lower incidence rates of diarrheal disease than control households, respectively, although the rates of the former two were not significant.

Table 4.4 – Stratified and unadjusted diarrheal incidence analysis

CHARACTERISTIC	IR[a] Intervention group	IR[a] Control group	IRR[b] (95% CI) (*Significance)[c]
Overall	0.006	0.024	0.26 (0.15-0.45)*
Age			
<2 years	0.056 (n=178)	0.096 (n=356)	0.59 (0.26-1.22)
2-4 years	0.014 (n=511)	0.033 (n=270)	0.41 (0.13-1.24)
>5 years	0.001 (n=2281)	0.007 (n=1625)	0.12 (0.01-0.53)*
Gender			
Female	0.004	0.020	0.22 (0.08-0.53)*
Male	0.009	0.029	0.30 (0.14-0.60)*
Community			
Brisas del Yuna	0.010	0.031	0.32 (0.14-0.69)*
Jayaco	0.005	0.021	0.22 (0.09-0.48)*
Week			
Week 1	0.008	0.043	0.19 (0.03-0.68)*
Week 2	0.022	0.035	0.62 (0.21-1.75)
Week 3	0.003	0.025	0.11 (0.00-0.84)*
Week 4	0.003	0.047	0.06 (0.00-0.38)*
Week 5	0.005	0.011	0.49 (0.04-4.32)
Week 6	0.005	0.018	0.30 (0.03-1.85)
Week 7	0.005	0.007	0.73 (0.05-10.14)
Week 8	0.000	0.007	0.00 (0.00-3.96)

a. IR = incidence rate

b. IRR = incidence rate ratio (unadjusted), where IRR < 1 show negative correlation for diarrheal disease, with control as referent.

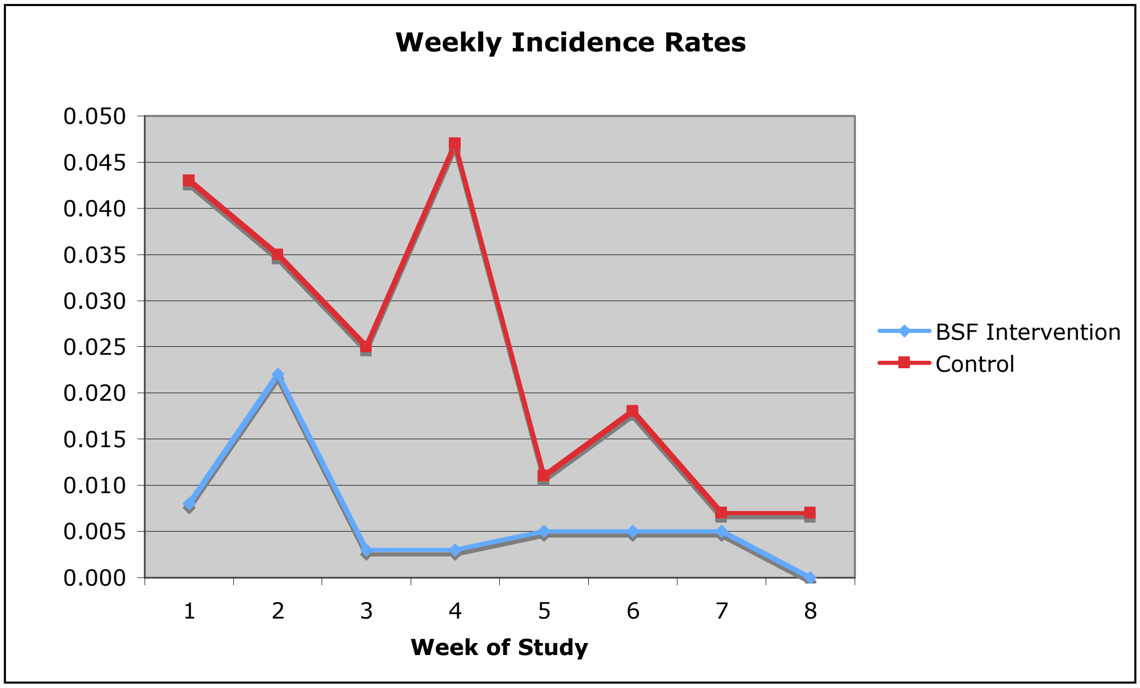
c. IRR considered significant if 95% confidence interval does not cross the null (1.00).

Females were found to experience less diarrheal incidence than males in both cohorts, and the incident rate ratios for both males and females were found to be significant. Females in BSF households experienced a 78% lower incidence rate of diarrheal disease than those in control households. Males in BSF households experienced a 70% lower incidence rate of diarrheal disease than those in control households.

In comparing the two principal communities of the study, Brisas del Yuna experienced higher incidence rates of diarrhea than Jayaco in both cohorts. BSF household participants in Brisas del Yuna experienced a 68% lower incidence rate of diarrheal disease than control household participants, which was significant. BSF household participants in Jayaco experienced a 78% lower incidence rate of diarrheal disease than control household participants, which was also significant.

Analysis by week found the effect of the BSF intervention varying from week to week, ranging from a 100% difference between intervention and control households seen in week 8 to a 27% difference seen in Week 7. Although lower diarrheal incidence was seen among BSF households in all eight weeks of the study, as highlighted in Figure 4.4, only three weeks (1, 3, and 4) showed significant incidence rate ratios.

Figure 4.4 – Weekly incidence rate comparison of cohorts



Multivariate analysis was conducted to assess for the potential confounding influence of selected cofactors due to their potential association with diarrheal disease. Of the factors added to the model, all of which are listed in Appendix D, two (categorical age and the presence of soap in the household) were found to result in greater than 10% change in effect, therefore influencing significantly the incidence rate ratio describing diarrheal disease among participants. As presence of soap in the household was measured only during initial cross-sectional interviews, it was not added into the model for this longitudinal assessment. However, categorical age was added into the model, so as to adjust for its effect as a confounder. Its inclusion in the model led to an overall incidence rate ratio of 0.39. Further details with this adjustment by week, gender, and community are detailed in Table 4.5.

Table 4.5 – Stratified and adjusted diarrheal incidence analysis

CHARACTERISTIC	**IRR[a] (95% CI) (*Significance)[b]**
Overall	0.39 (0.23-0.68)*
Gender	
Female	0.30 (0.13-0.72)*
Male	0.46 (0.23-0.92)*
Community	
Brisas del Yuna	0.43 (0.20-0.90)*
Jayaco	0.38 (0.17-0.83)*
Week	
Week 1	0.25 (0.07-0.91)*
Week 2	1.14 (0.41-3.19)
Week 3	0.18 (0.02-1.58)
Week 4	0.08 (0.01-0.64)*
Week 5	0.62 (0.10-3.92)
Week 6	0.36 (0.07-1.90)
Week 7	1.28 (0.17-9.90)
Week 8	- (-)[c]

a. IRR = incidence rate ratio (adjusted for categorical age and estimated by an odds ratio due to prevalence less than 0.10), where IRR < 1 show negative correlation for diarrheal disease, with control as referent.
b. IRR considered significant if 95% confidence interval does not cross the null (1.00).
c. IRR and 95% confidence interval, as estimated by odds ratio, not able to be calculated due to zero cases of diarrheal disease among intervention households.

The categorical age variable adjustment led to incidence rate ratios reflective of 14% and 28% higher incidence rates of diarrheal disease for week 2 and week 7, respectively, among participants in BSF households compared to those in control households. These positive correlations, in turn, suggest that the effect of the BSF intervention over time. The incidence rate ratios for all the remaining stratifications by week, gender, and community, however, suggest lower incidence rates of diarrheal disease among participants in BSF households. Those for week 1 and week 4, for females and males, and for Brisas del Yuna and Jayaco were found to be significant.

4.3.3 – Water Quality Analysis

Water samples were analyzed for all intervention and control households on a biweekly basis over the 8-week length of the prospective cohort study. A total of 717 and 368 samples were analyzed for raw and treated water concentrations and corresponding calculated reductions of *E. coli*, total coliforms, and turbidity among intervention and control households, respectively, as detailed in Table 4.6. Intended observations for intervention households were for both untreated and BSF treated water samples taken during a sampling visit, with 219 (84%) complete observations out of 260 possible interviews over four sampling rounds.

Concentrations of *E. coli* were categorized into decimal (order-of-magnitude) concentrations for untreated water samples with both cohorts, for BSF treated water samples in intervention households, and for other treated water samples in control households. Out of 229 intervention household untreated water samples, 77 (34%) had 10 or less *E. coli* MPN/100mL (Table 4.7). Out of 223 control household untreated water samples, 92 (41%) had 10 or less *E. coli* MPN/100mL (Table 4.7). Out of 228 BSF intervention household BSF treated water samples, 176 (77%) had 10 or less *E. coli* MPN/100mL (Table 4.8). Out of 123 control household other treated water samples, 86 (70%) had 10 or less *E. coli* MPN/100mL (Table 4.8). The World Health Organization (WHO) considers water samples from 0 to 10 MPN/100mL to be in the "reasonable" range of water safety (WHO, 2004).

Table 4.6 – Water sample numbers and totals

TYPE OF WATER SAMPLE	NUMBER (%)
Intervention Households – All	**N = 717**
- Untreated	229 (31.9%)
- BSF Treated	228 (31.8%)
- BSF Treated, Stored	229 (31.9%)
- BSF Treated, Boiled, Stored	28 (3.9%)
- Boiled	2 (0.3%)
- Chlorinated	1 (0.1%)
Control Households – All	**N = 368**
- Untreated	223 (60.6%)
- BSF Treated	0 (0.0%)
- BSF Treated, Stored	22 (6.0%)[a]
- BSF Treated, Boiled, Stored	5 (1.4%)[a]
- Boiled	97 (26.4%)
- Chlorinated	20 (5.4%)
- Cloth Strained	1 (0.3%)

a. On certain visits, control households provided BSF water samples as a result of using a neighbor's BSF.
Note: For reference, when both untreated and BSF treated water samples were taken during a sampling visit, it was considered a complete observation. For the intervention households, there were 219 complete observations.

Table 4.7 – *E. coli* concentrations of untreated water samples

Number (percentage[a]) of all samples by *E. coli* concentration of untreated household drinking water[b]

	<1 (MPN/100mL)	1-10 (MPN/100mL)	11-100 (MPN/100mL)	101-1000 (MPN/100mL)	1,001+ (MPN/100mL)	Total samples
Intervention	32 (14%)	45 (20%)	97 (42%)	35 (15%)	20 (9%)	229
Control	53 (24%)	39 (17%)	84 (38%)	37 (17%)	10 (4%)	223

a. Percentages with strata may not add up to 100% due to rounding.
b. Samples were filter influent in all intervention households taken directly at the time of visit (untreated water samples) and untreated samples for all control households.

Table 4.8 – *E. coli* concentrations of treated water samples

Number (percentage[a]) of all samples by *E. coli* concentration of treated household drinking water[bc]						
	<1 (MPN/100mL)	1-10 (MPN/100mL)	11-100 (MPN/100mL)	101-1000 (MPN/100mL)	1,001+ (MPN/100mL)	Total samples
Intervention	64 (28%)	112 (49%)	38 (17%)	8 (4%)	6 (3%)	228
Control	59 (48%)	27 (22%)	19 (15%)	11 (9%)	7 (6%)	123

a. Percentages with strata may not add up to 100% due to rounding.
b. Samples were filter effluent in all intervention households taken directly at the time of visit (BSF treated water samples) and other treatment samples for all control households.
c. All percentages represent samples where households reported all family members to be drinking this water.

Geometric mean concentrations of *E. coli* and total coliforms and geometric mean value of turbidity, all presented in Table 4.9, were calculated and stratified by community. For intervention households, geometric mean *E. coli* MPN/100 mL was 18.8 and 4.3 for untreated and BSF treated water, respectively; geometric mean total coliform MPN/100mL was 969 and 216 for untreated and BSF treated water, respectively; and geometric mean turbidity (NTU) was 1.1 and 0.7 for untreated and BSF treated water, respectively. For control households, geometric mean *E. coli* MPN/100 mL was 14.1 and 5.3 for untreated and other treated water, respectively; geometric mean total coliform MPN/100mL was 773 and 552 for untreated and other treated water, respectively; and geometric mean turbidity (NTU) was 1.2 and 1.5 for untreated and other treated water, respectively. Box plots of log transformed arithmetic mean concentrations of *E. coli* and total coliforms for intervention and control households are shown in Figures 4.5 and 4.6, respectively. In addition, further analysis and stratifications of the water sample data can be found in Appendix A, along with all of the additional data analysis for total coliforms equivalent to that presented here for *E. coli*.

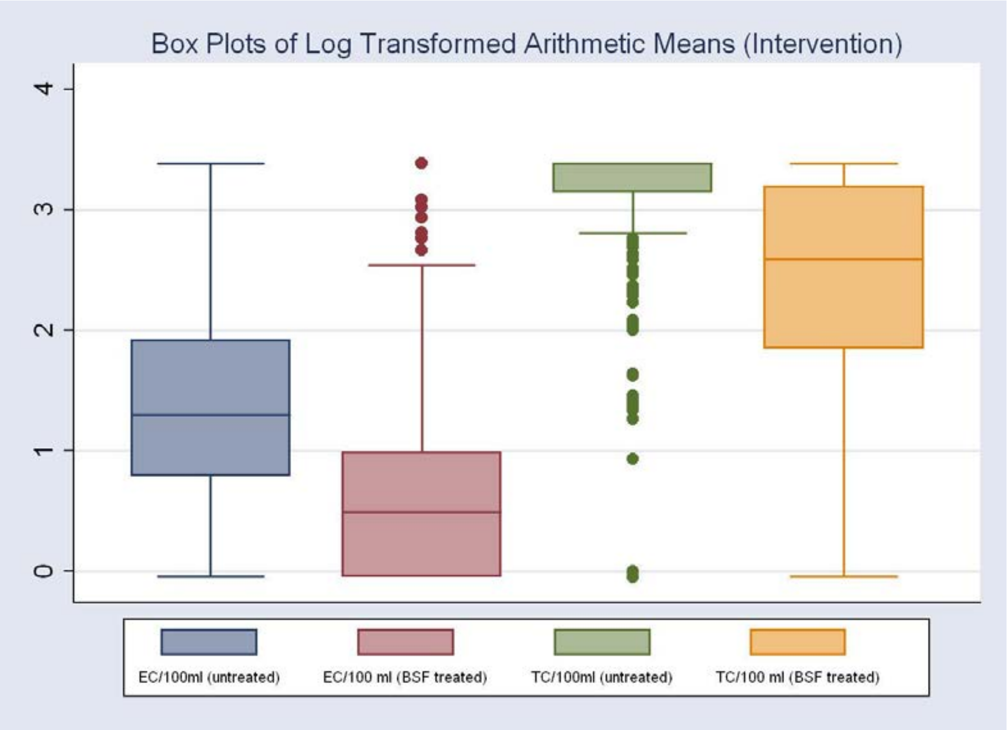
Table 4.9 – Geometric mean concentrations of *E. coli*, total coliforms, and turbidity in untreated and BSF treated water samples

All Samples	Untreated Water Quality[a] (geometric means)			Treated Water Quality[a] (geometric means) (BSF Treated Water – Intervention Other Treated[b] Water – Control)		
	E.coli/100 mL	TC/100mL	Turbidity (NTU)	*E.coli*/100 mL	TC/100mL	Turbidity (NTU)
All households	18.8	867	1.1	n/a[c]	n/a[c]	n/a[c]
Intervention	24.8	969	1.1	4.3	216	0.7
Brisas del Yuna	15.5	428	1.6	4.1	121	1.0
Jayaco Arriba	27.1	1620	0.9	4.0	269	0.5
KM 100	37.1	1285	0.9	6.0	401	0.6
KM 101	31.6	2211	0.9	5.3	586	0.6
KM 103	53.3	947	1.4	2.7	101	0.6
Majaguay	15.5	531	0.6	4.0	111	0.6
Control	14.1	773	1.2	5.3	552	1.5
Brisas del Yuna	9.4	340	1.8	9.0	700	2.4
Jayaco Arriba	18.6	1838	0.8	2.3	804	1.1
KM 100	9.7	631	0.7	3.7	198	0.7
KM 101	37.6	2353	0.7	n/a	n/a	n/a
KM 103	68.3	867	2.0	8.9	1934	2.7
Majaguay	4.7	1342	0.7	2.2	174	0.8

a. Data from filter households, untreated water and BSF treated water samples from 4 longitudinal sampling rounds.
b. Other treatments included boiling, chlorination, cloth straining, and bsf treatment and boiling together.
c. Since intervention and control treated samples are different, all household combinations are not applicable.

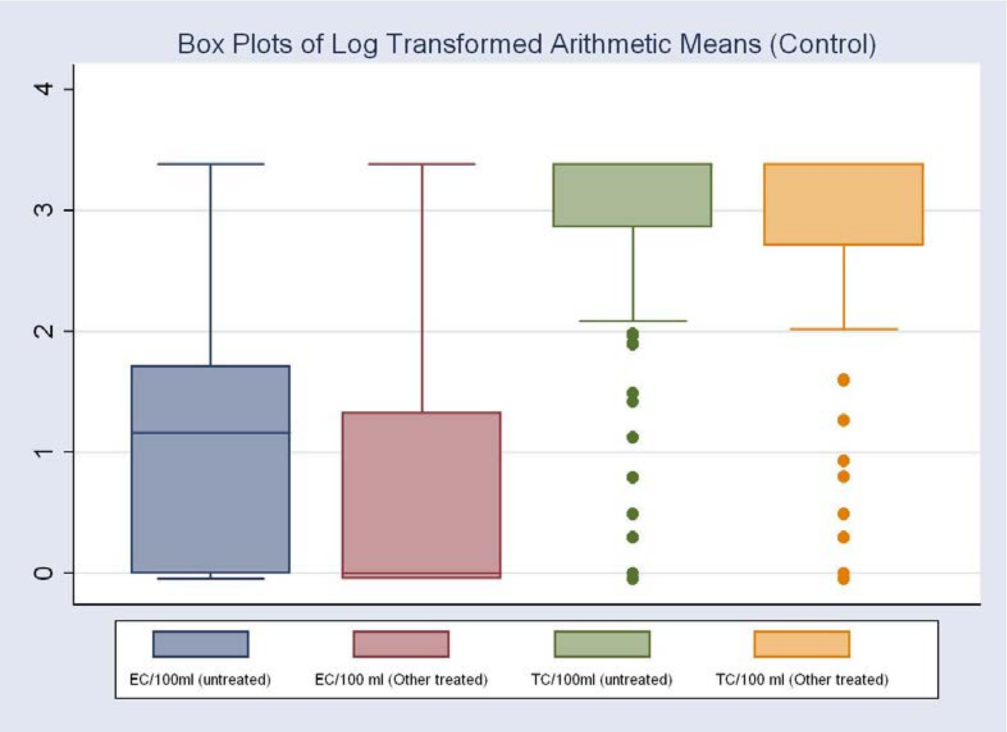
Average percent reductions in *E. coli*, total coliforms, and turbidity are provided in Table 4.10. For intervention households, reductions based on comparing concentration in untreated and BSF treated water were 83.6% for *E. coli*, 78.1% for total coliforms, and 18.3% for turbidity. For control households, these reductions were 60.0% for *E. coli*, -52.8% (an increase) for total coliforms, and -104.5% (an increase) for turbidity.

Figure 4.5 – Box plots of arithmetic means of *E. coli* and total coliforms (Intervention)



Note: EC – *E. coli*, TC – Total coliforms

Figure 4.6 – Box plots of arithmetic means of *E. coli* and total coliforms (Control)



Note: EC – *E. coli*, TC – Total coliforms

Table 4.10 – Percent reductions of *E. coli*, total coliforms, and turbidity in water samples of intervention and control households

Percent reductions[a] in water samples by *E. coli*, Total coliform, and Turbidity						
Group:	**Intervention**	**Control**	**Intervention**	**Control**	**Intervention**	**Control**
Samples compared for reduction:	Untreated to BSF Treated *E. coli*	Untreated to Other Treated *E. coli*	Untreated to BSF Treated Total Coliforms	Untreated to Other Treated Total Coliforms	Untreated to BSF Treated Turbidity	Untreated to Other Treated Turbidity
All communities	83.6%	60.0%	78.1%	(52.8%)	18.3%	(104.5%)
Brisas del Yuna	75.6%	22.0%	71.5%	(245.9%)	6.6%	(150.4%)
Jayaco Arriba	85.3%	88.4%	83.3%	50.1%	39.7%	(133.8%)
KM 100	83.8%	57.3%	68.8%	31.5%	9.8%	(36.8%)
KM 101	84.8%	n/a	74.0%	n/a	24.9%	n/a
KM 103	95.3%	88.0%	90.2%	(75.4%)	45.3%	(11.4%)
Majaguay	75.9%	4.1%	81.2%	41.2%	(56.6%)	(36.4%)

a. Percent reduction values are computed as $(1 - 10^{-\text{log reduction}})*100$ for *E. coli* and total coliform measures and as ((influent – effluent)/influent)*100 for turbidity.
b. Negative reductions are indicated by ( ).

Average $\log_{10}$ reductions in *E. coli* and total coliforms ranged from less than 0 to as high as 3.38 (<0% to 99.96%), as determined by the magnitude and range of bacteria concentrations measured. When bacteria concentrations in untreated water are low, quantifiable $\log_{10}$ reductions are also low, due to sample sizes and method detection limits. The distributions of $\log_{10}$ reductions for intervention households are shown as histograms for *E. coli* (Figures 4.7) and total coliforms (Figure 4.8). These distributions appear to be normally distributed except for the percentage of samples showing zero or negative $\log_{10}$ reductions. These distributions are presented as box plots in Figure 4.9. Based on decimal categories of $\log_{10}$ *E. coli* reductions for intervention households (Table 4.11), 32% were between 1 and 1.99, 10% between 2 and 2.99 and 2% greater than 3. Of the samples demonstrating 0 $\log_{10}$ *E. coli* reduction, 80% had <1 *E. coli* per 100 mL in the untreated water.

Figure 4.7 – Histogram of $\log_{10}$ reductions of *E. coli* (Intervention)

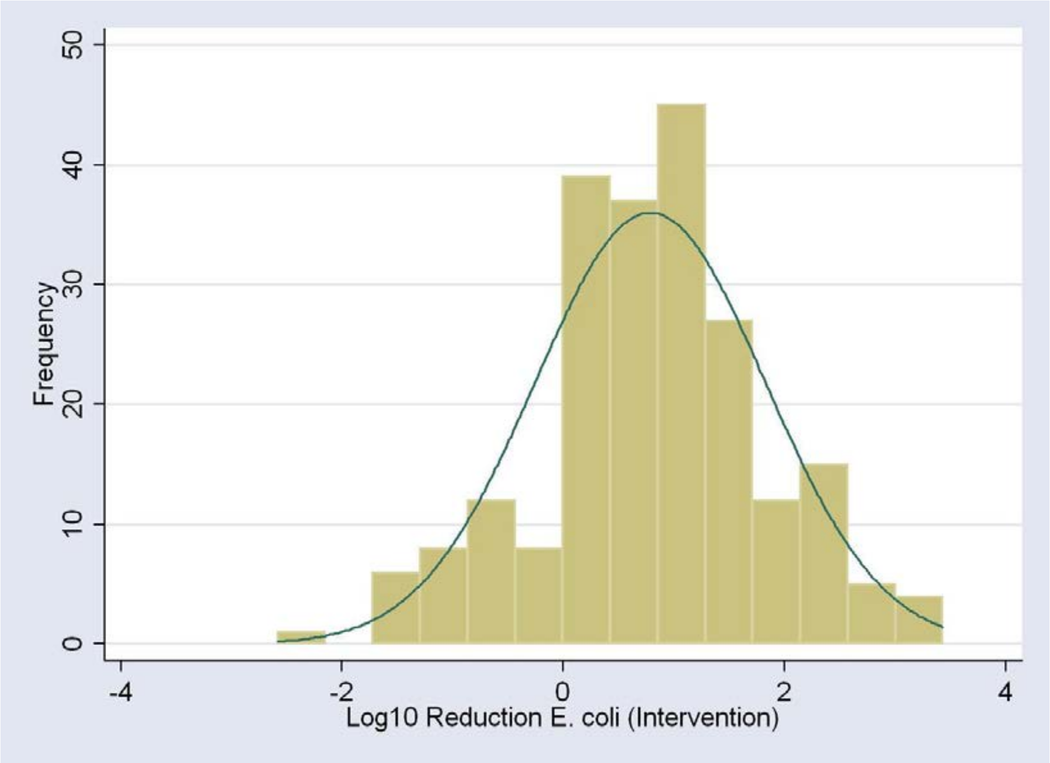


Figure 4.8 – Histogram of $\log_{10}$ reductions of total coliforms (Intervention)

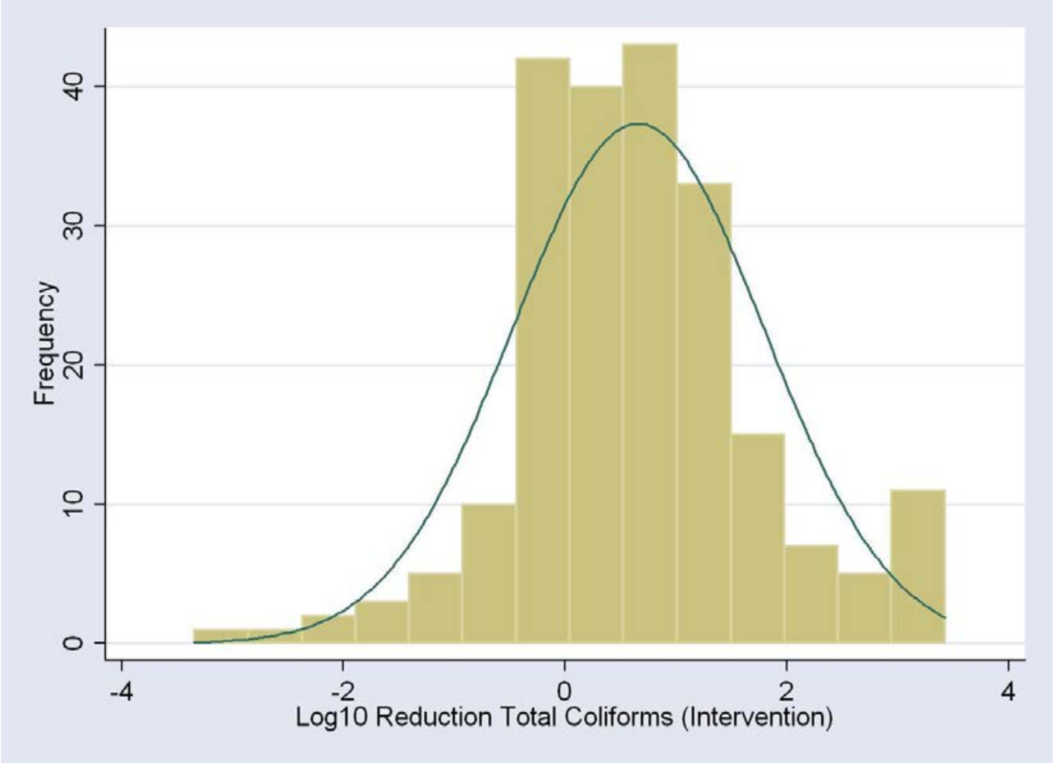


Figure 4.9 – Box plots of $\log_{10}$ reductions of *E. coli* and total coliforms (Intervention)

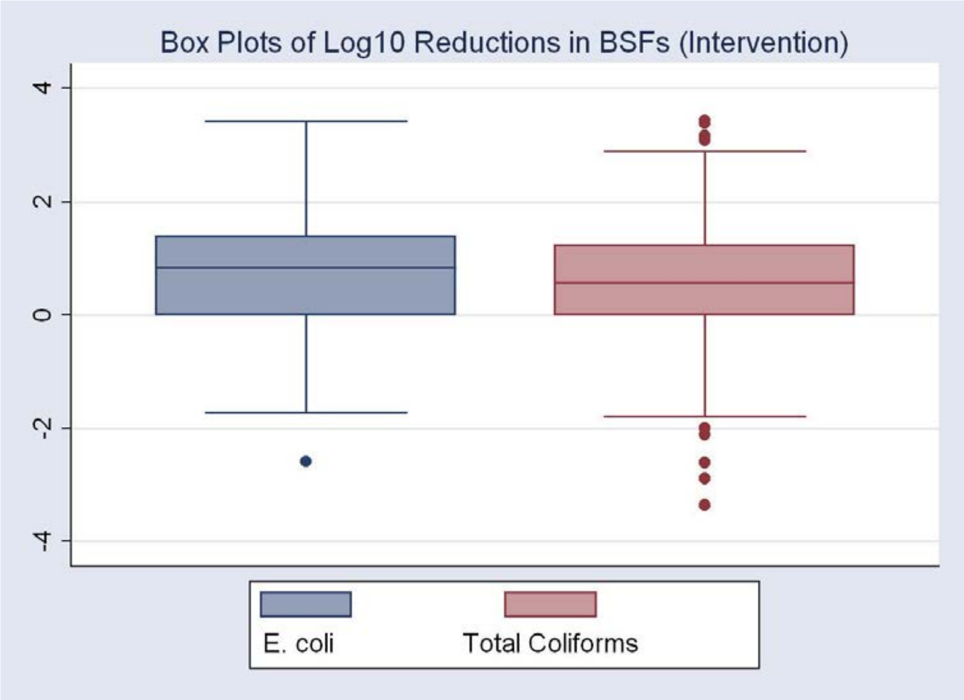


Table 4.11 – Categorical analysis of $\log_{10}$ *E. coli* reductions

E. coli $\log_{10}$ reduction values[a] (LRV) for intervention households (n=219[b]), as percentage[c] of all filter samples						
	<0[d]	0[e]	0.01-0.99	1-1.99	2-2.99	3-3.38
Intervention	16%	9%	31%	32%	10%	2%

a. Log_{10} reduction values are computed as the $\log_{10}$(effluent/influent); 1 LRV=90% reduction, 2 LRV=99% reduction, 3 LRV=99.99% reduction, and so on. Reduction is a function of influent water, however, and low LRV values do not necessarily indicate poor performance. In twenty-eight percent of samples (n=64), filters reduced product water to <1 *E. coli* per 100 mL, so reported LRVs are potential underestimates.
b. 219 (96%) sampling events (out of 229 total over 4 sampling rounds) yielded complete data to use in the LRV calculation.
c. Percentages may not add up to 100% due to rounding.
d. Negative LRV values indicate that the effluent water contains more *E. coli* than the influent water.
e. In 80% of these samples the influent water contained <1 *E. coli* per 100 mL.

The negative $\log_{10}$ reduction values seen for 16% of samples for *E. coli* correlates with increased concentration of *E. coli* in the BSF treated water compared with the untreated water. These negative reductions can be the result of a filter not functioning properly, the flushing of organisms built up within the filter or in the exit orifice, or variations in source water quality, such that the bacteriological quality of water previously applied to the filter and now being pushed out of the media of the filter bed is lower in quality than water delivered to the bed on the day of sampling.

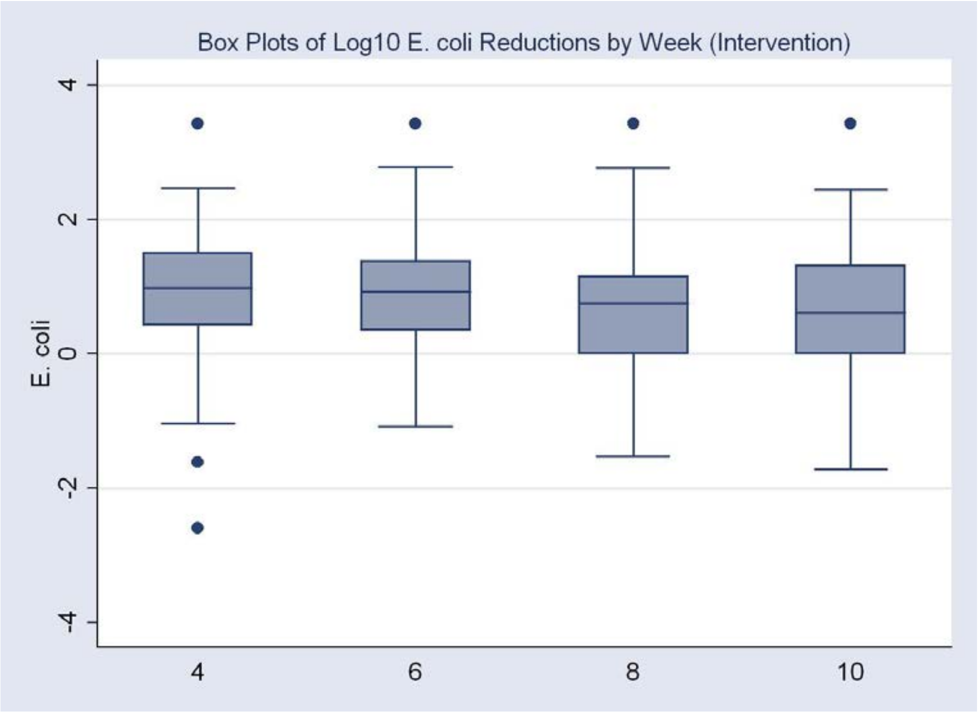
Categorical analysis also was conducted among intervention households for $\log_{10}$ reductions by week, as detailed in Table 4.12 and Figure 4.10 (*E. coli*). Percent reductions for the four sampling rounds ranged from 77.1% to 88.9% for *E. coli* and from 62.8% to 91.7% for total coliforms.

Table 4.12 – Percent reductions in water samples by week for *E. coli* and total coliforms (Intervention)

Percent reductions[a] for *E. coli* and TC in water samples of intervention households by sampling week								
Week:	**Week 1 (7/2-7/6/08)**		**Week 3 (7/16-7/20/08)**		**Week 5 (7/30-8/3/08)**		**Week 7 (8/13-8/17/08)**	
Indicator:	*E. coli*	Total Coliforms	*E. coli*	Total Coliforms	*E. coli*	Total Coliforms	*E. coli*	Total Coliforms
Interention	87.6%	78.7%	88.9%	91.7%	78.1%	62.8%	77.1%	68.8%

a. Percent reduction values are computed as $(1 - 10^{-\text{log reduction}})*100$ for *E. coli* and total coliform measures and as ((influent – effluent)/influent)*100 for turbidity.

Figure 4.10 – Box plots of $\log_{10}$ reductions of *E. coli* by week (Intervention)



Note: Week 4 = 7/2-7/6/08, Week 6 = 7/16-7/20/08, Week 8 = 7/30-8/3/08, Week 10 = 8/13-8/17/08

4.4 Discussion

4.4.1 Study Participants and Comparability of Cohorts

Participation in this prospective cohort study included 65 intervention households, where BSFs were installed between 8 and 22 months prior to interview, and 65 matched control households. The positive findings of initial trials, interventions, and studies of BSFs and the lack of specific follow-up studies to these trials and interventions was motivation for following specifically with households of a previous RCT in the DR (Fewtrell et al, 2005). A longitudinal, prospective cohort study following a cross-sectional sustainability assessment was a powerful study design to investigate the continued use, performance, and sustainability of the BSF as a POU technology.

While the study design was intended to provide the basis for robust comparison of filter and non-filter households, the intervention and control cohorts were not entirely comparable on all analyzed variables. There were significant differences in total number of people, people per household, mean age of participants less than 5 years of age, education level, paying for water, and distance to water source. The higher number of people (369 vs. 279) and people per household (5.68 vs. 4.29) seen in intervention households is not expected to have much of an impact on diarrheal incidence rates due to the proportional dependence of this variable on person-weeks. However, with a larger population, there is an opportunity for more diarrheal disease cases to be detected. Previous research has documented the disproportionate impact of diarrheal disease on children and age-related differences in diarrheal disease rates, with higher rates of diarrheal disease seen at younger ages (Kosek, Bern, & Guerrant, 2003). Therefore, the difference in average age for those under five (2.6 years for intervention vs. 1.8 years for control) is a potential source of bias in this study. Due to this lower average age of children in non-BSF control households and the associated likelihood that they will have a higher rate of diarrheal disease than the older children in intervention households as a result, the bias would overestimate the difference in incidence rates of diarrheal disease.

Increasing education level of caretakers or heads of households may have a positive impact on their ability to prevent diarrheal disease for themselves and their families. Therefore, the significant differences seen with primary and secondary education levels between cohorts are worth investigating, as higher levels of primary or secondary education in the BSF intervention cohort could lead inherently to lower incidence rates of diarrheal disease than those in the non-BSF control cohort. This difference in diarrheal disease incidence rates, which is not due to the BSF, could bias the calculated result by overestimating the difference in diarrheal disease incidence attributed to the BSF. Approximately two times more respondents in intervention verses control households reported receiving primary education, while approximately two times more respondents in control households verses intervention households reported receiving secondary education. These differences are opposite each other, such that each would bias the results in opposing directions. As a result when taken together, they are not expected to have much of an impact on diarrheal incidence rates.

The higher prevalence of paying for water (27.4% vs. 12.3%) and the closer proximity to the water source (72.1% vs. 54.8% less than 5 minutes) among intervention households verses control households are the final variables where the cohorts were found to be significantly different. Each of these is a potential source of bias and could lead to an overestimation of reduction of diarrheal disease incidence by the BSF if either variable is associated with lower incidence of diarrhea among the BSF intervention cohort as compared to the non-BSF control cohort. Together, all of these differences are potential sources of bias and challenge the comparability of the intervention and control cohorts for this study.

4.4.2 Sustained Health Impact Based on Diarrheal Disease Incidence

The principle finding from this study that further supports the BSF as a sustainable POU technology is the significant 61% reduction in diarrheal disease incidence rates seen among BSF households as compared to control households. This percent reduction was calculated using multivariate analysis that controlled for age, and it is found to be consistent with or even greater than analogous results of studies assessing the health impact of the BSF and other POU technologies.

Relative to previous BSF studies specifically, the observed reduction in diarrhea for BSF intervention compared to non-BSF control households is greater than reported in the previous RCT, which reported a 47% reduction in diarrheal disease incidence rates among BSF households as compared to control households (Stauber, 2007). It is relatively high in comparison to the reported diarrheal disease reduction rate of a similarly designed prospective cohort study of BSF and non-BSF households in Cambodia (44%) but lower than the high percentages of user reported health gains in Ethiopia (91.2%), in Haiti (95%), and in a six-country study (98.1%) (Liang, 2007; Earwaker, 2006; Duke et al., 2006; Kaiser et al., 2002). In considering each of these studies, it is important to highlight that populations in different countries may be influenced by various unique geographical, socioeconomic, socio-cultural, seasonal, and demographic factors that can influence BSF performance. Further, study designs can limit the interpretability of comparison analysis, especially for the strictly cross-sectional studies in Ethiopia and Haiti, neither of which provides health impact comparisons between BSF and non-BSF households.

For all POU technologies, estimates of diarrheal disease reductions, as determined through meta-analyses of RCTs, range from 35 to 51% for users (Fewtrell et al., 2005; Clasen et al., 2007), giving additional support to the credibility of the 61% reduction seen in this study as a positive indicator of sustainability. Ceramic water filters, the most comparable POU technology to the BSF (as opposed to chemical treatments, such as chlorine), have been shown to reduce diarrheal disease between 29 and 72%. In an analogous assessment of the pot-style ceramic water purifier in Cambodia, there was a 46% reduction in diarrheal prevalence for filter users as compared with non-users in a prospective cohort study.

Categorical analysis of unadjusted incidence rate ratios and the variation of incidence rate ratios from week to week do raise concern as to the limitations of this study. By unadjusted analysis, 41%, 59%, and 88% reductions in incidence rates of diarrheal disease are found for the categorical age groups of less than 2 years, 2 to 4 years, and 5 years or greater. Each of these is a positive indicator of the health impact of the BSF, but the values for each age group below the age of five are not significant. This result is of importance and concern for two reasons. One, this result is different than the higher impacts generally seen among the younger age groups, as was the case in analogous studies in Cambodia for the BSF and the ceramic water purifier (Liang, 2007; Brown, Sobsey, & Proum, 2007). Two, the health impact of POU technologies is particularly important for children, who are disproportionately affected by morbidity and mortality related to diarrheal disease (Kosek, Bern, & Guerrant, 2003).

When assessing the lack of significance for the differences seen with children aged less than 2 years and from 2 to 4 years, the particularly large confidence intervals signify that the opportunity to achieve significance is difficult given the small sample size (Intervention: n=178 (0-2 years) and n=511 (2-4 years) / Control: n=356 (0-2 years) and n=270 (2-4 years)). In addition, breast-feeding of children up to 2 years old was common for study participants, which would decrease the exposure of these infants to potentially contaminated drinking water, a limitation when considering the significance of differences in diarrheal incidence for children less than 2 years old.

The categorical analysis of adjusted incidence rate ratios by week found only two of the eight weeks with significant reductions in diarrheal disease among BSF households. Further, week 2 and week 7 showed 14% and 28% increases in diarrheal disease incidence rates, respectively, among BSF households as compared to control households. However, neither of these values was statistically significant. This variation suggests that the impact of the BSF can change over time and highlights the limitation of a longitudinal study of only eight weeks in length. Assessments over longer periods of time can allow for better understanding of variations in impact that may be the result of several potentially influential factors, as was the case with the seasonal analysis conducted for the RCT to which this study is a follow-up (Stauber, 2007). Further, these weekly comparisons are unique to this study and less important than the monthly or longer time comparisons seen in other studies.

It is important to note that the self reporting of diarrheal disease is a limitation and the lack of a placebo BSF precludes any ability to determine the influence of underreporting of diarrheal disease by BSF households. Both self-reporting and the technical and ethical issues associated with the placebo approach to controlling for a placebo effect are not unique to this study, however, as the majority of analogous studies face these same limitations.

The increase in geometric mean total coliforms and *E. coli* in BSF treated and stored water samples, as detailed in Table A.5 in Appendix A, is also important to note. One, this result highlights the critical component of safe storage in point-of-use water treatment systems. Two, this increase may underestimate the diarrheal disease reductions possible if only directly treated BSF water was consumed.

4.4.3 Water Quality Analysis

Analysis of the microbiological drinking water quality for BSF users (intervention) and non-users (control) revealed more significant water quality improvements by the BSF than by other used forms of treatment, low levels of improvement by the BSF as compared to laboratory results, and relatively low levels of fecal contamination of influent waters.

Though contamination of influent or source water, as measured by geometric mean concentrations, was lower among control households verses intervention households for *E. coli* (14.1 vs. 24.8 MPN/100mL), the contamination of water used for drinking was higher for *E. coli* (5.3 vs. 4.3 MPN/100mL). These differences are reflected further in the percent reductions achieved by the BSF in comparison to other treatment options practiced: 83.6% reduction for BSF vs. 60% reduction using other treatment (*E.*

coli), and 18.3% reduction for BSF vs. 104.5% increase using other treatment (turbidity). Due to the variations in the other treatments used, these comparisons should be regarded as basic, but they do support the higher quality drinking water seen with intervention households in the RCT, where intervention drinking water, as measuered by *E. coli* concentration, was lower than that for controls by 50% or more (Stauber, 2007).

With the growing laboratory and field data on the BSF, it is important to consider its effectiveness as well. In comparison to the average reduction of 79% for *E. coli* seen in Stauber's RCT in 2006, the BSF reduction of 83.6% is a slight improvement and supports the BSF as a sustainable POU technology. Further, this reduction is either comparable to or an improvement on reductions seen in analogous studies in Ethiopia and Kenya (Earwaker, 2006; Fewster, Mol, & Wiesent-Brandsma, 2004).

Nonetheless, this level of reduction in *E. coli* concentration is low in comparison to laboratory results for the BSF, where it has been shown to reduce bacterial indicators of fecal contamination by 90 to 99% (Stauber et al., 2006). Further, it is low in comparison to reduction rates seen in other analogous studies in Haiti, Cambodia, and elsewhere (Duke et al, 2006; Liang et al, 2007; Kaiser et al, 2002).

This result could be related to the relatively low contamination levels seen in the influent or untreated water samples, where 76% of the untreated water samples were less than 100 MPN/100 mL for *E. coli*. With low initial concentrations of indicators and the given detection limits of <1 MPN/100 mL to >2419.6 MPN/100 mL, the $\log_{10}$ reduction values calculated may be underestimates of those actually achieved by the BSF. The inability to measure values and reductions beyond the detection limits serves as a significant weakness of the laboratory analysis in this study.

Negative $\log_{10}$ reductions in *E. coli* were found in 16% of the water samples, which is concerning. These negative reductions signified an increase in *E. coli* concentration in BSF treated water samples as compared to untreated water samples. These negative reductions can be the result of a filter not functioning properly, the flushing of organisms built up within the filter, or variations in source water quality. A possible explanation for such negative reductions is that the water stored within the filter bed was of less quality than the source water being poured into the filter. Further, concentrations of total coliforms and *E. coli* have the propensity to change over time.

The variation in percent reduction seen across the four sampling rounds for *E. coli*, 77.1% to 88.9%, does not fall outside of analogous measures seen in other field studies. At the same time, it does highlight that changes can be seen from week to week. A weakness of this study is its inability to look at changes for longer periods of time or with different seasons, as was done and found to be significant for the RCT (Stauber, 2007).

It is important to note that the geometric mean for *E. coli* among BSF treated water samples was 4.3 MPN/100 mL, which is within the "reasonable" range of water safety (0-10 MPN/100 mL), according to WHO definitions (WHO, 2004). On the other hand, the geometric mean for total coliforms among BSF treated water samples was 131.1, which falls into the "dangerous" range of water safety (100-1000 MPN/100 mL), according to WHO definitions (WHO, 2004). High coliform values observed in effluent or BSF treated water, in addition to being influenced by relatively low contamination levels in influent water, can result from growth and survival of total coliforms within in the filter or on the filter outlet.

Average turbidity reductions seen between untreated water and BSF treated water were low at 18.3%. Similar to the reductions discussed above, the low turbidity levels (1.1 NTU average) seen in the untreated water samples provide an explanation for the low reductions. Further, the average turbidity level of the BSF treated water (0.7 NTU) falls below the United States Environmental Protection Agency (EPA) standard of 1 NTU, and the average turbidity level of the untreated water (1.1 NTU) adheres to the WHO standard of less than 5 NTU (WHO, 2004).

Chapter 5: Conclusion

5.1 Summary

The sustainability of the Biosand filter (BSF) was assessed through cross-sectional analysis of continued use, performance effectiveness, and sustained water quality improvement and longitudinal analysis of sustained health impact, measured as diarrheal disease and sustained water quality improvement. The results suggest the BSF is a highly sustainable point-of-use (POU) water treatment technology.

For BSFs in use for an average of one year and up to approximately two years, 90% continued use rates and low rates of breakage are strong positive indicators of the sustainability of the BSF. These rates were seen in both households formerly part of a randomized controlled trial and those associated with a non-governmental organization (NGO) implementation program, and they were supportive of and higher than analogous results seen for the BSF and for other POU treatment technologies.

For BSF households where the filter was installed for ten to sixteen months in comparison with non-BSF control households, incidence rates of diarrheal disease were reduced by 61%, which is a strong positive indicator of BSF sustainability.

Water quality improvement, as measured by reduction of fecal indicator bacteria, was found to be low (84 to 88%) in comparison to reductions seen in the laboratory but comparable to analogous rates seen for the BSF in other field assessments. Low levels of influent contamination and turbidity may help explain the low reduction levels.

Study limitations include lack of comparability between longitudinal cohorts, self-reporting of most factors, and inability to use a placebo BSF for control households. Despite these limitations, the filter was found to satisfy daily needs, improve health outcomes among users, require little maintenance, and be acceptable among users, all supporting the BSF a sustainable POU water treatment technology.

5.2 Future Research

Additional assessments of sustainability are needed in different settings to ensure the results seen in Bonao, Dominican Republic are generalizable to a larger scale and to compare measures for the concrete and plastic versions of the BSF. Further, more specific analysis is necessary to reach conclusions regarding the impact of time in use, level of poverty, and POU education and training on the lifetime and longevity of the BSF and other POU technologies.

Future research should also build on the robust evidence of BSF effectiveness and sustainability by conducting analysis of cost effectiveness and scalability. These issues will require interdisciplinary efforts among business analysts, policy makers, and public health researchers and scientists, and they will be critical to enhancing implementation schemes with the BSF and other POU technologies.

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Appendix A: Additional Laboratory Analysis

A.1 – Introduction

The principal results of the laboratory analysis were provided in Chapter 3 and Chapter 4 of this technical report. This appendix contains tables of additional stratifications and calculations of the laboratory data. The detail of this analysis is not necessarily useful in generalizing results or taking results to scale, but the detail, especially that by community, could be beneficial for more focused and directed implementation analysis conducted by organizations and future researchers in the Dominican Republic.

A.2 – Additional Analysis for Sustainability Assessment (Chapter 3)

Table A.1 – *E. coli* concentrations of untreated water samples

Number (percentage[a]) of all samples by *E. coli* concentration of untreated water[b]

	<1 (MPN/100mL)	1-10 (MPN/100mL)	11-100 (MPN/100mL)	101-1000 (MPN/100mL)	1,001+ (MPN/100mL)	Total samples
All communities	19 (11%)	36 (22%)	63 (38%)	37 (22%)	12 (7%)	167
RCT	16 (14%)	21 (19%)	44 (40%)	21 (19%)	9 (8%)	111
Brisas del Yuna	6 (21%)	6 (21%)	7 (25%)	5 (18%)	4 (14%)	28
Jayaco Arriba	0 (0%)	2 (9%)	11 (50%)	8 (36%)	1 (5%)	22
KM 100	3 (19%)	5 (31%)	5 (31%)	1 (6%)	2 (13%)	16
KM 101	0 (0%)	1 (5%)	14 (74%)	3 (16%)	1 (5%)	19
KM 103	6 (35%)	4 (24%)	4 (24%)	2 (12%)	1 (6%)	17
Majaguay	1 (11%)	3 (33%)	3 (33%)	2 (22%)	0 (0%)	9
Non-RCT	3 (5%)	15 (27%)	19 (34%)	16 (29%)	3 (5%)	56
Arroyo Toro	0 (0%)	1 (20%)	3 (60%)	1 (20%)	0 (0%)	5
El Chispero	0 (0%)	7 (70%)	2 (20%)	1 (10%)	0 (0%)	10
Ingenio	0 (0%)	2 (40%)	1 (20%)	1 (20%)	1 (20%)	5
Jima	1 (11%)	2 (22%)	2 (22%)	4 (44%)	0 (0%)	9
Los Quemados	0 (0%)	2 (33%)	2 (33%)	1 (17%)	1 (17%)	6
Masipedro	0 (0%)	0 (0%)	0 (0%)	5 (100%)	0 (0%)	5
Palmerito	2 (20%)	1 (10%)	4 (40%)	3 (30%)	0 (0%)	10
Sabana del Puerto	0 (0%)	0 (0%)	5 (83%)	0 (0%)	1 (17%)	6

a. Percentages with strata may not add up to 100% due to rounding.
b. Samples were filter influent in all households, taken at the time of visit (untreated water samples).

Table A.2 – *E. coli* concentrations of BSF treated water samples

Number (percentage[a]) of all samples by *E. coli* concentration of treated household drinking water[b]

	<1 (MPN/100mL)	1-10 (MPN/100mL)	11-100 (MPN/100mL)	101-1000 (MPN/100mL)	1,001+ (MPN/100mL)	Total samples
All communities	68 (40%)	65 (38%)	28 (16%)	7 (4%)	2 (1%)	170
RCT	45 (39%)	48 (42%)	17 (15%)	3 (3%)	2 (2%)	115
Brisas del Yuna	13 (45%)	10 (34%)	4 (14%)	2 (7%)	0 (0%)	29
Jayaco Arriba	13 (59%)	7 (32%)	1 (5%)	0 (0%)	1 (5%)	22
KM 100	4 (24%)	7 (41%)	5 (29%)	0 (0%)	1 (6%)	17
KM 101	4 (21%)	12 (63%)	3 (16%)	0 (0%)	0 (0%)	19
KM 103	9 (45%)	8 (40%)	2 (10%)	1 (5%)	0 (0%)	20
Majaguay	2 (25%)	4 (50%)	2 (25%)	0 (0%)	0 (0%)	8
Non-RCT	23 (42%)	17 (31%)	11 (20%)	4 (7%)	0 (0%)	55
Arroyo Toro	3 (60%)	2 (40%)	0 (0%)	0 (0%)	0 (0%)	5
El Chispero	3 (30%)	6 (60%)	1 (10%)	0 (0%)	0 (0%)	10
Ingenio	4 (80%)	1 (20%)	0 (0%)	0 (0%)	0 (0%)	5
Jima	3 (33%)	2 (22%)	3 (33%)	1 (11%)	0 (0%)	9
Los Quemados	1 (20%)	0 (0%)	2 (40%)	2 (40%)	0 (0%)	5
Masipedro	1 (20%)	3 (60%)	1 (20%)	0 (0%)	0 (0%)	5
Palmerito	5 (50%)	2 (20%)	3 (30%)	0 (0%)	0 (0%)	10
Sabana del Puerto	3 (50%)	1 (17%)	1 (17%)	1 (17%)	0 (0%)	6

a. Percentages with strata may not add up to 100% due to rounding.
b. Samples were filter effluent in all households, taken directly at the time of visit (BSF treated water samples).

Table A.3 – Total coliform concentrations of untreated water samples

Number (percentage[a]) of all samples by Total Coliform concentration of untreated water[b]

	<1 (MPN/100mL)	1-10 (MPN/100mL)	11-100 (MPN/100mL)	101-1000 (MPN/100mL)	1,001+ (MPN/100mL)	Total samples
All communities	7 (4%)	1 (1%)	5 (3%)	21 (13%)	133 (80%)	167
RCT	6 (5%)	0 (0%)	4 (4%)	17 (15%)	84 (76%)	111
Brisas del Yuna	4 (14%)	0 (0%)	1 (4%)	6 (21%)	17 (61%)	28
Jayaco Arriba	0 (0%)	0 (0%)	0 (0%)	1 (5%)	21 (95%)	22
KM 100	0 (0%)	0 (0%)	0 (0%)	4 (25%)	12 (75%)	16
KM 101	0 (0%)	0 (0%)	0 (0%)	0 (0%)	19 (100%)	19
KM 103	2 (12%)	0 (0%)	3 (18%)	3 (18%)	9 (53%)	17
Majaguay	0 (0%)	0 (0%)	0 (0%)	3 (33%)	6 (67%)	9
Non-RCT	1 (2%)	1 (2%)	1 (2%)	4 (7%)	49 (88%)	56
Arroyo Toro	0 (0%)	0 (0%)	0 (0%)	0 (0%)	5 (100%)	5
El Chispero	0 (0%)	0 (0%)	0 (0%)	2 (20%)	8 (80%)	10
Ingenio	0 (0%)	0 (0%)	0 (0%)	0 (0%)	5 (100%)	5
Jima	0 (0%)	0 (0%)	0 (0%)	1 (11%)	8 (89%)	9
Los Quemados	0 (0%)	0 (0%)	1 (17%)	1 (17%)	4 (67%)	6
Masipedro	0 (0%)	0 (0%)	0 (0%)	0 (0%)	5 (100%)	5
Palmerito	1 (10%)	1 (10%)	0 (0%)	0 (0%)	8 (80%)	10
Sabana del Puerto	0 (0%)	0 (0%)	0 (0%)	0 (0%)	6 (100%)	6

a. Percentages with strata may not add up to 100% due to rounding.
b. Samples were filter influent in all households, taken at the time of visit (untreated water samples).

Table A.4 – Total coliform concentrations of BSF treated water samples

Number (percentage[a]) of all samples by Total Coliform concentration of treated household drinking water[b]

	<1 (MPN/100mL)	1-10 (MPN/100mL)	11-100 (MPN/100mL)	101-1000 (MPN/100mL)	1,001+ (MPN/100mL)	Total samples
All communities	17 (10%)	13 (8%)	36 (21%)	61 (36%)	43 (25%)	170
RCT	9 (8%)	11 (10%)	26 (23%)	43 (37%)	26 (23%)	115
Brisas del Yuna	1 (3%)	2 (7%)	9 (31%)	13 (45%)	4 (14%)	29
Jayaco Arriba	3 (14%)	0 (0%)	8 (36%)	6 (27%)	5 (23%)	22
KM 100	2 (12%)	1 (6%)	2 (12%)	7 (41%)	5 (29%)	17
KM 101	1 (5%)	0 (0%)	2 (11%)	10 (53%)	6 (32%)	19
KM 103	2 (10%)	7 (35%)	2 (10%)	7 (35%)	2 (10%)	20
Majaguay	0 (0%)	1 (13%)	3 (38%)	0 (0%)	4 (50%)	8
Non-RCT	8 (15%)	2 (4%)	10 (18%)	18 (33%)	17 (31%)	55
Arroyo Toro	0 (0%)	0 (0%)	1 (20%)	4 (80%)	0 (0%)	5
El Chispero	2 (20%)	0 (0%)	2 (20%)	4 (40%)	2 (20%)	10
Ingenio	1 (20%)	2 (40%)	0 (0%)	2 (40%)	0 (0%)	5
Jima	2 (22%)	0 (0%)	1 (11%)	2 (22%)	4 (44%)	9
Los Quemados	0 (0%)	0 (0%)	1 (20%)	1 (20%)	3 (60%)	5
Masipedro	0 (0%)	0 (0%)	0 (0%)	3 (60%)	2 (40%)	5
Palmerito	0 (0%)	0 (0%)	5 (50%)	1 (10%)	4 (40%)	10
Sabana del Puerto	3 (50%)	0 (0%)	0 (0%)	1 (17%)	2 (33%)	6

a. Percentages with strata may not add up to 100% due to rounding.
b. Samples were filter effluent in all households, taken directly at the time of visit (BSF treated water samples).

Table A.5 – Geometric mean concentrations of *E. coli*, Total coliforms, and turbidity in BSF treated and stored and BSF treated, boiled, and stored water samples

All Samples	Water quality data[a], geometric means (BSF Treated & Stored Water)			Water quality data[a], geometric means (BSF Treated, Boiled, & Stored Water)		
	E.coli/100 mL	TC/100mL	Turbidity (NTU)	*E.coli*/100 mL	TC/100mL	Turbidity (NTU)
All communities	12.2	981.0	0.7	n/a[b]	n/a[b]	n/a[b]
RCT	11.3	1064.0	0.8	5.2	2038.1	1.5
Brisas del Yuna	12.4	723.5	0.7	12.0	2419.7	1.0
Jayaco Arriba	13.6	2129.7	0.7	5.2	2419.7	0.9
KM 100	19.6	1130.1	0.6	0.9	1218.0	1.3
KM 101	16.5	1425.3	0.7	n/a	n/a	n/a
KM 103	4.6	831.0	1.3	12.5	2419.7	2.6
Majaguay	9.5	745.8	0.4	n/a	n/a	n/a
Non-RCT	16.3	807.7	0.7	n/a[b]	n/a[b]	n/a[b]
Arroyo Toro	12.7	2419.7	0.3	n/a[b]	n/a[b]	n/a[b]
El Chispero	8.0	1469.4	0.8	n/a[b]	n/a[b]	n/a[b]
Ingenio	5.1	709.9	1.0	n/a[b]	n/a[b]	n/a[b]
Jima	18.4	748.9	1.0	n/a[b]	n/a[b]	n/a[b]
Los Quemados	8.6	104.1	0.5	n/a[b]	n/a[b]	n/a[b]
Masipedro	134.2	2419.7	0.5	n/a[b]	n/a[b]	n/a[b]
Palmerito	6.7	308.8	0.6	n/a[b]	n/a[b]	n/a[b]
Sabana del Puerto	127.6	2419.7	0.6	n/a[b]	n/a[b]	n/a[b]

a. Data from filter households, BSF treated and stored water and BSF treated, boiled, and stored water samples from 1 sustainability sampling round.
b. No BSF, treated, boiled, and stored water samples were taken from non-RCT households. Therefore, only RCT values are reported for the associated columns.

Table A.6 – Categorical analysis of $\log_{10}$ reductions of *E. coli*

Percentage[a] of all filter samples by *E. coli* $\log_{10}$ reduction values[b] (LRV) (n=163[c])

	<0[d]	0[e]	0.01-0.99	1-1.99	2-2.99	3-3.38
All communities	16%	9%	27%	32%	12%	5%
RCT	16%	12%	23%	33%	10%	6%
Brisas del Yuna	23%	15%	15%	23%	15%	8%
Jayaco Arriba	5%	0%	23%	50%	18%	5%
KM 100	25%	19%	19%	25%	6%	6%
KM 101	11%	0%	26%	53%	5%	5%
KM 103	12%	24%	35%	24%	0%	6%
Majaguay	25%	25%	25%	13%	13%	0%
Non-RCT	16%	2%	35%	29%	15%	4%
Arroyo Toro	0%	0%	20%	60%	20%	0%
El Chispero	30%	0%	40%	20%	10%	0%
Ingenio	0%	0%	40%	20%	20%	20%
Jima	11%	0%	67%	11%	11%	0%
Los Quemados	40%	0%	20%	20%	20%	0%
Masipedro	0%	0%	20%	60%	20%	0%
Palmerito	20%	10%	30%	20%	20%	0%
Sabana del Puerto	17%	0%	17%	50%	0%	17%

a. Percentages may not add up to 100% due to rounding.

b. Log_{10} reduction values are computed as the $\log_{10}$(effluent/influent); 1 LRV=90% reduction, 2 LRV=99% reduction, and 3 LRV=99.9% reduction. Reduction is a function of influent water, however, and low LRV values do not necessarily indicate poor performance. In forty percent of samples (n=68), filters reduced product water to <1 *E. coli* per 100 mL, so reported LRVs are potential underestimates.

c. 163 (87%) sampling events (out of 188 total sampled one time each) yielded complete data to use in the LRV calculation.

d. Negative LRV values indicate that the effluent water contains more *E. coli* than the influent water.

e. In 79% of these samples the influent water contained <1 *E. coli* per 100 mL.

Table A.7 – Categorical analysis of $\log_{10}$ reductions of total coliforms

Percentage[a] of all filter samples by Total Coliform $\log_{10}$ reduction values[b] (LRV) (n=163[c])

	<0[d]	0[e]	0.01-0.99	1-1.99	2-2.99	3-3.38
All communities	14%	10%	32%	25%	8%	10%
RCT	16%	8%	32%	29%	6%	9%
Brisas del Yuna	23%	4%	35%	31%	4%	4%
Jayaco Arriba	14%	5%	27%	32%	9%	14%
KM 100	13%	6%	38%	25%	0%	19%
KM 101	5%	16%	47%	26%	0%	5%
KM 103	24%	6%	18%	29%	12%	12%
Majaguay	13%	25%	25%	25%	13%	0%
Non-RCT	11%	15%	31%	18%	13%	13%
Arroyo Toro	0%	0%	60%	40%	0%	0%
El Chispero	20%	0%	40%	10%	10%	20%
Ingenio	0%	0%	20%	20%	40%	20%
Jima	0%	33%	33%	11%	11%	11%
Los Quemados	40%	0%	40%	0%	20%	0%
Masipedro	0%	20%	60%	20%	0%	0%
Palmerito	20%	20%	10%	30%	20%	0%
Sabana del Puerto	0%	33%	0%	17%	0%	50%

a. Percentages may not add up to 100% due to rounding.

b. Log_{10} reduction values are computed as the $\log_{10}$(effluent/influent); 1 LRV=90% reduction, 2 LRV=99% reduction, and 3 LRV=99.9% reduction. Reduction is a function of influent water, however, and low LRV values do not necessarily indicate poor performance. In ten percent of samples (n=17), filters reduced product water to <1 Total Coliforms per 100 mL, so reported LRVs are potential underestimates.

c. 163 (87%) sampling events (out of 188 total sampled one time each) yielded complete data to use in the LRV calculation.

d. Negative LRV values indicate that the effluent water contains more Total Coliforms than the influent water.

e. In 100% of these samples, the influent water contained >2419.6 Total Coliforms per 100 mL.

A.3 – Additional Analysis for Sustained Health Impact Assessment (Chapter 4)

Table A.8 – *E. coli* concentrations of untreated water samples

Number (percentage[a]) of all samples by *E. coli* concentration of untreated household drinking water[b]						
	<1 (MPN/100mL)	1-10 (MPN/100mL)	11-100 (MPN/100mL)	101-1000 (MPN/100mL)	1,001+ (MPN/100mL)	Total samples
Intervention	32 (14%)	45 (20%)	97 (42%)	35 (15%)	20 (9%)	229
Brisas del Yuna	20 (29%)	13 (19%)	18 (26%)	13 (19%)	6 (9%)	70
Jayaco Arriba	3 (5%)	13 (20%)	37 (56%)	8 (12%)	5 (8%)	66
KM 100	3 (9%)	6 (17%)	17 (49%)	4 (11%)	5 (14%)	35
KM 101	1 (4%)	5 (19%)	18 (67%)	2 (7%)	1 (4%)	27
KM 103	2 (12%)	4 (24%)	3 (18%)	5 (29%)	3 (18%)	17
Majaguay	3 (21%)	4 (29%)	4 (29%)	3 (21%)	0 (0%)	14
Control	53 (24%)	39 (17%)	84 (38%)	37 (17%)	10 (4%)	223
Brisas del Yuna	31 (35%)	15 (17%)	24 (27%)	14 (16%)	5 (6%)	89
Jayaco Arriba	9 (16%)	7 (13%)	30 (54%)	7 (13%)	3 (5%)	56
KM 100	7 (24%)	5 (17%)	15 (52%)	2 (7%)	0 (0%)	29
KM 101	2 (11%)	3 (16%)	7 (37%)	6 (32%)	1 (5%)	19
KM 103	2 (12%)	2 (12%)	4 (24%)	8 (47%)	1 (6%)	17
Majaguay	2 (15%)	7 (54%)	4 (31%)	0 (0%)	0 (0%)	13

a. Percentages with strata may not add up to 100% due to rounding.
b. Samples were filter effluent in all intervention households taken directly at the time of visit (BSF treated water samples) and other treatment samples for all control households.

Table A.9 – *E. coli* concentrations of treated water samples

Number (percentage[a]) of all samples by *E. coli* concentration of treated household drinking water[bc]						
	<1 (MPN/100mL)	1-10 (MPN/100mL)	11-100 (MPN/100mL)	101-1000 (MPN/100mL)	1,001+ (MPN/100mL)	Total samples
Intervention	64 (28%)	112 (49%)	38 (17%)	8 (4%)	6 (3%)	228
Brisas del Yuna	25 (36%)	31 (45%)	7 (10%)	3 (4%)	3 (4%)	69
Jayaco Arriba	19 (29%)	31 (48%)	10 (15%)	3 (5%)	2 (3%)	65
KM 100	6 (17%)	19 (54%)	8 (23%)	1 (3%)	1 (3%)	35
KM 101	2 (7%)	19 (70%)	5 (19%)	1 (4%)	0 (0%)	27
KM 103	10 (56%)	2 (11%)	6 (33%)	0 (0%)	0 (0%)	18
Majaguay	2 (14%)	10 (71%)	2 (14%)	0 (0%)	0 (0%)	14
Control	59 (48%)	27 (22%)	19 (15%)	11 (9%)	7 (6%)	123
Brisas del Yuna	21 (39%)	14 (26%)	8 (15%)	6 (11%)	5 (9%)	54
Jayaco Arriba	14 (67%)	3 (14%)	3 (14%)	0 (0%)	1 (5%)	21
KM 100	13 (50%)	5 (19%)	6 (23%)	2 (8%)	0 (0%)	26
KM 101	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0
KM 103	4 (31%)	4 (31%)	2 (15%)	2 (15%)	1 (8%)	13
Majaguay	7 (78%)	1 (11%)	0 (0%)	1 (11%)	0 (0%)	9

a. Percentages with strata may not add up to 100% due to rounding.
b. Samples were filter effluent in all intervention households taken directly at the time of visit (BSF treated water samples) and other treatment samples for all control households.
c. All percentages represent samples where households reported all family members to be drinking this water.

Table A.10 – Total coliform concentrations of untreated water samples

Number (percentage[a]) of all samples by Total Coliform concentration of untreated household drinking water[b]						
	<1 (MPN/100mL)	1-10 (MPN/100mL)	11-100 (MPN/100mL)	101-1000 (MPN/100mL)	1,001+ (MPN/100mL)	Total samples
Intervention	11 (5%)	2 (1%)	9 (4%)	31 (14%)	176 (31%)	229
Brisas del Yuna	8 (11%)	2 (3%)	4 (6%)	11 (16%)	45 (64%)	70
Jayaco Arriba	0 (0%)	0 (0%)	3 (5%)	6 (9%)	57 (86%)	66
KM 100	2 (6%)	0 (0%)	0 (0%)	4 (11%)	29 (83%)	35
KM 101	0 (0%)	0 (0%)	0 (0%)	1 (4%)	26 (96%)	27
KM 103	0 (0%)	0 (0%)	1 (6%)	5 (29%)	11 (65%)	17
Majaguay	1 (7%)	0 (0%)	1 (7%)	4 (29%)	8 (57%)	14
Control	14 (6%)	7 (3%)	8 (4%)	31 (14%)	163 (73%)	223
Brisas del Yuna	12 (13%)	4 (4%)	5 (6%)	16 (18%)	52 (58%)	89
Jayaco Arriba	0 (0%)	0 (0%)	1 (2%)	6 (11%)	49 (88%)	56
KM 100	2 (7%)	1 (3%)	1 (3%)	6 (21%)	19 (66%)	29
KM 101	0 (0%)	0 (0%)	0 (0%)	0 (0%)	19 (100%)	19
KM 103	0 (0%)	2 (12%)	0 (0%)	1 (6%)	14 (82%)	17
Majaguay	0 (0%)	0 (0%)	1 (8%)	2 (15%)	10 (77%)	13

a. Percentages with strata may not add up to 100% due to rounding.
b. Samples were filter effluent in all intervention households taken directly at the time of visit (BSF treated water samples) and other treatment samples for all control households.

Table A.11 – Total coliform concentrations of treated water samples

Number (percentage[a]) of all samples by Total Coliform concentration of treated household drinking water[bc]

	<1 (MPN/100mL)	1-10 (MPN/100mL)	11-100 (MPN/100mL)	101-1000 (MPN/100mL)	1,001+ (MPN/100mL)	Total samples
Intervention	18 (8%)	10 (4%)	38 (17%)	91 (40%)	71 (31%)	228
Brisas del Yuna	7 (10%)	6 (9%)	14 (20%)	26 (38%)	16 (23%)	69
Jayaco Arriba	4 (6%)	3 (5%)	9 (14%)	25 (38%)	24 (37%)	65
KM 100	2 (6%)	0 (0%)	5 (14%)	14 (40%)	14 (40%)	35
KM 101	0 (0%)	0 (0%)	3 (11%)	12 (44%)	12 (44%)	27
KM 103	3 (17%)	1 (6%)	3 (17%)	9 (50%)	2 (11%)	18
Majaguay	2 (14%)	0 (0%)	4 (29%)	5 (36%)	3 (21%)	14
Control	13 (11%)	7 (6%)	3 (2%)	10 (8%)	90 (73%)	123
Brisas del Yuna	6 (11%)	1 (2%)	1 (2%)	4 (7%)	42 (78%)	54
Jayaco Arriba	2 (10%)	0 (0%)	1 (5%)	1 (5%)	17 (81%)	21
KM 100	5 (19%)	3 (12%)	1 (4%)	1 (4%)	16 (62%)	26
KM 101	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0
KM 103	0 (0%)	0 (0%)	0 (0%)	2 (15%)	11 (85%)	13
Majaguay	0 (0%)	3 (33%)	0 (0%)	2 (22%)	4 (44%)	9

a. Percentages with strata may not add up to 100% due to rounding.

b. Samples were filter effluent in all intervention households taken directly at the time of visit (BSF treated water samples) and other treatment samples for all control households.

c. All percentages represent samples where households reported all family members to be drinking this water.

Table A.12 – Geometric mean concentrations of *E. coli*, total coliforms, and turbidity in BSF treated and stored and other treated and stored water samples

All Samples	Water quality data[a], geometric means (BSF Treated & Stored Water)			Water quality data[a], geometric means (Other Treated[b] & Stored Water)		
	E.coli/100 mL	TC/100mL	Turbidity (NTU)	*E.coli*/100 mL	TC/100mL	Turbidity (NTU)
All households	11.3	874.6	0.7	6.0	639.3	1.5
Intervention	10.6	845.9	0.7	10.1	1145.3	1.3
Brisas del Yuna	12.0	1022.0	1.0	10.3	1649.9	2.5
Jayaco Arriba	8.2	849.5	0.6	23.2	2419.7	1.1
KM 100	11.8	654.1	0.6	1.8	548.7	1.1
KM 101	13.0	1695.9	0.7	n/a	n/a	n/a
KM 103	11.7	741.8	0.7	12.5	153.7	1.5
Majaguay	7.9	217.8	0.5	21.2	1401.5	0.5
Control	21.0	1237.4	0.8	5.3	551.9	1.5
Brisas del Yuna	3.6[c]	528.4[c]	0.7[c]	9.0	700.3	2.4
Jayaco Arriba	16.0[c]	2419.7[c]	1.1[c]	2.3	804.2	1.1
KM 100	51.5[c]	1995.8[c]	0.5[c]	3.7	198.1	0.7
KM 101	53.1[d]	2419.7[d]	0.8[d]	n/a	n/a	n/a
KM 103	n/a	n/a	n/a	8.9	1933.5	2.7
Majaguay	20.5[e]	498.7[e]	0.9[e]	2.2	173.5	0.8

a. Data from filter households, BSF treated and stored water and other treated and stored water samples from 4 longitudinal sampling rounds.

b. Other treatments included boiling, chlorination, cloth straining, and bsf treatment and boiling together.

c. Same household providing BSF water from neighbor's BSF each of the 4 sampling visits.

d. Two households providing BSF water from neighbor's BSF on 2 sampling visits, and one household on 1 sampling visit.

e. One household providing BSF water from neighbor's BSF each of the 4 sampling visits, and one household on 1 sampling visit.

Table A.13 – Categorical analysis of $\log_{10}$ reductions of *E. coli* (Intervention)

Percentage[a] of all filter samples by *E. coli* $\log_{10}$ reduction values[b] (LRV) for intervention households (n=219[c])

	<0[d]	0[e]	0.01-0.99	1-1.99	2-2.99	3-3.38
Intervention	16%	9%	31%	32%	10%	2%
Brisas del Yuna	19%	22%	25%	19%	14%	2%
Jayaco Arriba	18%	2%	31%	42%	6%	2%
KM 100	17%	6%	31%	34%	11%	0%
KM 101	12%	0%	48%	36%	0%	4%
KM 103	0%	12%	29%	29%	24%	6%
Majaguay	23%	8%	31%	31%	8%	0%

a. Percentages may not add up to 100% due to rounding.
b. $\log_{10}$ reduction values are computed as the $\log_{10}$(effluent/influent); 1 LRV=90% reduction, 2 LRV=99% reduction, 3 LRV=99.99% reduction, and so on. Reduction is a function of influent water, however, and low LRV values do not necessarily indicate poor performance. In twenty-eight percent of samples (n=64), filters reduced product water to <1 *E. coli* per 100 mL, so reported LRVs are potential underestimates.
c. 219 (96%) sampling events (out of 229 total over 4 sampling rounds) yielded complete data to use in the LRV calculation.
d. Negative LRV values indicate that the effluent water contains more *E. coli* than the influent water.
e. In 80% of these samples the influent water contained <1 *E. coli* per 100 mL.

Table A.14 – Categorical analysis of $\log_{10}$ reductions of total coliforms (Intervention)

Percentage[a] of all filter samples by Total Coliform $\log_{10}$ reduction values[b] (LRV) for intervention households (n=219[c])

	<0[d]	0[e]	0.01-0.99	1-1.99	2-2.99	3-3.38
Intervention	12%	17%	38%	22%	5%	5%
Brisas del Yuna	19%	17%	30%	20%	9%	5%
Jayaco Arriba	11%	15%	38%	23%	3%	9%
KM 100	9%	23%	49%	14%	3%	3%
KM 101	4%	20%	52%	24%	0%	0%
KM 103	6%	12%	24%	41%	18%	0%
Majaguay	15%	8%	46%	23%	0%	8%

a. Percentages may not add up to 100% due to rounding.
b. $\log_{10}$ reduction values are computed as the $\log_{10}$(effluent/influent); 1 LRV=90% reduction, 2 LRV=99% reduction, 3 LRV=99.99% reduction, and so on. Reduction is a function of influent water, however, and low LRV values do not necessarily indicate poor performance. In eight percent of samples (n=18), filters reduced product water to <1 Total Coliforms per 100 mL, so reported LRVs are potential underestimates.
c. 219 (96%) sampling events (out of 229 total over 4 sampling rounds) yielded complete data to use in the LRV calculation for intervention households.
d. Negative LRV values indicate that the effluent water contains more Total Coliforms than the influent water.
e. In 13.5% of these samples, the influent water contained <1 Total Coliforms per 100 mL.

Appendix B: Sample Size and Study Period Calculations

B.1 – Theory and Background

The risk ratio for diarrheal disease necessary for an effective study was estimated to be 0.80 as a result of the previous RCT in 2006 as well as initial cross-sectional analysis in February 2007. This ratio equated to a targeted minimum detectable diarrheal disease reduction of at least 20% for those having and using the BSF in comparison with those not having or using the BSF. Using a power of 80% and α of 0.05, sample size calculations were performed to determine the number of households and length of study needed in order to achieve at least a 20% reduction in diarrheal disease among BSF users in comparison with those not using the BSF. Calculations were based the previous work of Diggle et. al, Leon, and Killip, Mahfoud, and Pearce, and the summary is provided in Table B.1.

B.2 - Calculations

The unadjusted calculation, where the proportion of participants with diarrhea in the exposed or non-BSF intervention cohort was set at 0.20 (20%) and the household size was estimated at 5.19 persons based on cross-sectional data, suggested the need for 59 households per cohort and seven visits per household to achieve effectiveness. Taking potential clustering of observations among participants into consideration, the calculation suggested the need for 63 households per cohort and seven visits per household to achieve effectiveness. Given these results, conservative targets of 70 households per cohort and a study period of 8 weeks (8 visits) were established. Despite the relatively short length of the study, these targets were set conservatively above the calculated results to take into account a potential attrition rate of 10%.

Table B.1 – Sample Size and Study Period Calculations

Power of 80%, 6 postbaseline visits (7 total)		
Computation of sample size required accounting for longitudinal clustering in individuals only (1,2)		
RR	risk ratio	0.8
Pa	proportion with diarrhea in exposed	0.16
Pb	proportion with diarrhea in unexposed	0.2
Qa	1-Pa	0.84
Qb	1-Pb	0.8
	Za/2	1.96
	Zb	0.8416
P bar	(Pa+Pb)/2	0.18
Q bar	1-Pbar	0.82
n	number of postbaseline obs per pers	6
rho	intraclass corr coeff (ICC)	0.05
d	smallest diff to be detected	0.04
m	number of participants per group	301.4487749
h	households needed at 5.19 ppl/house	58.08261559

For clustering within households, we must use another ICC (3)		
ICC	intracluster correlation coeff (rho)	0.05
m	number of subjects in a cluster (hh size)	5.19
k	number of clusters	58.08261559
DE	design effect	1.2095
RSS	required # people = subjects * DE	364.6022932
Adj HH	Total adjusted households needed	**62.86246435**

1. Diggle, P.J., Heagerty, P., Liang, K.-Y., and Zeger, S.L. 2002. Analysis of longitudinal data, 2nd edition. Oxford: Oxford University Press.
2. Leon, A.C. 2004. “Sample-size requirements for comparisons of two groups on repeated observations of a binary outcome”. *Evaluation and the Health Professions* 27(1): 34-44.
3. Killip, S., Mahfoud, Z., and Pearce, K. 2004. “What is an intracluster correlation coefficient? Crucial concepts for primary care researchers”. *Annals of Family Medicine* 2(3): 204-208.

Appendix C: List of Variables and Coding used in Logistic Regression

VARIABLE	DESCRIPTION	CODING
Diarrhea	*Outcome variable*. Describes the presence of a case of diarrhea during each week of observation.	0 = no diarrhea 1 = diarrhea Note: Missing if still experiencing case of diarrhea from previous week
Intervention	*Main exposure variable* (Ch. 4). Generated at the household level and describes whether or not the household was in the BSF intervention cohort or non-BSF control cohort.	0 = non-BSF control cohort 1 = BSF intervention cohort
Community	*Binary variable*. Describes the community location as a categorical variable.	0 = Jayaco 1 = Brisas del Yuna
Age	*Ordinal variable*. Classifies participants in one of three age groups: <2, 2-4, and ≥5 years of age.	0 = if < 2 years of age 1 = if 2 to 4 years of age 2 = if ≥ 5 years of age
Gender	*Binary variable*. Participant's gender.	0 = female 1 = male
Week	*Categorical variable*. Stratifies the data into eight categories for the eight study weeks: 1-8.	Indicator variables for all 8 possible weeks.
Assets	*Ordinal variable*. Summary of number of six household assets: motorcycle/moped, refrigerator, television, washer, fan, cell phone.	0 = in none of the six assets 1 = if any one of the six assets 2 = if any two of the six assets 3 = if any three of the six assets 4 = if any four of the six assets 5 = if any five of the six assets 6 = all six assets
Education	*Binary variable*. Describes whether or not the primary respondent and the primary respondent's spouse received any primary education.	0 = if no primary education for one or both 1 = if any primary education for both
Health Education	*Binary variable*. Describes whether primary respondent received health education about preventing or treating diarrhea from any source.	0 = no health education 1 = health education
Soap Use	*Binary variable*. Describes use and presence of soap in household.	0 = no soap 1 = soap
Sanitation	*Binary variable*. Describes household access to shared or private latrines or toilets.	0 = private 1 = shared

VARIABLE	DESCRIPTION	CODING
Safe Storage	*Binary variable*. Describes use of safe storage practices at household level, defined as using a covered or narrow mouth water storage container.	0 = no safe storage 1 = safe storage
Handwashing	*Binary variable*. Describes whether or not household members "always" wash their hands with soap and water after defecating, as reported by primary respondent.	0 = not "always" washing hands 1 = "always" wash hands
Drinking Water Source	*Categorical variable*. Describes the source of drinking water reported during each week of observation. Responses were not mutually exclusive, and responses included were: surface, ground, rain, piped, and bottled water.	Indicator variables for all 5 possible sources.
Pay for Water	*Binary variable*. Describes any amount of payment for water by household.	0 = do not pay for water 1 = pay for water
Time to Source	*Categorical variable*. Describes the amount of time it takes to get to drinking water source from the home, classified into five groups: <5, 5-9, 10-19, 20-39, and ≥40 minutes.	0 = < 5 minutes 1 = 5 to 9 minutes 2 = 10 to 19 minutes 3 = 20 to 39 minutes 4 = ≥ 40 minutes
Cement Construction	*Binary variable*. Describes whether or not the house is made out of cement.	0 = not cement construction 1 = cement construction
Wood Construction	*Binary variable*. Describes whether or not the house is made out of wood.	0 = not wood construction 1 = wood construction
Tile Roof	*Binary variable*. Describes whether or not the house roof is made of tile.	0 = not tile roof 1 = tile roof
Cement Floor	*Binary variable*. Describes whether or not the house floor is made of cement.	0 = not cement floor 1 = cement floor
Mud Floor	*Binary variable*. Describes whether or not the house floor is made of mud/dirt.	0 = not mud floor 1 = mud floor