

# **BIOSAND HOUSEHOLD WATER FILTER EVALUATION 2001**

**A Comprehensive Evaluation of the Samaritan's Purse BioSand Filter (BSF) Projects in  
Kenya, Mozambique, Cambodia, Vietnam, Honduras, and Nicaragua**



**SUBMITTED TO  
Samaritan's Purse Canada**

**SUBMITTED BY**  
**Nathan Kaiser, B.A.      Kaida Liang, B.A.**  
**Marianne Maertens, B.Sc.      Ryan Snider, B.A. M.Sc.**

**SUBMITTED ON  
February 15, 2002**

## ACKNOWLEDGEMENTS

The contributions of the following organizations and individuals were essential in the completion of this Evaluation. Their assistance has been greatly valued and our greatest appreciation is extended to:

- Accord Research, Public Opinion Research Company  
Accord Research is owned and operated through the University of Calgary, Alberta. Accord Research advised Samaritan's Purse throughout the development of the BioSand Household Water Filter Questionnaire and completed exhaustive statistical analysis of the data.
- Dr. David Manz, P.Eng  
Dr. Manz is the inventor and patent holder of the BioSand Household Water Filter in Calgary, Alberta. The technological information he provided regarding the BioSand Household Water Filter was invaluable.
- Dr. Gwendolyn Hollaar, BSc. M.D. MPH FRCS(C)  
Dr. Hollaar is a physician based out of Calgary, Alberta, with extensive overseas experience in international health. She assisted Samaritan's Purse in the development of the Wellness criteria for the BioSand Household Water Filter Questionnaire.
- Dr. Geoff Ibbotson, BSc. MSc. M.D. FRCS(C)  
Dr. Ibbotson is a medical researcher and physician in international health based out of Calgary, Alberta. He provided advice during the editing of the final report.

Samaritan's Purse Canada would like to show appreciation to Oscar Carre, Vasco Chirimdzane, and the Canicado BSF Team for their effort in the Evaluation in Mozambique.

Samaritan's Purse Canada would like to show appreciation to the Kenyan Water Projects Manager, Maina Muthee, and the Kenyan team of BSF Technicians and trainers in Ngangani who were instrumental in the entire Evaluation.

In addition, Samaritan's Purse Canada would also like to thank ADRA for the use of their Incubator in Kampong Thom, Cambodia. The assistance of the Cambodian Water Project Manager Darren Tosh, CIDA Interns, and local BSF Technicians was essential to the completion of the Evaluation.

Samaritan's Purse Canada would like to show appreciation to the Samaritan's Purse – Vietnam staff for their assistance. In particular the help of Country Director John Pham and Tuan, who were pivotal in completing the Evaluation in Vietnam.

In Nicaragua Samaritan's Purse Canada would like to show appreciation to Country Director Dexter Cuthbert and the BSF Technicians who worked relentlessly to complete the Evaluation.

Samaritan's Purse Canada would like to thank David Chang, the Country Director in Honduras and the BSF Technicians who worked on the Evaluation.

## EXECUTIVE SUMMARY

One billion people worldwide do not have access to a safe water supply or sanitation. Contaminated water can contain numerous disease-causing pathogens which negatively affect the health of individuals. One child every 8 seconds worldwide dies from a water related illness (WHO, 1996). Equivalently 3.4 million people die yearly from water related illness. Access to clean drinking water is a right for all people (WHO, 2001), but many in developing countries do not have access to any water treatment option. Samaritan's Purse Canada felt it essential to address this crisis through implementing the Clean Water for Life Program.

The water treatment process of using slow-sand filter technology is centuries old. Dr. David Manz while at the University of Calgary Canada, built on this knowledge and developed an intermittent slow-sand filter, the BioSand Filter (BSF). The BSF is a low-cost water treatment option that can be used in developing countries which functions without electricity, running water, moving parts, or any other added inputs. The BSF technology is a water quality treatment option that addresses World Health Organization concerns of sustainability and program effectiveness for water treatment projects in developing countries.

The World Health Organization defines health as "a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity". There are many interacting factors affecting the health and wellness of individuals including food preparation, hygiene, contaminated food and environment. Wellness and health in individuals is the main objective of the Samaritan's Purse Water Projects. Wellness in individuals is a combination of observed physical conditions and mental perception of health. The BSF is an effective method for improving water quality, which is an essential component for wellness in individuals.

Samaritan's Purse has built and distributed over 14,000 BioSand Filters in 24 countries by using local materials and supplies and building filters within the communities. In June 2001, an internal Samaritan's Purse document was circulated on the parameters for an Evaluation of the Samaritan's Purse BSF program. Five objectives were identified: **sustainability, effectiveness, lessons learned, recommendations** and **Christian ministry**. In October 2001, an Evaluation was initiated in Mozambique, Kenya, Cambodia, Vietnam, Honduras and Nicaragua to evaluate a total of 100 households in each country. An additional objective of **creating an Evaluation process** and baseline data for future Evaluations was determined during the Evaluation initiation.

The BioSand Household Water Filter Evaluation contained two components, a Questionnaire and a Performance Evaluation. The Questionnaire was developed to interpret the **sustainability** of the BSF, and to **learn** from the BSF recipients in order to enhance future project effectiveness. Similarly, a Performance Evaluation including a water quality testing protocol, corresponding with wellness responses from the Questionnaire, was developed to address the **effectiveness** of the BSF. Water quality testing is important in order to determine that the BSF technology is working and functioning according to specifications. A brief summary of the Evaluation is as follows:

- **98.4 %** of all BSF recipients are using their filter on a regular basis.
- **93.0 %** of fecal coliform in the source water is removed by the BSF.

- **88.5 %** of all households surveyed use their BSF every day.
- **85.0 %** of the households surveyed report that they would be drinking their water directly from the source if they did not own a BSF.
- **98.1 %** of the households surveyed report that the BSF has improved the health of their household.
- **5.0 %** of the households surveyed rank their health BEFORE receiving a BSF as excellent.
- **82.4 %** of the households surveyed rank their health AFTER receiving a BSF as excellent.

The WHO Drinking Water Guidelines state that there can be no *E. coli* present in any drinking water sample. A system that could purify water to its purest state would include a multiple step water treatment process. Although disinfection is an important component to any water treatment program, raw water can not be treated with disinfection. The BSF is an essential step in meeting the WHO drinking water guidelines. The BSF Evaluation of Samaritan's Purse projects discovered that the average fecal coliform removal rate under field conditions is 93%. The BSF is documented by scientific literature to remove 97% of fecal coliform present in contaminated water in laboratory conditions. It can be concluded from this that although the Evaluation removal rates are lower, the BSF is functioning as an intermittent slow sand filter. This being known, from the literature it is shown that the BSF is filtering 100% of giardia, 99.89% of cryptosporidia, 100% of worms, and 100% of parasites, thus improving water quality.

There are many vectors that affect wellness in individuals including contaminated food, food preparation, hygiene, environment, and access to clean drinking water. The BSF is effective at reducing the incidence of water-borne pathogens to sub-infectious levels through filtering contaminated water. This knowledge in combination with a 93% removal rate for *E. coli* indicates that the health of individuals is being positively impacted. Over 98.4% of BSF recipients are currently using the BSFs installed in their homes, indicating the **sustainability** of the BSF in the communities. Also 88.5% of BSF recipients use their BSF every single day, which proves the **appropriateness** of the BSF project. The BSF significantly reduces the need for fuel wood, or coal fires used for boiling water, which reduces resource consumption and decreases the workload of women. These factors all point to a positive impact on community wellness, an essential criterion for determining the effectiveness objective of the BSF Evaluation.

Through listening to and learning from the BSF beneficiaries and BSF Technicians, the Evaluation Team developed recommendations to further enhance future program effectiveness. The main recommendations are as follows: **assist** BSF recipients with a properly labeled clean water bucket and dirty water bucket in order to help them distinguish between dirty (river), and clean (filtered) water, and to **educate** beneficiaries, using appropriate teaching resources, on the relationship between water quality and the transmission of water-borne diseases. The goal of these recommendations is to further improve overall community health.

Through a careful and comprehensive Evaluation of the BioSand Filter across three geographic regions of the world, the Samaritan's Purse Evaluation Team is confident in the **effectiveness**, **appropriateness**, and **sustainability** of the BSF. The recommendations developed from the survey results will improve the BSF program and build on the BSF reputation in developing countries even further. The lives of individuals in developing communities are positively impacted and community health is improved through the use of the BioSand Filter.

## NOMENCLATURE

APEGGA –	Association of Professional Engineers, Geologists and Geophysicists of Alberta
APHA –	American Public Health Association
BSF –	BioSand Water Filter
cfu –	colony forming unit
CIDA –	Canadian International Development Agency
CHE –	Community Health Educator
DO –	District Official
<i>E. coli</i> –	<i>Escherichia coli</i>
Evaluation Team -	Samaritan's Purse Canada Evaluation Team
GDWQ –	Guidelines for Drinking Water Quality
IDRC –	International Development Resource Center
ISSF –	Intermittent Slow Sand Filtration
ISO –	International Organization for Standardization
Low technology –	A technology that is not complex, mechanized or computerized.
MIT –	Massachusetts Institute of Technology
PAHO –	Pan American Health Organization
Pathogen -	A disease causing bacteria, virus, protozoa or parasite
Schmutzdecke -	The biological layer in the BioSand Water Filter
SP –	Samaritan's Purse
SPSS -	Statistical Package for the Social Sciences Database Program
USAID –	United States Agency for International Development
WHO –	World Health Organization

**TABLE OF CONTENTS**

1.0	INTRODUCTION .....	1
1.1	Overview of the BioSand Filter .....	1
1.2	History of the Samaritan’s Purse BioSand Filter Program .....	4
1.3	BioSand Filter Expectations Under Optimal Conditions .....	4
1.4	Construction of the BioSand Household Water Filter .....	6
1.5	Development of Community Health and Wellness .....	6
2.0	OBJECTIVES OF THE EVALUATION .....	9
3.0	METHODOLOGY.....	10
3.1	Survey Development.....	10
3.2	Water Quality Analysis Approach.....	11
3.2.1	Procedures for Water Quality Testing .....	12
3.2.2	Procedure for Arriving In Country or Base Location .....	13
3.2.3	Procedure for Field Lab Set-up.....	13
3.2.4	Procedure for Disinfecting Equipment .....	14
3.2.5	Procedure for Preparing Dilution Water .....	15
3.2.6	Procedure for Recording Sample Testing .....	15
3.2.7	Procedure for Sample Collection .....	15
3.2.8	Procedure for Arriving in Town/Village/Household .....	16
3.2.9	Procedure for Fecal Coliform Test.....	16
3.2.10	Procedure for Counting Colonies .....	19
3.3	Water Quality Testing Data Analysis .....	20
4.0	IMPLEMENTATION OF THE PERFORMANCE EVALUATION .....	21
4.1	Community Selection.....	21
4.1.1	Community Selection Option 1 .....	21
4.1.2	Community Selection Option 2.....	21
4.1.3	Difficulties in Community Selection .....	21
4.2	Household Selection .....	21
4.2.1	Household Selection Option 1 .....	22
4.2.2	Household Selection Option 2 .....	22
4.2.3	Household Selection Option 3 .....	22
4.2.4	Difficulties Encountered.....	22
4.3	Sampling Approaches for the Various Countries .....	23
4.3.1	Kenya .....	23
4.3.2	Mozambique .....	23
4.3.3	Cambodia .....	24
4.3.4	Vietnam.....	25
4.3.5	Honduras .....	25
4.3.6	Nicaragua .....	25

5.0	RESULTS AND DESCRIPTION.....	27
5.1	Fecal Coliform Removal Rates .....	27
5.2	Trends and Indicators of Living Conditions .....	30
5.3	Trends and Indicators of User Compliance .....	32
5.4	Trends and Indicators of Household Wellness .....	37
6.0	INTERPRETATION OF RESULTS .....	43
6.1	Interpreting Fecal Coliform Removal Rates .....	43
6.1.1	Known Scientific Research.....	43
6.1.2	Recognized Water Standards .....	44
6.1.3	Results Scenarios .....	45
6.1.4	Science and the BSF Performance Evaluation.....	47
6.2	Interpreting Indicators in Living Conditions .....	48
6.3	Interpreting Indicators of User Compliance .....	50
6.4	Interpreting Indicators of Household Wellness .....	51
6.5	Difficulties Encountered and Lessons Learned .....	52
6.5.1	Kenya .....	52
6.5.2	Mozambique .....	52
6.5.3	Cambodia .....	53
6.5.4	Vietnam.....	53
6.5.5	Honduras .....	53
6.5.6	Nicaragua .....	54
7.0	RECOMMENDATIONS FOR ENHANCING PROJECT EFFECTIVENESS.....	55
7.1	Overall Recommendations .....	55
7.2	Country Specific .....	55
7.2.1	Kenya .....	56
7.2.2	Mozambique .....	56
7.2.3	Cambodia .....	56
7.2.4	Vietnam.....	57
7.2.5	Honduras and Nicaragua .....	57
7.3	The Importance of User Education.....	57
7.3.1	Kenya & Mozambique .....	58
7.3.2	Cambodia and Vietnam.....	58
7.3.3	Honduras and Nicaragua .....	59
7.4	Education Program.....	59
7.4.1	Education Materials .....	60
7.5	Future Evaluation System.....	61
8.0	CONCLUSIONS.....	62
9.0	LITERATURE CITED .....	65

**LIST OF APPENDICES**

- A SURVEY MATERIALS
  - A.1 BioSand Filter Cross-Section
  - A.2 Samaritan’s Purse BioSand Filter Questionnaire
- B WATER QUALITY TESTING MATERIALS
  - B.1 Water Quality Testing Sheet for the BioSand Water Filter
  - B.2 Water Quality Testing Results Spreadsheet
- C SURVEY RESULTS
- D WATER QUALITY TESTING RESULTS
  - D.1 Water Quality Testing Results Mozambique
  - D.2 Water Quality Testing Results Kenya
  - D.3 Water Quality Testing Results Cambodia
  - D.4 Water Quality Testing Results Vietnam
  - D.5 Water Quality Testing Results Nicaragua
  - D.6 Water Quality Testing Results Honduras

**LIST OF FIGURES**

**Figure 1: BioSand Filter in Honduras.....3**

**Figure 2: Field laboratory equipment.....14**

**Figure 3: An overhead view of colony forming units in the source (1450 cfu/100mL).....19**

**Figure 4: A typical survey being carried out by a local SP Evaluation Team member.....24**

**Figure 5: Predictive Fecal Coliform Removal.....28**

**Figure 6: Predictive Fecal Coliform Removal by country .....29**

**Figure 7: Year of BioSand Filter installation.....31**

**Figure 8: The primary water source for BioSand Filter recipients .....32**

**Figure 9: Percentage of BioSand Filters still in use.....33**

**Figure 10: The degree to which the beneficiaries use their BioSand Filter.....33**

**Figure 11: Description of the user’s knowledge of BioSand Filter maintenance .....35**

**Figure 12: Methods of Pre -Filtration.....35**

**Figure 13: Methods of Post-Filtration.....36**

**Figure 14: Purposes and Uses of the filtered water .....36**

**Figure 15: The number of beneficiaries per Household BioSand Filter.....37**

**Figure 16: Percentage of BSF beneficiaries who believe the BioSand Filter has improved the health of their household.....38**

**Figure 17: Responses to how household health has improved.....39**

**Figure 18: Percentage of BioSand Filter recipients with access to a Health Center.....40**

**Figure 19: The percentage of BioSand Filter beneficiaries with Diarrhea in the past month .....41**

**Figure 20: The percentage of BioSand Filter beneficiaries who have experienced vomiting in the past month.....41**

**Figure 21: The Percentage of BioSand Filter Beneficiaries Experiencing Intestinal Worms in the Past Month** .....42

**Figure 22: Perceived Household Health Before and After Receiving the BioSand Filter**...42

**Figure 23: Animal Contact with BSF in Honduras.**.....49

**Figure 24: Shallow Well Water for Household in Cambodia.** .....50

**Figure 25: Flooded streets in Honduras in the aftermath of the tropical storm.** .....54

**Figure 26: Iron residue resulting from high concentration of dissolved iron in source water.**.....57

**Figure 27: Filter recipient in Vietnam.** .....59

**LIST OF TABLES**

Table 1: Average Fecal Coliform Removal Rates for the Individual Countries .....29

Table 2: Average Outflow Rates (mL/min) for the Individual Countries .....30

Table 3 Characteristics of Households Receiving BioSand Filters .....31

Table 4: Observed Characteristics of the BioSand Filter.....34

## 1.0 INTRODUCTION

Access to safe water is a basic human right (WHO, 2001) that has been denied to a large proportion of the world's population. Only 0.7% of the world's water supply is available for consumption and, unfortunately, it is disproportionately distributed. Over one half of the people living in developing countries suffer from diseases related to unsafe water supply and sanitization (WHO, 1996). One billion people worldwide do not have access to a safe water supply, and water pollution contaminates many areas where populations are concentrated. Contaminated water can contain many disease-causing pathogens which negatively affect the health of individuals. One child every 8 seconds worldwide dies from a water related illness (WHO, 1996), equivalently 3.4 million people die yearly from water related illness. Thus, in developing countries it becomes essential to improve wellness by improving access to both water and sanitation.

In a statement published by the WHO in 1974, it is stated that there are several methods to purify water but "no other single treatment process can effect such an improvement in the physical, chemical and bacteriological quality of normal surface waters as that accomplished by biological (slow sand) filtration". The World Health Organization states that "a lack of sustainability and ineffective systems aggravate" the already burgeoning contaminated water supply problem (WHO, 2001). It is essential that low-technology water treatment solutions be introduced so that the health of communities will not be burdened further. Low-technology means that the solution is not complex, mechanized, or computerized. The BSF program is a water treatment option that can be used to meet this objective.

The BioSand Water Filter (BSF) was developed by Dr. Manz in conjunction with the University of Calgary, Alberta. It functions as an intermittent slow-sand filter and cleans the water through several removal mechanisms. These removal mechanisms are a biological, physical, and chemical transformation of contaminated water. The most significant removal is through the biological layer present in the top layer of media in the BSF. As will be discussed to a much greater extent in Section 1.1, the intermittent slow-sand filter design allows for the user to utilize the filter whenever the water source must be purified.

### 1.1 Overview of the BioSand Filter

Biological or slow sand filtration is a low-technology solution that can be used in the purification of contaminated water. Sand filtration was first used to purify water on a large scale in Scotland (1804) and became widely used in Britain (1852), reaching widespread use in North America by 1885 (Huisman and Wood, 1974). Sand filtration was introduced as a viable treatment option to reduce turbidity and the transmission of cholera and typhoid in drinking water. The known benefits of sand filtration have been expanded since the 1800's to a technology that is widely incorporated into the water treatment process of municipal drinking water systems worldwide.

There are three different categories of sand filters that are used in water treatment facilities around the world. The original method was called slow-sand filtration, which as the name describes, allows the continuous flow of water through a sand media in order to remove the contaminants from the water. Changes to this design were made to decrease the size of the filter, allowing the water to penetrate the sand column more rapidly, and this new design was subsequently called rapid-sand filtration. The latest development in sand filtration is called intermittent-sand filtration and this process involves the use of a slow-sand filter that permits occasional, as opposed to constant use. Although there have been minor changes and deviations from the original, the design and function of intermittent-slow sand filtration has not changed dramatically since 1868 (Metcalf and Eddy, 1991).

These three categories of sand filtration have design specifications that optimize their use in different applications. When reviewing the literature, one can often become confused as the terms “slow-sand filtration” and “intermittent slow-sand filtration” is often interchanged. However, both models rely on the same technology with the sole difference lying in basic design alterations so that the intermittent slow-sand filter does not require continuous water flow. Consequently, intermittent slow-sand filtration is more suitable and appropriate for purifying water in developing countries than that of rapid-sand filtration.

Intermittent slow-sand filtration has many benefits which make it suitable for use in developing countries. Primarily, it is a low-cost, low technology, sustainable water treatment option that requires little skill to operate (Schulz and Okun, 1992). Secondly, the process does not require moving parts or any chemical additives (Schulz and Okun, 1992), as the main mechanisms of removal are microbiological (Davis and Lambert, 2000). Finally, intermittent slow-sand filters require very little water in order to clean the filter media. In areas where water quantity is limited, this characteristic is extremely important.

As mentioned previously, intermittent slow-sand filtration is a technology that has been used in different capacities since the late 1800's. Applications of intermittent slow-sand filtration are found in small communities or individual residences. Dr. David Manz, in conjunction with the University of Calgary, developed an intermittent slow-sand filter for household use. The patented filter has been named the BioSand Household Filter (BSF), and is capable of removing giardia, cryptosporidia, typhoid, cholera, rust, stains, metallic taste, algae, sulphuric smell, silt, toxins and heavy metals (Samaritan's Purse, 1998).

The BSF design as seen in Appendix A, utilizes a biological layer or *schmutzdecke* on top of the sand media inside the filter as the main filtering mechanism. The biological content of the source water creates a mat of microorganisms that aid in cleaning the water as it is filtered. The BSF design provides five centimeters of resting water above the sand column to protect the *schmutzdecke* between uses. Pouring water into the filter replenishes the biological layer after daily use. While the water is flowing through the filter, the majority of the physical, biological and chemical transformations of the water occur in the top 10cm of the filter media.

The BSF is a point-of-use filter that allows the user to collect the water from the filter spout after pouring water into the top of the filter. There are no pumps required as the filter is a gravity fed unit. Water must be poured into the filter for filtered water to flow out. There are no chemical additives required because of the natural filter mechanisms inherent in the design. The only external required materials are two buckets, one to pour the water into the filter and another to collect the filtered water, Figure 1.



**Figure 1: BioSand Filter in Honduras.**

There are two physical components that distribute the force of the water as it is poured into the filter so it does not disrupt the schmutzdecke. The first is a diffuser plate that collects any large objects in the water and at the same time allows oxygen to reach the standing water in the filter. The second component is five centimeters of resting water inside the filter, which absorbs the force of the water passing through the diffuser plate while transferring oxygen to the biological layer. These are design components that distinguish the BSF from other sand filters.

## 1.2 History of the Samaritan's Purse BioSand Filter Program

Although the process of slow-sand filtration is centuries old, Dr. David Manz first developed the BioSand Filter (BSF) while teaching at the University of Calgary, Alberta, Canada. The design, the name, and the idea are owned and protected under patent and copyright law. Samaritan's Purse is using the design with permission under specific guidelines. Essential to the agreement between Dr. Manz and Samaritan's Purse is the guideline to promote and maintain the integrity of the BioSand Filter design. Samaritan's Purse has agreed not to alter the design of the BioSand Filter in any way or misrepresent the inventor, and has done its best to maintain the integrity of the design. In addition, Samaritan's Purse has always stressed the importance of this guideline amongst its workshop participants as well as all others using or promoting the technology.

Samaritan's Purse has been involved in transferring this technology to 34 CIDA-sponsored interns, as well as over 50 non-governmental partner organizations. Throughout this period, Samaritan's Purse has seen improvement in project site selection, design, and relationships with local partners. Samaritan's Purse and partner organizations have built and distributed over 14,000 BioSand Filters in 24 countries. These countries include:

Benin	Honduras	Pakistan
Brazil	Indonesia	Russia
Cambodia	Ivory Coast	Sudan
Canada	Kenya	Thailand
Dominican Republic	Laos	Uganda
Ecuador	Mexico	Vietnam
El Salvador	Mozambique	
Ethiopia	Nepal	
Guatemala	Nicaragua	

## 1.3 BioSand Filter Expectations Under Optimal Conditions

The BSF is a low-technology water treatment option which functions without electricity, running water, moving parts or any other added inputs. The filter is built using local materials in the communities to foster individual ownership of the filter. The BSF is designed for household use and provides clean drinking water for families who use the filter. The design accounts for the reality that people use their filter when they need clean water, and they are not required to run water continuously through the filter in order for it to work.

Although a system that could clean water to an entirely pure state would include a multiple step water treatment process, evaluations undertaken by scientists have proven that sand filtration is an effective method of removing pathogens from contaminated water. The World Health Organization (WHO) describes a pathogen as a disease causing

bacteria, virus, protozoa or parasite that can live in water, and has reported that slow-sand filtration removes up to 99% of all pathogens from contaminated water (WHO, 1993,1997). In *Engineering in Emergencies*, it is stated that intermittent slow sand filtration produces potable water (Davis and Lambert, 2000).

Several independent studies have been undertaken in order to accurately evaluate the BSF. During the developmental stages of the filter, the following reports were written including *Slow Sand Filtration* by Dr. David Manz, and the University of Calgary Graduate Thesis entitled *Nicaragua Community Scale Household Filter Project* by Byron Buzunis. The BSF has also undergone a thorough collaborative evaluation by Environment Canada and Davnor Water Treatment Technologies. In the report, *Toxicant and Parasite Challenge of the Manz Intermittent Slow Sand Filter*, the BSF was reported to remove up to 97% of fecal coliform, 100% of giardia cysts and 99.98% of cryptosporidium oocysts (Palmateer, et al, 1999). The results of each of these reports conclude that the BSF is an effective water treatment solution.

Similarly, in the report entitled *The Nepal Water Project 2001*, MIT Graduate Students traveled to Nepal to evaluate rural water treatment technologies. They considered the Corning CerCor ceramic membrane filter, household solar disinfection (SODIS), and the BSF. In Nepal, the BSF was evaluated to have an average *E. coli* removal rate of 83% for functioning filters (Hurd et al, 2001). The other two water treatment systems were effective at microbial removal, but they were either too expensive or unreliable in all environments. This report concluded that the BSF is the most appropriate technology for microbial removal of contaminated drinking water in developing countries.

There are a few technical limitations to the function of the BSF. First, the BSF does not function in freezing temperatures, as the microbial activity of the schmutzdecke slows down and the filter does not work as documented. Also, if the turbidity of the source water is extremely high, the filter will become clogged with sediment or particles until water flow stops. However, as the flow of the filter decreases from the optimal design flow rate, the effectiveness of the filter is not compromised. The clogging of the filter indicates that maintenance on the filter media is required. The BSF will perform at maximum capabilities when the aforementioned conditions are applied and the user complies with proper maintenance procedure.

Under optimal operating conditions, the BSF is expected to remove 97% of fecal coliform, 100 % of giardia cysts, 99.98% cryptosporidium oocysts, 100 % of worms, 100% of parasites, and up to 90% of organic and inorganic toxicants from contaminated water. Also, the BSF improves physical characteristics of water such as taste, smell, and color. These expectations are documented through research and published in scientific literature.

#### **1.4 Construction of the BioSand Household Water Filter**

Samaritan's Purse conducts extensive training sessions for partners and CIDA interns regarding the construction and implementation of BSF projects in developing countries. The focus of the construction is based on the agreement between Samaritan's Purse and Dr. Manz. The agreement states that the original design specifications of the BSF will not be altered in any way. Thus, the BSF technology is the same for every project in the world through maintaining the specifications of the filter design.

During construction of the BSF, the materials from local suppliers are used to ensure the sustainability of the project. The BSF molds are built according to the original design plans. The concrete used in the BSF body is created with local sand, gravel, and cement. However, the filter media, sand, and gravel inside the filter are selected carefully according to grade and quality. It is essential that the sand and gravel be sourced from an uncontaminated location so that there will be no possibility of cross contaminating the water as it is being filtered.

Acceptable sand and gravel sources are from locations high above flood plains or from quarries. Filter sand sources that are not accepted include river sand or flood plain gravel, which may be exposed to biological contaminants. Once an uncontaminated source is located, then the proper grain size must be separated. The grain size of the sand influences the physical and chemical removal mechanisms of the filter, and the specific sizes are included in the design specifications.

In most countries, the greatest challenge is to locate clean filter sand and gravel to meet the design specifications, but this effort is needed to ensure the quality of the BSF filters. This ensures that there is no biological contamination of the filter media. However, if for some reason there is contamination present in the filter, the media will regenerate through daily use over a period of three months. This means, over a period of time, oxygen or food are denied to the biological contaminant in the filter media, and they can not grow. Under anaerobic conditions any biological contaminants present will not survive, other than the schmutzdecke that develops on the surface of the filter media.

#### **1.5 Development of Community Health and Wellness**

Community Health and Wellness is the ultimate goal of any Samaritan's Purse Water Project. Wellness in individuals is a combination of observed physical conditions and mental perception of health. The World Health Organization defines health as "a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity". It is a fact that there are many interacting factors affecting the health and wellness of individuals including food preparation, hygiene, contaminated food, and environment.

Individual health is determined by many factors. Analyzing the results of water quality testing is very effective at determining whether illness will result after consuming the

water. However, there are no known threshold values of illness caused by waterborne pathogens. Improving water quality and the exact positive affect this has on health is not known because it is impossible to isolate one of many factors affecting health. In the same way, it is not accurate to define the wellness of individuals solely by the number of bacteria present in a water sample.

There is no single water treatment process that can purify water to the purest state. In order to do so, there must be a multiple barrier system including disinfection. A multiple barrier system means that there are several components or a series of processes that consecutively treat the water. However, in water treatment it is widely understood that disinfection cannot be applied directly to raw water. The physical, chemical, and biological condition of raw water interferes with the effectiveness of any disinfection process. Organic matter and suspended particles significantly reduce the effectiveness of disinfection and may produce harmful by-products. There must be a preliminary treatment component that transforms the condition of the water so that disinfection such as chlorination can be used. Preliminary treatment methods include slow sand filtration.

The World Health Organization states that there must be no *E. coli* bacteria present in any 100 mL of sample of drinking water. In *Engineering for Emergencies* it is stated, “although it may be a desirable target to reach eventually, this guideline is not practical in many untreated, or partially treated, supplies in developing countries. An acceptable and attainable microbiological water quality will depend on individual circumstances” (Davis and Lambert, 2000). The use of *E. coli* as an indicator of the sanitary condition of water is accepted because *E. coli* exhibits the same removal by water treatment as that of most waterborne pathogens. Most strains of *E. coli* bacteria can not cause illness, however specific strains of *E. coli* have been proven to make individuals sick. The presence of *E. coli* in water does not indicate that illness will result from the *E. coli*, but from the other pathogens that exist in water.

According to the expectations of BSF performance Section 1.3, the BSF can remove over 97% of fecal coliform from water. In the same research it states that 100% of giardia, 99.89% of cryptosporidia, 100% of worms and 100% of parasites are removed from water by the BSF. This is the function of slow sand filtration, which is accepted and proven in scientific circles. The literature from previous research states that while the BSF removes 100% of specific pathogens from water, at the same time, a percentage of *E. coli* may remain in the water. In the USAID Field Operating Guide it states, “A large quantity of reasonably safe water is preferable to a smaller amount of very pure water.”

Through use of the BSF, there is a significant reduction of pathogens in water to sub-infectious levels in individuals. In order to further complete the purification of the filtered water, it is recommended to apply disinfection such as chlorination. Samaritan's Purse has always promoted the use of disinfection after filtration. However in many communities this method is not applied for various reasons including a lack of accessibility or affordability in most situations. The BSF has improved the health of individuals in developing communities, to the point where they do not see the need for any post filtration treatment.

The BSF impacts the wellness of communities by positively affecting the environment and freeing time for women in developing countries. Economies and civil society are highly influenced by women in developing countries. They are active in urban and rural areas in skilled and semi-skilled work, as well as operating small businesses and markets. Despite these high rates of economic activity, women continue to face substantial hardship and discrimination within the labor market. Poor access to health services, education, and clean water further exacerbates the problem. The BSF filters water, significantly reducing the need of fuel wood, or coal fires, which are necessary for boiling water. The time spent by children and women foraging for wood and tending fires for boiling water can then be used for other tasks. This corresponds to a reduction in resource consumption, an increase in time to be spent on other activities, and an improvement in health of the households.

There are many disease bearing vectors which impact the health of communities in developing countries. The health of individuals is impacted positively if diseases are reduced in their water, which is only one of the many ways they can contract illness. If a person lives under the perpetual threat of diarrhea, their ability to work and attend school are compromised. Potable drinking water is one of the aspects which influence a healthy living environment. Wellness is a complete picture of individual health. Improving water quality is one aspect of a healthy environment, positively impacting community wellness.

## 2.0 OBJECTIVES OF THE EVALUATION

As Samaritan's Purse has been implementing BSF projects for over four years now, the organization thought it prudent to conduct an extensive Evaluation. In June 2001, an internal Samaritan's Purse document was circulated identifying the parameters for a BSF Evaluation. The following five objectives were identified to assist SP in the evaluation process and, in October 2001, an Evaluation was initiated in Mozambique, Kenya, Cambodia, Vietnam, Honduras and Nicaragua.

Objective	Activity
<b>1. Sustainability</b>	A Comprehensive Questionnaire on the appropriateness and user's compliance with the BSF.
<b>2. Effectiveness</b>	A Performance Evaluation on the source, pause, and filter's outflow, as well as an evaluation of the BSFs impact on household wellness.
<b>3. Lessons Learned</b>	Learning from BSF recipients to enhance future project effectiveness.
<b>4. Recommendations</b>	A comprehensive picture of the pros, cons, and recommendations for increasing future project effectiveness.
<b>5. Christian Ministry</b>	Perceived to be more accurately evaluated by the local SP Partner.

The comprehensive BSF Questionnaire contained questions pertaining to project sustainability and user compliance, in order to aid in the interpretation of the results and to assist the evaluators with putting the results into context. The Performance Evaluation consisted of water quality testing according to World Health Organization Standards, in order to check that the BSF technology is working and that the BSF functions according to specifications. Effectiveness of the BSF is determined from the results of the Performance Evaluation, combined with the wellness of beneficiaries as reported in the BSF Questionnaire. Finally, the BSF Evaluation was designed and structured in such a way that the evaluators were able to listen and learn from the beneficiaries as to how future projects and compliance rates could be improved.

These three components together, interpreted properly, generate a picture of the BSF's effectiveness, the importance of proper user compliance, the impact of the BSF on community health, and provide direction and **recommendations** for enhancing future project effectiveness. Likewise, in keeping with the mission of Samaritan's Purse, it was decided to evaluate the **Christian ministry** associated with the projects, but it is obvious that Samaritan's Purse partners would more accurately carry this out independently.

During the development of the Evaluation, it was determined that there was no precedence of Evaluation methodologies for similar projects and that no baseline data existed. To address this, Samaritan's Purse adopted a final objective in order to rectify this problem for future Evaluation processes. The final objective of **creating an evaluation system**, including procedures and baseline data, will be extremely useful in analyzing future projects of a similar nature.

### 3.0 METHODOLOGY

The methodology presents the method used for the survey and the water quality analysis.

#### 3.1 Survey Development

The BioSand Household Water Filter Evaluation Questionnaire was developed to address three aspects of the Evaluation criteria. The comprehensive Questionnaire was developed to interpret the **sustainability** and **effectiveness** of the BSF technology, the user's compliance with the BSF, and to **learn from the BSF recipients** in order to enhance future project effectiveness. To reduce bias, survey questions focus on observations rather than beneficiary response.

The creation of the survey was the result of a collaborative effort between Samaritan's Purse, Dr. Hollaar, and Accord Research. Samaritan's Purse determined that there were four sections that would be represented in the survey. These areas include User Profile, Compliance, Wellness, and Household Health. The total survey questions were distributed between these four survey sections (Appendix A). Upon completion of the draft copy of the questionnaire, Dr. Hollaar was consulted to refine the Health and Wellness questions. Accord Research was consulted throughout the formatting of the survey to ensure that statistical analysis could effectively be applied to the survey responses.

The Questionnaire contained questions that included words such as clean, dirty, durable, good condition, deep and shallow wells. These descriptive words were defined during the development of the Evaluation and during the preliminary training of the Evaluation Team. The word "clean" was defined to describe a surface that was not being covered with any foreign substances other than those part of the original construction. "Dirty" was defined as the presence of foreign organisms or particles on the surface of the object not part of original construction. The words "durable materials" were defined to reflect a solid material, which protected inhabitants from factors, such as weather. "Good condition" meant that the object was still fully functional for the purpose it was designed. Shallow wells included wells that were hand dug, not capped and not extending past three meters into the ground. Deep wells were defined as wells that were drilled, driven tube, auger bored, jetted, or hand dug that extended past three meters into the ground. The meaning of these words were defined in the context of the survey questions.

The Evaluation team eliminated survey bias by using standard procedures. To avoid cultural misunderstandings, the local staff was integrally involved in the survey process. As well, the survey questions were designed to reduce possible subjective responses from beneficiaries, and most information gathered was from observations. Finally, all BSFs surveyed were installed for at least three months before the Evaluation commenced in order that the beneficiaries would have had sufficient time to develop a pattern of usage with their BSF.

### 3.2 Water Quality Analysis Approach

There are microbial, physical, and chemical aspects of water that can be tested. However, the indicators of water quality that are most important are those that will cause immediate illness (WHO, 1993). Therefore, knowing the microbial quality of drinking water is of the utmost importance. An indicator is used to determine the possibility that disease-causing pathogens are contained in the water. There are several indicators of microbial water quality that can be used and these include **total coliform**, **fecal coliform**, and *Escherichia coli*.

**Total coliform** include all of the bacteria that are found in water. Testing conducted for the total coliform group indicates the overall biological quality of a water supply. The tests that indicate the presence of total coliform in water are easy to apply and are used worldwide (WHO, 1993). The Guidelines for Drinking Water Quality state that “total coliform bacteria are not acceptable indicators of sanitary quality of rural water supplies, particularly in tropical areas where many bacteria of no sanitary significance occur in almost all untreated supplies” (WHO, 1993).

**Fecal coliform** are a type of total coliform or bacteria that originate from the intestines of all animals and humans. In one gram of feces there can be 10 billion fecal coliform bacteria (WHO, 1993). Water becomes contaminated with fecal coliform after it is in contact with feces. After entering water, fecal coliform have a short life span because they are suited to live in the digestive tract of humans or animals. The survival of fecal coliform outside of the digestive tract is dependant upon environmental conditions. The presence of fecal coliform in a water sample indicates the possible presence of numerous waterborne diseases such as cholera, dysentery, and typhoid.

*Escherichia coli* or *E. coli* are specific types of fecal coliform, which are used as indicators of the sanitary conditions of the water in question. There are many different strains of *E. coli* and most strains are harmless to human health (WHO, 1996). However, there are a few strains of the bacteria such as *E. coli* 0157:H7 which can cause illness (EPA, 2001). Specific testing must be conducted to differentiate between strains of *E. coli*.

The amount of *E. coli* that must be ingested to make a human ill is very high, but there is no known ingestion level that will cause illness. *E. coli* is removed by the same water treatment as most waterborne pathogens (Tchobanoglous and Schroeder, 1987). Therefore in water quality testing, the presence of *E. coli* is also an indication of a contamination by pathogens. There is no defined level of contamination by these pathogens which causes disease in humans (WHO, 1993). Waterborne pathogens can be bacteria, viruses, protozoa, and parasites, which cause illness such as typhoid, cholera, and dysentery in humans.

It is extremely expensive and difficult to test in the field for all of the bacteria, viruses, protozoa, and parasites that are present in water. Each of these tests would require expensive high-tech equipment which is difficult to use under field conditions. Thus, it

was decided that the Evaluation Team test and base the analysis on the quantification of the indicator organism, *E. coli*, in the sampled water. The Guidelines for Drinking Water Quality states that “total coliform bacteria are not acceptable indicators of sanitary quality of rural water supplies, particularly in tropical areas where many bacteria of no sanitary significance occur in almost all untreated supplies” (WHO, 1993).

The World Health Organization Guidelines for Drinking Water Quality state that drinking water must not contain any *E. coli* (WHO, 1993). However, within the Guidelines for Drinking Water Quality, the WHO comments, with respect to isolated communities in developing countries, that “the guideline values recommended here should be regarded as a goal for the future” (WHO, 1997), and recommends that the respective nation should set “medium-term guidelines” (WHO, 1997) until this level of water quality can be achieved. Many developing countries do not have interim guidelines and consequently, the results of all water quality testing in developing countries must be evaluated relative to the WHO guidelines.

### **3.2.1 Procedures for Water Quality Testing**

The goal of a sampling procedure is to ensure consistency across the sampling locations. All of the procedures have been taken collectively from ISO 9308-1:1990, Guidelines for Drinking Water Quality and Standard Methods for the Examination of Water and Wastewater. The water quality indicator test that was applied in this Evaluation was for the detection of *E. coli* in sampled water. *E. coli* can be detected using a variety of different methods outlined by the WHO for the evaluation of water quality. The two most widely accepted methods are the membrane filter method or the multiple-fermentation tube method. For the purpose of this study, the Evaluation Team employed the membrane filter method due to the method’s high precision in the field according to the WHO - Guidelines for Drinking Water Quality, Volume 3.

As the BioSand Household Water Filter Evaluation was conducted under field conditions within six developing countries, the membrane filter method was the most accurate for these operating conditions. The membrane filter method using MFC Broth is able to isolate the *E. coli* bacteria present in 100 mL of sampled water. The results were recorded according to the international standard of water contamination per 100 mL of water sampled. The membrane filter method can be briefly described as collecting the bacteria from a 100 mL sample, culturing the bacteria, and then counting the number of bacteria in the water sample.

The equipment that was used in the membrane filter method was S&S Biopath MFC Broth, S&S Biopath 100 mL microbiological monitors, a portable single chamber Millipore Incubator, and ancillary glassware. Each of the field laboratories was equipped with the same analytical equipment and used the same analytical process. In the analysis, dilutions were used according to international water quality procedures and predicted water contamination. Using dilutions for highly contaminated water increases the accuracy of the water quality results. Due to the high contamination of most source

water, dilutions were applied at a 1:10 or a 1:100 ratio. A dilution does not change the bacterial content of the water; it decreases the amount of bacteria analyzed, increasing the accuracy of the reported results.

It was essential to use dilutions in the water quality analysis due to the high concentrations of *E. coli* in many source samples. A dilution does not alter the amount of *E. coli* present in the water sample; it only reduces the number of colonies isolated in the analysis. If dilutions are not applied to highly contaminated samples, then there will be too many bacteria isolated making it difficult to count the number of colonies in the water. A calculation is required to report the colonies present in 100 mL of water sampled from a dilution.

Following proper waste disposal procedures for water quality testing, the possible transmission of sickness was reduced. The colonized filter paper used in the analysis has bacteria which are harmful to human health. Also, the testing equipment that had come into contact with the samples was contaminated and required disinfecting. The testing equipment and filter paper, which are disposable, were placed in a bleach solution to kill any harmful bacteria. After deactivation, these items were disposed of through the local waste collection program. The multi-use equipment was also disassembled and disinfected according to standard operating procedures.

### ***3.2.2 Procedure for Arriving In Country or Base Location***

- Collaborate with Country Director to create timeline, access to utilities, and transportation.
- Check all supplies necessary for setting up laboratory and sampling.
- Locate place to store supplies and work area to set up field laboratory.
- Acquire stove, pots, and fuel necessary to boil water and equipment.
- Assemble field laboratory.
- Sterilize equipment and prepare dilution water by boiling water for 20 minutes, then boiling equipment for one minute.
- Equip local partner in procedures of water sampling and filling out the survey.
- Determine villages to sample and beneficiary lists to survey.
- Label bottles and Petrie dishes for next day sampling.
- Source-out ice and put in sampling cooler and storage cooler.

### ***3.2.3 Procedure for Field Lab Set-up***

- Locate room with light, counter top, electrical outlet, and storage shelves or cupboard in an area where dust is minimal and animals and small children do not have access, Figure 2.
- Locate water source and find place to dispose of water used in testing.
- Determine where waste can be disposed of.

- Designate areas of field lab for boiling water, disinfecting equipment, storing disinfected equipment, and work area.
- Disinfect lab area and equipment with bleach.
- Check that there is sufficient lighting for work area.
- Organize testing equipment in dust free location.
- Place incubator out of the way and turn on to test that the temperature can be maintained.
- Post signage to identify area as a field lab and that authorized personnel only should be permitted entrance.
- Label equipment such as boiled water containers.
- Record data.



**Figure 2: Field laboratory equipment.**

### **3.2.4 Procedure for Disinfecting Equipment**

- Locate pot, stove, fuel, water and set up drying rack.
- Boil water at a rolling boil for 20 minutes.
- Disassemble multi-use equipment.

- When disinfecting equipment make certain the water has boiled for 20 minutes previously, and fully submerge the multi-use equipment for one minute to kill all vegetative cells.
- Disinfect storage containers.
- Use tongs to transfer lab equipment from boiling water to drying rack.
- Let equipment air dry in dust free area.
- Put equipment in airtight disinfected storage containers.
- Use fresh water every consecutive time that equipment is disinfected.
- Cover drying racks when not in use to reduce dust collection on surfaces.

### ***3.2.5 Procedure for Preparing Dilution Water***

- Locate pot, stove, fuel, and water.
- Boil water at a rolling boil for 20 minutes.
- Remove from heat, let the water cool to room temperature.
- If chlorine is suspected, leave standing overnight.
- Add water to disinfected containers, and seal containers shut.
- Label containers as “clean water” containers.

### ***3.2.6 Procedure for Recording Sample Testing***

The following information must be recorded for each sample on the Water Quality Testing Sheet and/or the Water Quality Testing Results Spreadsheet. These data sheets are included in Appendix B. The results from the analysis must be verified through the signature of a witness.

- Country - Honduras, Nicaragua, Mozambique, Kenya, Cambodia, Vietnam
- Village/Town – Determined upon arrival in country
- # of Filter – Determined at time of sample
- Sample Type – Inlet, Outlet, Pause
- # of Sample in Country
- Date of Sample
- Date of Analysis
- Dilution Calculation

### ***3.2.7 Procedure for Sample Collection***

- Use a 250 mL disinfected sample bottle.
- Fully submerge the sample bottle under the surface of the water.
- Do not disturb biofilm or suspend particles in water to be tested.
- Fill bottle to 2.5 cm from the top of the neck.
- Ensure that there is at least 100 mL of water collected per sample.
- Optimal sample storage temperature is 4 to 10 degrees in a lighttight, insulated container.

### **3.2.8 Procedure for Arriving in Town/Village/Household**

- Using standard operating procedures from Section 4.1 and Section 4.2, generate household survey list.
- Checklist equipment required to sample.
- Locate the home with a filter and approach owner.
- Introduce and outline the purpose of visit and what you would like to do.
- Begin going through the Questionnaire, and at the filter make general observations at the filter.
- Take the first water sample of the pause water.
- Identify the water source location and take a grab sample.
- Add 20L of dirty water to the filter.
- While waiting for the water level to reach 15 cm from the top of the filter reservoir, fill out the survey.
- At a water depth of 15 cm from the top of the filter reservoir, measure the flow rate (ml/minute).
- Record flow rate (ml/minute).
- When water depth in reservoir is 5 cm above diffuser plate ledge, take the third water sample from the spout.
- Ensure that all sample bottles are firmly closed after each home and stored in the cooler.
- Finish the Questionnaire.
- Record all information on the Environmental Testing Sheet.
- Show appreciation to the family for their time.
- Progress to the next home.

### **3.2.9 Procedure for Fecal Coliform Test**

The following procedures have been taken from ISO 9308-1:1990, Guidelines for Drinking Water Quality (WHO, 1997), and Standard Methods for the Examination of Water and Wastewater (APHA, 1976).

- Ensure Field laboratory area is clean.
- Wear gloves.
- Check graduated cylinders, filter apparatus, syringes.
- Ensure Filter apparatus is assembled and check that it is working.
- Have at least 150 mL of boiled water for preparation of each sample on hand.
- Bring pot of water to a rolling boil for 20 minutes to disinfect lab equipment.
- Label clean water syringe or wash bottle.
- Remove samples from cooler that will be analyzed.
- Analyze in order of outlet, pause, and then water source. Change gloves between each filter analysis.
- Based on the source type or water sample condition, determine whether a dilution is required.

### **No dilution**

- Agitate sample to be analyzed.
- Put monitor on filtering flask.
- Add 20 mL of pre-boiled water to monitor to wet the filter paper.
- Remove 10 mL of contaminated water with syringe and add directly to monitor.
- Vacuum pump the prepared sample through the filter paper.
- Rinse the monitor walls with three syringes of clean water or approximately 30 mL of water from the wash bottles.
- Vacuum pump the wash water through the filter paper.
- Remove monitor from filtering flask.
- Remove funnel from Petrie dish.
- Add MF-C indicator to filter paper surface, without touching the filter paper.
- Place Petrie dish on flask apparatus.
- Vacuum pump the indicator through the filter paper, make certain the water has been removed from the filter paper surface.
- Remove the Petrie dish from the flask apparatus.
- Place the plug in the bottom of the Petrie dish and add the Petrie dish lid.
- Check that the Petrie dish label is complete.
- Put dish in incubator and check that the incubator temperature is at 44.5 degrees.
- Leave the Petrie dish for 24 hours in incubator.
- Keep water sample until colonies are counted.
- Document in record.
- After 24 hours remove Petrie dish from incubator, remove lid, count colonies.
- Record results in record spreadsheet.

### **For a 1:10 dilution**

- To begin a 1:10 dilution, fill clean graduated cylinder with 90 mL of pre-boiled water, measuring the meniscus.
- Agitate sample to be analyzed.
- Remove 10 mL of contaminated water with syringe and add directly to graduated cylinder. Dispose of syringe.
- Agitate graduated cylinder.
- Put monitor on filtering flask.
- Add 20 mL of disinfected water to monitor to wet the filter paper.
- Using another syringe add 10 mL of diluted sample from graduated cylinder to monitor. Dispose of syringe.
- Vacuum pump the prepared sample through the filter paper.
- Rinse the monitor walls with 3 syringes of clean water or approximately 30 mL of water from the wash bottles.
- Vacuum pump the wash water through the filter paper.
- Remove monitor from filtering flask.

- Remove funnel from Petrie dish.
- Add MF-C indicator to filter paper surface, do not touch the filter paper.
- Place Petrie dish on flask apparatus.
- Vacuum pump the indicator through the filter paper, make certain the water has been removed from the filter paper surface.
- Remove the Petrie dish from the flask apparatus.
- Place the plug in the bottom of the Petrie dish and add the Petrie dish lid.
- Check that the Petrie dish label is complete.
- Put dish in incubator; check that the incubator temperature is at 44.5 degrees.
- Leave the Petrie dish for 24 hours in incubator.
- Keep water sample until colonies are counted.
- Document in record.
- After 24 hours remove Petrie dish from incubator, remove lid, count colonies.
- Record results in record

#### **For a 1:100 dilution**

- To being a 1:100 dilution, fill two clean graduated cylinders with 90 mL each of pre-boiled water, measuring the meniscus.
- Put monitor on filtering flask.
- Add 20 mL of disinfected water to monitor to wet the filter paper.
- Agitate sample to be analyzed.
- Remove 10 mL of contaminated water with syringe and add directly to 1<sup>st</sup> graduated cylinder. Dispose of syringe.
- Agitate graduated cylinder.
- Remove 10 mL of diluted sample from 1<sup>st</sup> graduated cylinder and add directly to 2<sup>nd</sup> graduated cylinder. Dispose of syringe.
- Agitate graduated cylinder.
- Using another syringe add 10 mL of diluted sample from 2<sup>nd</sup> graduated cylinder to monitor. Dispose of syringe.
- Vacuum pump the prepared sample through the filter paper.
- Rinse the monitor walls with three syringes of clean water or approximately 30 mL of water from the wash bottles.
- Vacuum pump the wash water through the filter paper.
- Remove monitor from filtering flask.
- Remove funnel from Petrie dish.
- Add MF-C indicator to filter paper surface, without touching the filter paper.
- Place Petrie dish on flask apparatus.
- Vacuum pump the indicator through the filter paper, making certain the water has been removed from the filter paper surface.
- Remove the Petrie dish from the flask apparatus.
- Place the plug in the bottom of the Petrie dish and add the Petrie dish lid.
- Check that the Petrie dish label is complete.
- Put dish in incubator and check that the incubator temperature is at 44.5 degrees.

- Leave the Petrie dish for 24 hours in incubator.
- Keep water sample until colonies are counted
- Document in record.
- After 24 hours remove Petrie dish from incubator, remove lid, count colonies.
- Record results in record.

### 3.2.10 Procedure for Counting Colonies

- Remove Petrie dish from incubator.
- Place on clean surface under bright light, see Figure 3.
- Remove lid from Petrie dish.
- Using magnifying glass, count colonies on the grid starting upper left edge moving left to right, top to bottom.
- Count only blue colonies.
- Record number of colonies on record sheet.
- If applicable, complete dilution calculation.
- Count each Petrie dish at least three times and average colony count.
- Disinfect and dispose of Petrie dish and filter paper in bleach bucket.
- Clean out sample bottles from corresponding water sample.



**Figure 3: An overhead view of colony forming units in the Source (1450 cfu/100mL), the Pause (30 cfu/100mL) and the Outflow (0 c fu/100mL)**

### 3.3 Water Quality Testing Data Analysis

There are two components that must be considered to evaluate the **effectiveness** objective. These two components are a Performance Evaluation, combined with wellness responses from the Questionnaire. The Performance Evaluation of the source water, pause water, and outflow from the BSF was essential in order to accurately calculate the fecal coliform removal rates for the various countries. Thus, the ACCORD Research Group was contracted to accurately and independently analyze the raw data using the Statistical Package for the Social Sciences (SPSS) Database Program. Using SPSS, fecal coliform removal rates were calculated for the overall BSF program and for each individual country. With this information, it was possible to plot the data points and calculate the average fecal coliform removal rates using a linear regression with a 95.00% mean prediction interval. It should be noted that in producing the plot, all points with greater than 10,000 cfu/100mL as a source value were removed as outliers. Both the responses from the Water Quality Testing, and the Questionnaire were analyzed in SPSS.

## **4.0 IMPLEMENTATION OF THE PERFORMANCE EVALUATION**

As mentioned previously, the Performance Evaluation was implemented across three geographic regions including Central America, Africa and Southeast Asia. It was imperative that the Evaluation Team set up a method of community and household selection that was as random and unbiased as possible. This selection took place on three levels; country, project, and household. The Evaluation was limited in individual countries by the number and accessibility of project sites.

### **4.1 Community Selection**

The following options were used in order to randomly select communities from the country being surveyed. In order to sample 100 filters from each country based on a 10% *Random Household Selection* criteria, there had to be 1000 filters available.

#### ***4.1.1 Community Selection Option 1***

In countries where all the recipient communities had been listed according to their name and number of filters, the Evaluation Team randomly selected the communities by drawing from a hat or lottery. Communities chosen for possible surveying had at least 10 BSFs. Once the Evaluation Team had selected enough communities to obtain a total of 1000 households, the team was then able to use the *Random Household Selection* criteria. This option was applied in Nicaragua, Honduras, Cambodia, and Vietnam.

#### ***4.1.2 Community Selection Option 2***

In countries where there are less than 10 communities with BSF projects, the surveyor was limited to surveying those communities, but employed the *Random Household Selection* criteria in order to make the sample as random and unbiased as possible. This option was applied in Kenya and Mozambique.

#### ***4.1.3 Difficulties in Community Selection***

Working in developing communities brings many challenging realities including a lack of infrastructure, extreme climate, varied geography and varied political structures, which had to be overcome to implement the Evaluation. In some cases, under extenuating circumstances such as tropical storms, these factors limited the Evaluation community selection criteria, and making it impossible to survey certain areas.

### **4.2 Household Selection**

In each country, 100 households were surveyed based on the following procedures. A *Random Household Selection Criteria* of surveying 10% of filters from each community

was included in the Survey. This means 100 filters could be surveyed from a filter pool of 1000 filters.

#### ***4.2.1 Household Selection Option 1***

In certain projects the BSF recipients had been listed according to their name, location, and date of installation. The Evaluation Team was able to select random numbers and go through this list selecting the households that correspond with those numbers i.e. 1,3,5,9,14. This option was applied in Tenwek, Canicado, and all the villages in Vietnam.

#### ***4.2.2 Household Selection Option 2***

In the projects where all the BSF recipient households were arranged in a grid-like pattern, the Evaluation Team chose a random number i.e. three and then walked from house to house surveying every third house along the grid. This option was applied in Santa Rita and Valle Menier.

#### ***4.2.3 Household Selection Option 3***

This option pertains to project locations that did not meet either of these first two requirements. In this case, the Evaluation Team chose a random number i.e. three and then asked the local Project Manager to guide them to all the households that had received a BSF within the designated area, but only conducted a household survey on every third house that they were guided to. This option was applied in Ngangani, all the villages in Cambodia, and all the villages in Nicaragua except Valle Menier.

#### ***4.2.4 Difficulties Encountered***

As there could be a possibility for the local Project Manager to want to show the highlights of the project, it was imperative that the Evaluation Team stressed the fact that the survey was an evaluation of the BSF, and NOT an evaluation of the local Project Manager. It is believed that this helped to alleviate some of the bias. It frequently occurred that members of the randomly chosen houses were not present during the survey teams visit. When this was the case, the Evaluation Team selected either the next house on the list, the next house in the grid, or the next house that the local guide took them to.

There could be a tendency for the beneficiary to try and “embellish” the survey responses, either to appease the Evaluator, or to make himself/herself appear in a better light. For this reason, the Evaluation Team tried to be as unobtrusive as possible. In addition, the survey was designed in such a way that most of the survey responses could be obtained through observation, thus leading to a greater degree of accuracy.

### **4.3 Sampling Approaches for the Various Countries**

In order to conduct an Evaluation that was as accurate and unbiased as possible, the Evaluation Team designed and documented a random sampling method that would assist with meeting these parameters. Geographies, climates, and infrastructures varied drastically from country to country, the specific sampling approaches are documented below.

#### **4.3.1 Kenya**

The climate in Kenya during the months of October through November is extremely dry leading up to the rainy season. The roads, although dusty, are quite good and make access to the houses possible. In Kenya, over 1700 BioSand Water Filters have been built and installed. The projects in Kenya have been ongoing for the past 4 years with a focus on small projects run by local partners. In 2001, from October 19th to November 3<sup>rd</sup>, an extensive water quality survey was undertaken in the communities of Ngangani and Tenwek. One hundred filters, 50 in each community were visited and analyzed following the outlined procedures.

The communities of Ngangani and Tenwek had the largest projects and had been implemented over the longest period of time. It was decided that these two communities would be surveyed. The Ngangani project is a Samaritan's Purse project directed by CIDA interns, and the Tenwek project was implemented by the Tenwek Community Development Team. The Evaluation Team surveyed every third house on the master list and, in the event that the beneficiary was not at home, the next house on the list was surveyed.

#### **4.3.2 Mozambique**

The climate in Mozambique during the month of November is quite humid and rainy. Traveling by road becomes quite difficult, and the vast majority of the surveys were carried out on foot. At the time of the survey, 292 BioSand Water Filters had been built and installed, all in the community of Canicado. This project was first started in February 2002 in response to the Limpopo Floods. In November 2001, during the period of November 3-14, an extensive water quality survey was undertaken in the community of Canicado, Figure 4. One hundred filters were visited and analyzed following the outlined procedures.

The community of Canicado has only had filters for the past eight months. Similar to Kenya, as all the filter recipients had been recorded on a master list, it was possible to obtain a random sample by surveying every third house on the list. Again, in the event that the beneficiary was not at home, the next house on the list was surveyed.



**Figure 4: A typical survey being carried out by a local SP Evaluation Team member in Mozambique.**

### ***4.3.3 Cambodia***

In Cambodia, there has been over 2,200 BioSand Water Filters built and installed since 1999. Currently, the Canadian International Development Agency (CIDA) is sponsoring a three-year project in conjunction with Samaritan's Purse Canada and the HAGAR Project, to build a projected 7,000 filters. CIDA is funding two projects in Cambodia, one in Kratie province, and the other in Kampong Thom province. Thus, it was necessary for the Evaluation Team to set-up and utilize two field laboratories.

During the period from November 4<sup>th</sup>-16<sup>th</sup>, surveying was undertaken in Cambodia and a total of 93 surveys were completed. The village selection in both Kampong Thom and Kratie was determined from the available village lists. This was based on the security within the area, geographic realities, and the criterion that the village have at least 10 BSFs from which to sample a 10% coverage. Thus, a total of 18 villages were surveyed in Kampong Thom province and a total of six villages were surveyed in Kratie Province.

In order to randomly select filters from a village where there were no accurate maps available, the Evaluation Team started at the edge of the village and then went house to house evaluating every fifth filter. Depending on the layout of the village, the team would progress along each path until the village had been completely covered. The

samples were then stored in a large cooler until they could be analyzed at the field laboratory in Kampong Thom or Kratie.

#### **4.3.4 Vietnam**

In the country of Vietnam, over 4,200 BioSand Water Filters have been built and installed to date. The project in Vietnam has been ongoing for the past three years with a focus on production in Hatay Province. From October 19<sup>th</sup> to November 3<sup>rd</sup> 2001, extensive survey and water quality tests were undertaken in four villages. A total of 92 filters were visited and analyzed following the outlined procedures.

The reality of political and geographical restrictions made it impossible to survey several villages. This resulted in a shortlist of the following four villages from Hatay Province: Thuong Mo, Phu Kim, Kim Quan, and Dong Thap. Due to the pre-established survey size, all four villages were surveyed. As each village is sub-divided into hamlets, 10% of the filters were randomly chosen from each hamlet in order to ensure a proper and unbiased representation. As in all locations, the filters to be surveyed were chosen using a list of randomly generated numbers taken from the Internet. During the initial meeting with the Vice-chairman at each village, the list of filter owners to be surveyed were counted off out from the record books using the randomly generated number list. The actual survey list of filter owners was kept confidential until the time of the survey.

#### **4.3.5 Honduras**

BSF filters have been built and installed in Honduras since 1999 in response to Hurricane Mitch. The filters in Honduras were surveyed over the last two weeks of October, and data from 100 filters was collected from 10 randomly selected villages within a two-hour drive of San Pedro Sula. This was mainly due to the poor weather resulting from a tropical storm. The roads around La Ceiba were in poor condition after a tropical storm swept through during the first week of surveying. The *Random Household Selection*, determined that the number three or the number four was used to selection which household would be surveyed in the community. Again, following the household selection procedure when a home was empty or did not have a filter, the next home was surveyed. The samples were collected and transported to the field laboratory in San Pedro Sula, according to standard operating procedures.

#### **4.3.6 Nicaragua**

Nicaragua has been a BSF project location since 1997, and over 3,000 filters have been installed to date. The Nicaraguan Evaluation was undertaken in the first two weeks of October 2001 and data from 100 filters was collected. In Nicaragua, two types of filters have been installed. These include the plastic and cement cast filter bodies. The filter flow rates between these two types are not comparable and as a result households with the plastic filters were not surveyed. In most instances villages have either one type or

the other, this meaning that only villages with cement filters were considered. Unfortunately this limited the number of villages that could be surveyed to only 9.

Households were randomly selected using the number three or four, but in cases where the house was empty or did not have a filter, the next home was surveyed. The samples were then collected and transported to the field laboratory in Managua, where they were analyzed according to standard operating procedures.

## 5.0 RESULTS AND DESCRIPTION

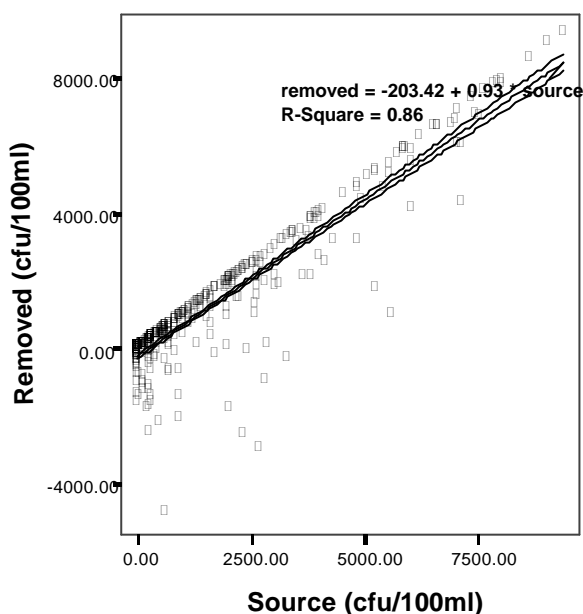
From October to December 2001, Samaritan's Purse Evaluation Teams set out to six different countries and surveyed 585 households which had received a BSF at least three months prior to the Evaluation. A number of qualitative and quantitative questions complemented listening to local health officials and administrators. The following results have been calculated and cross-tabulated from this data in conjunction with the ACCORD Research Group at the University of Calgary, Canada.

Included in Appendix C are the cross-tabulated survey responses and in Appendix D are the water quality testing results for each country. Samaritan's Purse acknowledges that every single survey response from Appendix C is not discussed in this document.

### 5.1 Fecal Coliform Removal Rates

The interactive graph in Figure 5 shows the predictive value for fecal coliform removal of 93% for all countries. Fecal coliform removal rates were calculated through analyzing and determining the cfu/100mL in the source water, pause water, and the effluent. It is important to note that this is a predictive value, and not simply a mean calculation. A mean would be an inaccurate representation of removal rates due to the variety of data collected. For example, it is impossible to determine removal efficiencies for the BSF when there was no *E. coli* in the source or outlet water. A few filters recorded negative removal rates, and calculating a straight mean would place greater emphasis on this, which is not representative of the data set.

**Figure 5: Predictive Fecal Coliform Removal**



*Note: Chart plotted with SPSS – ACCORD Research*

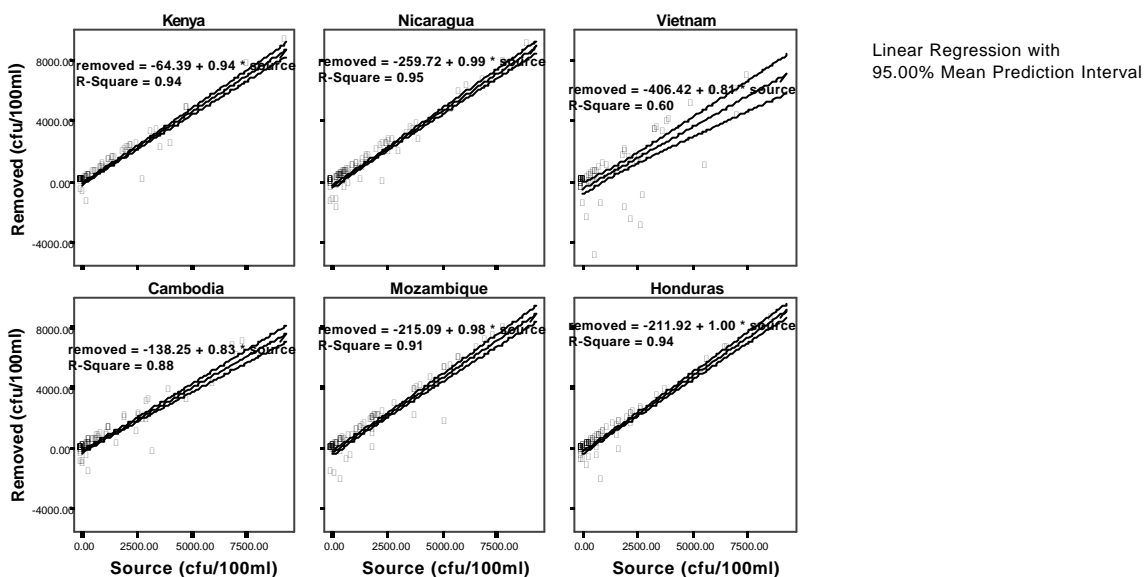
In order to fully satisfy the Performance Evaluation of the BSF, the Evaluation Team decided that it was imperative to determine the fecal coliform removal rates for the individual countries. Thus ACCORD Research determined that in order to most accurately decipher between the removal rates for the different countries, it would employ the equation:

$$\text{Amount Removed} = (\text{Source Value} \times 0.93\%) - 203.42$$

where -203.42 is the point where the linear regression crosses the y-axis. Thus, for the individual countries the respective removal rates can be seen in Table 1:

<b>Table 1: Average Fecal Coliform Removal Rates for the Individual Countries</b>	
Honduras	100 %
Nicaragua	99 %
Mozambique	98 %
Kenya	94 %
Cambodia	83 %
Vietnam	81 %
World Average (sample size = 577)	93%

**Figure 6: Predictive Fecal Coliform Removal by Country**



*Note: Charts plotted with SPSS – ACCORD Research*

In order to support these numbers, the interactive graphs for each of the six countries are illustrated above, plotting the fecal coliform cfu/100mL removed on the y-axis versus the fecal coliform cfu/100mL present in the source water on the x-axis. Figure 6 employs a linear regression with a 95.00% mean prediction interval on each of the graphs in order to determine the predictive value, or fecal coliform removal rate, in each of the countries.

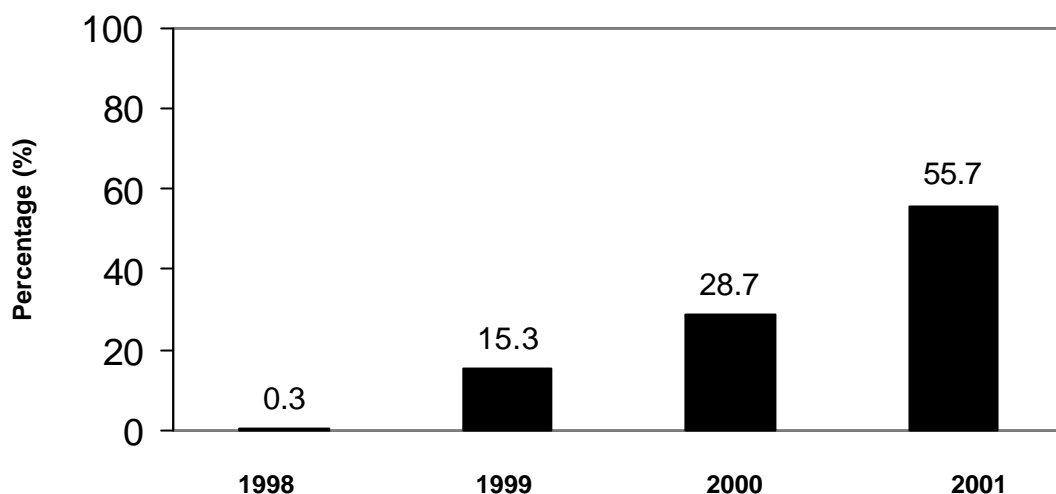
In addition to calculating and plotting the average fecal coliform removal rates, ACCORD Research was instrumental in calculating the mean outflow rates for the BSF within the various countries. Although it must be noted that outflow rate is NOT an indicator of removal rate efficiency, it is an indicator of BSF maintenance and/or the turbidity of the source water. As can be seen from Table 2 below, the mean outflow rate for the entire survey is 567 mL/min with Mozambique having the highest flow rate of 703 mL/min and Vietnam the lowest flow rates of 300 mL/minute. The design flow rate for the BSF is between 600 mL and 1000 mL/ minute.

Mozambique	703
Honduras	672
Cambodia	622
Nicaragua	570
Kenya	522
Vietnam	300
World Average (sample size = 577)	567

## 5.2 Trends and Indicators of Living Conditions

The BSF survey was designed in categories to identify trends affecting the BSF program and to address areas of improvement. From Figure 7, it can be seen that BSF installation has increased rapidly over the past few years with over half of the surveyed BSFs installed in the year 2001. This growth is a possible indication of an increase in the transfer of technology into communities. With an increase of technology transfer, it is important to evaluate the impact on beneficiaries' lifestyles.

**Figure 7: Year of BioSand Filter Installation**

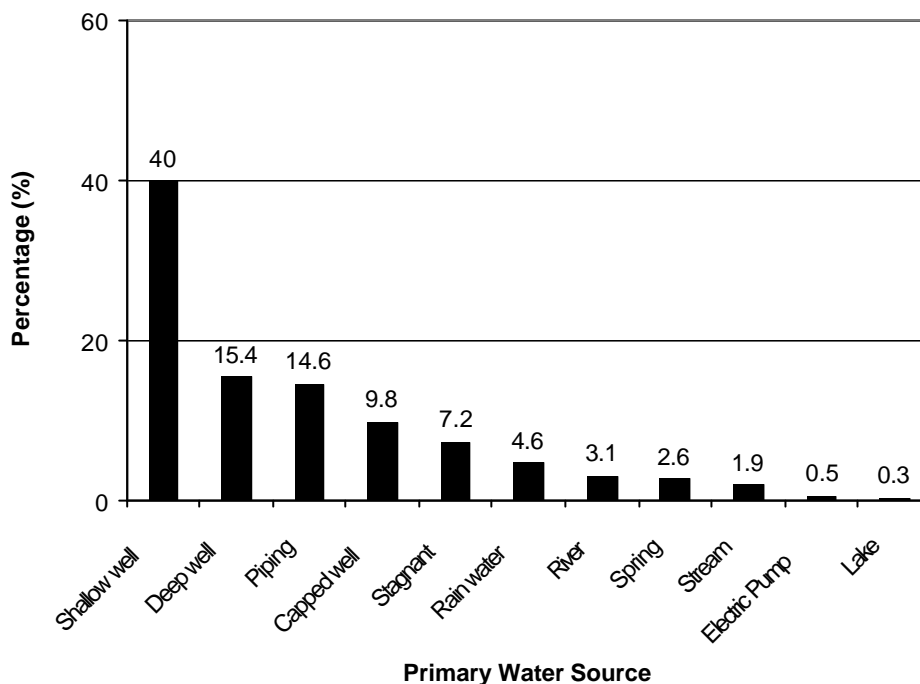


The Evaluation Team felt that in order to get an accurate picture of the beneficiaries receiving BSFs, it would be valuable to observe the socio-economic level of the beneficiary. For this reason, a number of observations were made in order to get as accurate results as possible. Table 3 displays the results from the various characteristics observed and records the percentage of households that demonstrated a positive response. Of exceptional interest is Question 14, which shows that only 16.3% of all the households surveyed have access to running water.

Characteristic observed.	Percentage Observed to be "Yes"
Q10a. Does the house have a cement floor?	49.1%
Q10b. Is the floor clean?	67.2%
Q11a. Is the roof made of durable materials?	86.1%
Q11b. Is the roof in good condition?	86.7%
Q12a. Are the walls made of durable materials?	72.4%
Q12b. Are the walls in good condition?	80.5%
Q12c. Are the walls clean?	77.2%
Q13. Is there a door?	96.0%
Q14. Is there running water?	16.3%
Q15. Is there a latrine with a structure?	49.3%
Q16. Does the house have electricity?	41.1%
Q17a. Do the beneficiaries have animals?	78.9%
Q17b. Are the animals able to enter the house?	37.7%
Q18. Is the waste dumped or burned at least 10m away?	55.8%

The source water type most commonly used for the BSF was found to use shallow wells. As can be seen in Figure 8, 40% of BSF recipients collect their water from shallow wells and 15.4% draw their water from deep wells.

**Figure 8: The Primary Water Source for BioSand Filter Recipients**



### 5.3 Trends and Indicators of User Compliance

A section in the BSF survey contained questions to increase understanding of beneficiary user compliance. As can be seen in Figure 9, 98.4% of BSF recipients are using their filter on a regular basis to provide their drinking water. All of the households surveyed had been using their filters for at least three months, the amount of time determined by which the BSF recipient would have to develop a routine pattern of usage.

**Figure 9: Percentage of BioSand Filters Still In Use**

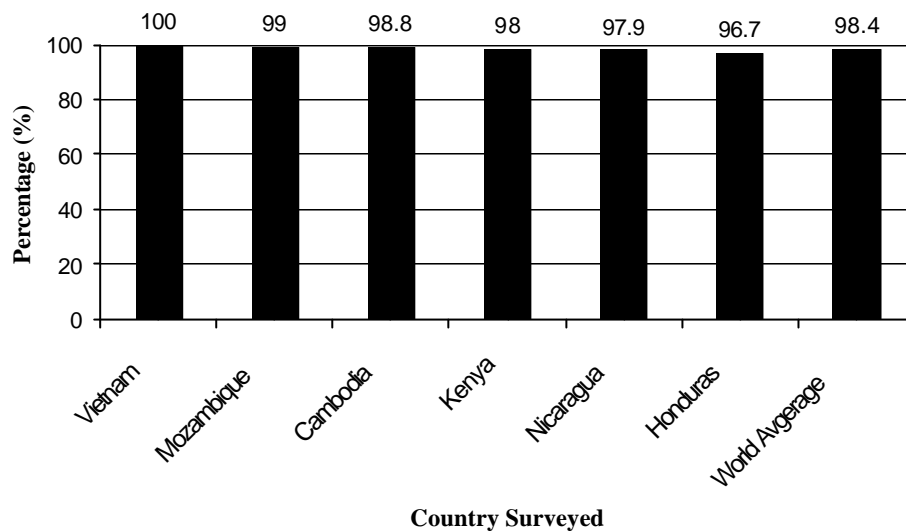
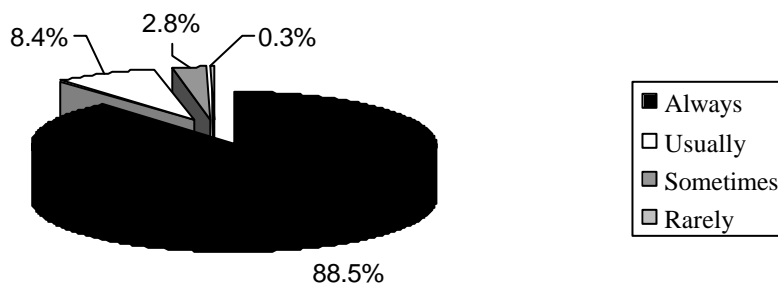


Figure 10 depicts the degree to which the beneficiaries are using their BSFs and, consequently, the degree to which they incorporate the BSF into their daily lives. All BSFs were installed from 3-36 months prior to the survey and, since the beneficiaries are still using their BSFs, user compliance is indicated.

**Figure 10: The Degree to Which the Beneficiaries Use Their BioSand Filter**



The Evaluation Team realized that in order to make sense of the average removal rates demonstrated by the water quality tests, it was essential to observe the characteristics of the BSF, and the level to which it was being maintained. BSFs that are maintained and used properly will perform optimally. Thus, Table 4 illustrates the various observations that were made concerning the BSF and the level to which the observations were positive.

Of all the observations, Survey questions 25a and 25b were of most concern to the Evaluation Team as they show that one-third of all BSFs in the survey are installed outside the house and are accessible to animals such as cows, goats, pigs and dogs. Through statistical analysis of the data, ACCORD Research group calculated that BSFs located inside the house had removal rates over twice as great as those that were located outside the house and accessible to animals, children, and contamination.

<b>Table 4: Observed Characteristics of the BioSand Filter</b> (Averaged Results for all Six Countries)	
Characteristic Observed	Percentage Observed to be "Yes"
Q20. Is the BSF clean?	78.8%
Q21a. Is the BSF set on level ground?	94.0%
Q21b. Is the BSF still functional?	99.3%
Q22a. Is the plastic spout present?	96.6%
Q22c. Is the plastic spout clean?	66.1%
Q23a. Is the BSF lid in its proper place?	93.6%
Q24a. Are there insects/food/animals on the diffuser plate?	15.4%
Q24c. Is the inside of the BSF clean?	81.3%
Q25a. Is the BSF inside the house?	66.7%
Q25b. Is the BSF located away from animals?	65.9%
Q26a. Is the diffuser plate present?	99.3%
Q28. Is the resting water level 5cm above the sand?	28.2%
Q29. Does the owner use two buckets?	80.6%

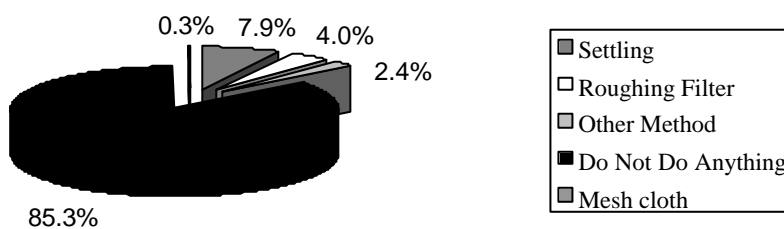
BSFs perform better when they are maintained properly and are used by owners with a high level of knowledge and understanding. The Evaluation Team found it imperative to determine the level of knowledge of proper BSF maintenance. Thus, Figure 11 illustrates that over two-thirds of all recipient households have a member which has a clear and proper understanding of the BSF and the necessary maintenance.

**Figure 11: Description of User Knowledge of BioSand Filter Maintenance**



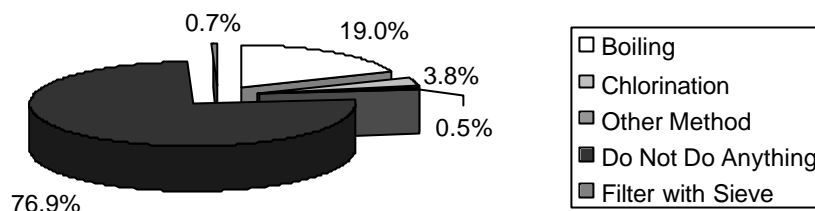
Similar to the importance of the source water consumed by the BSF recipients, the Evaluation Team thought it important to determine whether the source water was treated before being poured into the BSF. In Figure 12, it can be seen that over 85% of BSF recipients do not use any pre-filtration treatment. Local health officials believe this number can be extrapolated to the population as a whole, indicating that in households without BSFs, over 85% of the community consumes the drinking water directly from the source.

**Figure 12: Methods of Pre-Filtration**



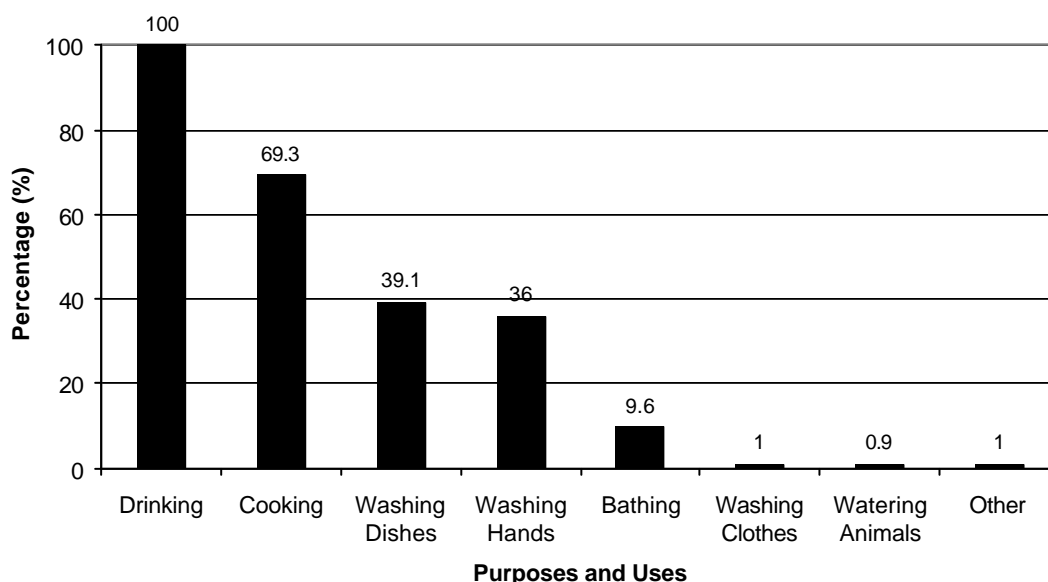
Similar to the previous figure, Figure 13 displays the methods of post-filtration that BSF recipients are using for their drinking water. From the figure, it can be determined that although 19.0% of those surveyed boil their water after filtration, 76.9% of those surveyed do not use any method of post-filtration. Interestingly, of those who said that they boil their water after filtering it, 97.8% of them were Vietnamese respondents. It must be noted that in Vietnam, drinking water is used primarily for making tea.

**Figure 13: Methods of Post-Filtration**



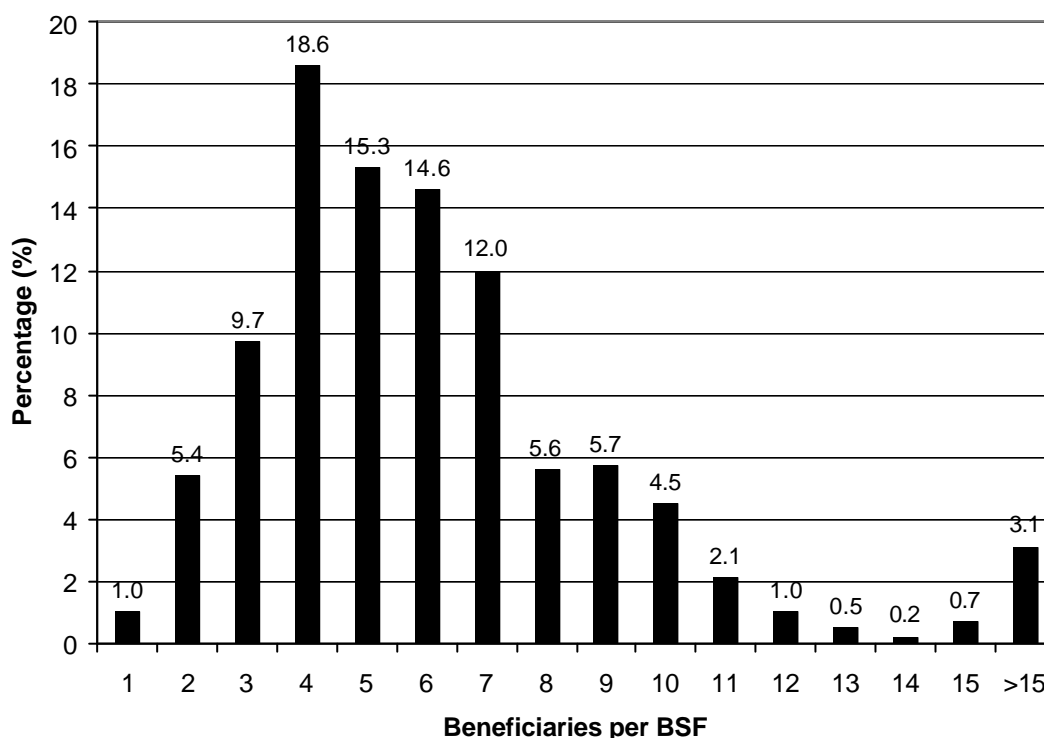
From Figure 14, it can be determined that BSF recipients are learning to use the filtered water for purposes other than drinking. From the figure, it can be seen that 100% of the recipients use the filtered water primarily for drinking, but are also using the filtered water for cooking, washing hands/teeth, and washing dishes or utensils. It should be noted that, once again, Vietnam records the highest levels of water consumption for these purposes, with 100% compliance in all four categories. Mozambique, however, records the lowest compliance levels when using water for these other purposes, showing less understanding of the relationship between clean water and basic hygiene.

**Figure 14: Purposes and Uses of the Filtered Water**



When conducting the survey, the Evaluation Team determined the number of beneficiaries per household. In Figure 15, it can be seen that the majority of BSFs service from 4-7 beneficiaries, but there are many filters providing clean water for eight or more beneficiaries every day. In a few cases, as those charted in the greater than 15 cohort, the household BSF was located at an orphanage, health clinic, school, or hospital and served a much larger population.

**Figure 15: The Number of Beneficiaries per Household BioSand Filter**

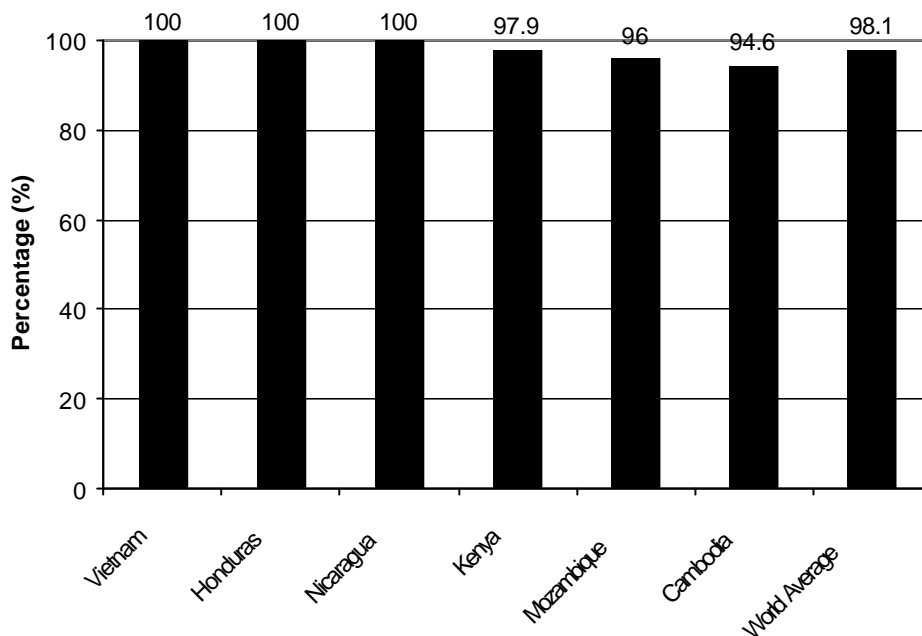


The full compliment of Survey responses can be found in Appendix C.

#### 5.4 Trends and Indicators of Household Wellness

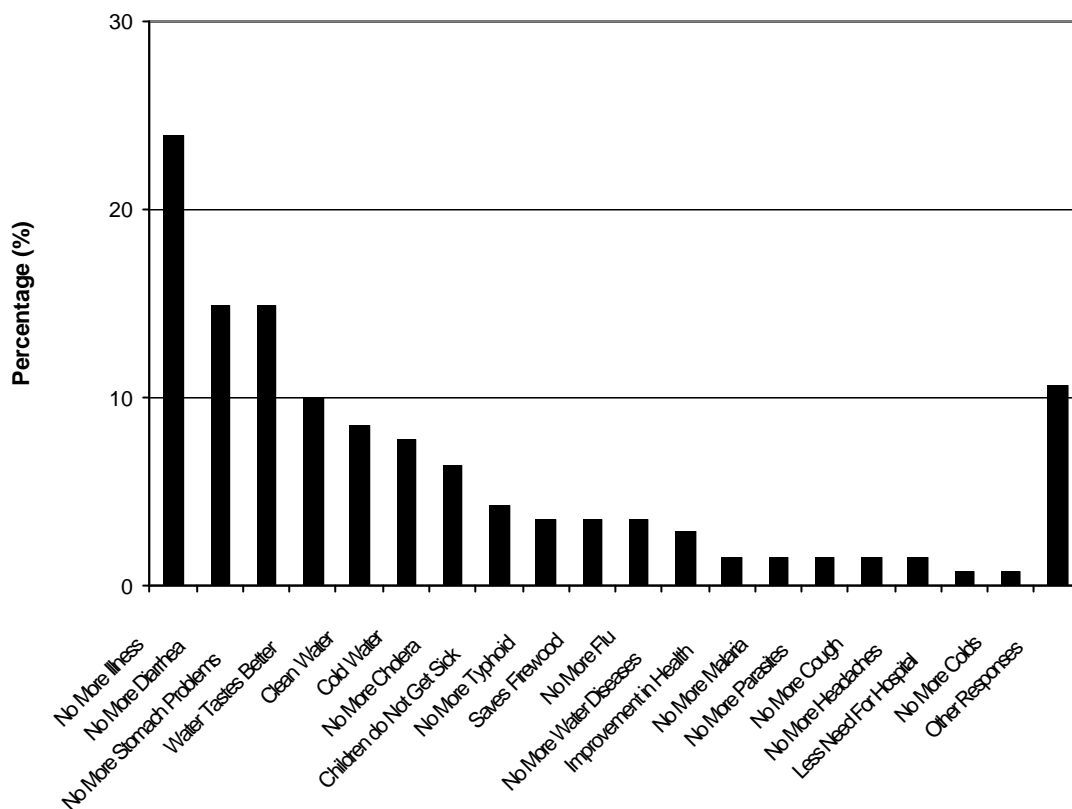
In order to satisfy the objective of BSF **effectiveness**, the performance of the BSF within the various countries was evaluated, as well as the BSFs impact on wellness and community health. For this reason, the beneficiaries in all countries were asked a series of questions in order to determine their thoughts and perceptions on the impact and effectiveness of their BSF. From Figure 16, it can be seen that 98.1% of all respondents believe that the BSF to have dramatically improved health and wellness within their household.

**Figure 16: Percentage of BSF Beneficiaries Who Believe the BioSand Filter has improved the Health of Their Household**

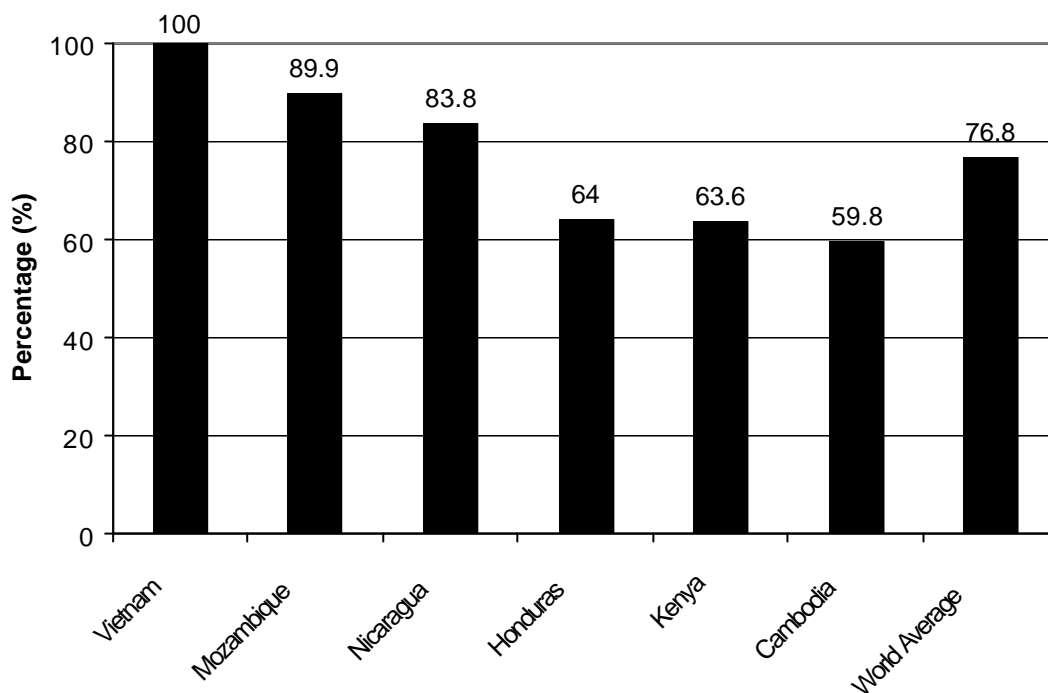


Once the Evaluation Team had posed the questions concerning the beneficiaries' perceptions of their household health, qualitative questions were asked in order to determine their reasoning for the manner in which their health had improved. As can be seen in Figure 17, the reasons ranged from "no more illness" to "saves firewood needed for boiling" to "no more colds". The largest cohort was 23.9% of beneficiaries responding that their health had improved with no more illness from using the BSF.

**Figure 17: Responses to How Household Health Has Improved**



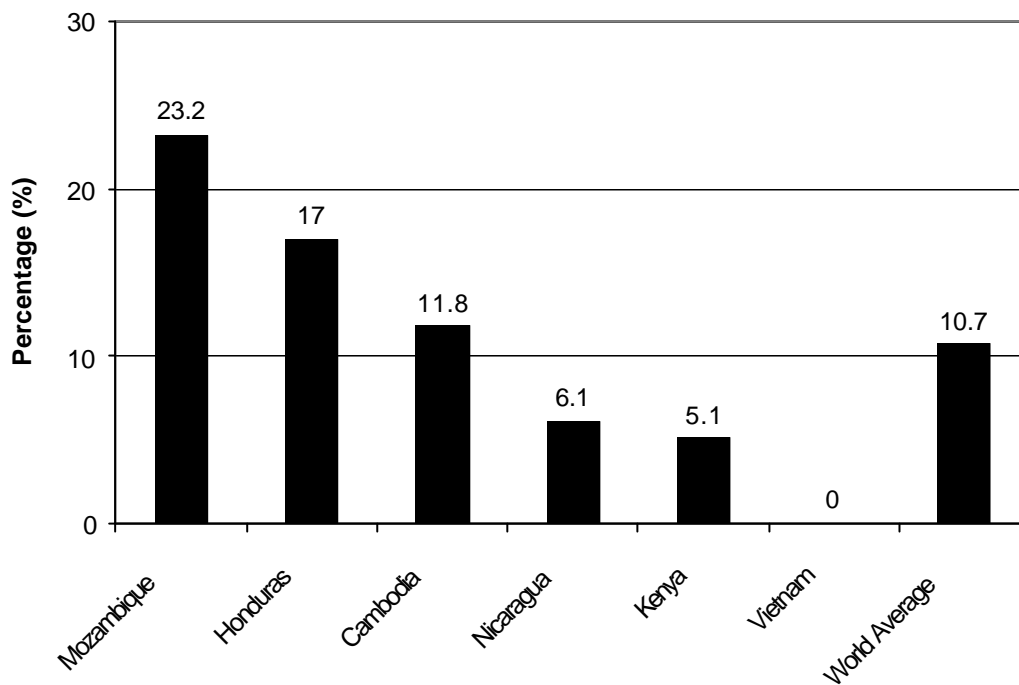
In addition to determining the impact that the BSF had on household wellness, BSF recipients were asked whether they had access to a health center. It was believed that recipients who did have access to a health center, would also possess a greater knowledge and understanding of health related issues and, thus, would better realize the benefits of the BSF. Figure 18 breaks the responses down according to country, with 100% of the Vietnamese recipients having access to a health center, while only 59.8% of the Cambodian recipients did. In addition to the improved education that a health center provides, it is also an indicator of access to medications when needed by the local population.

**Figure 18: Percentage of BioSand Filter Recipients with Access to a Health Center**

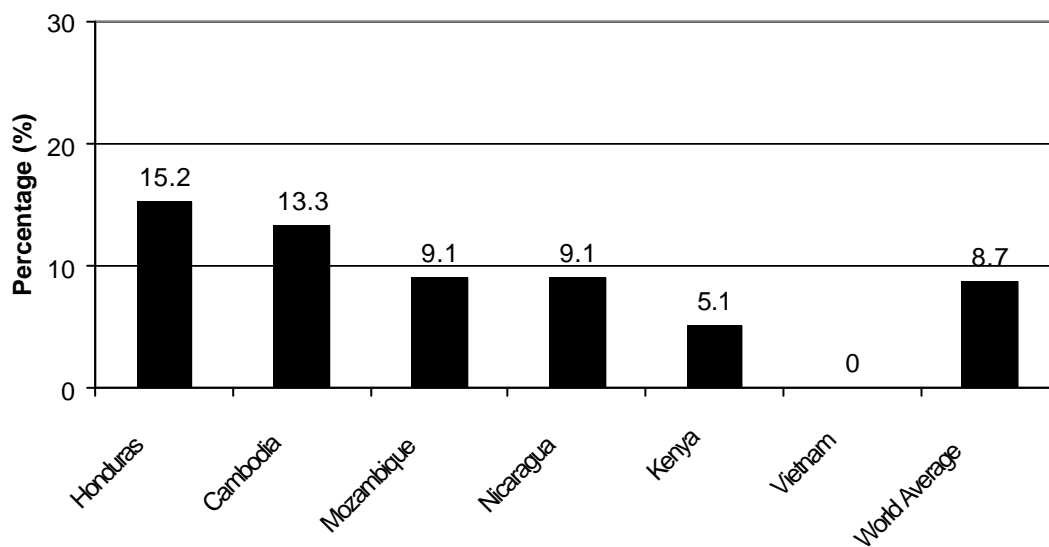
In order to assess the impact that the BSF was having on household health and wellness, the Evaluation Team asked the head of the household, whether any members of their household had experienced diarrhea, vomiting, or intestinal worms in their stool within the past month. Sixty-five percent of those surveyed were women. As Figure 19, Figure 20 and Figure 21 illustrate, the average response rate for these illnesses was 10.7%, 8.7% and 15% respectively with obvious variations from country to country. Once again, the respondents from Vietnam expressed the least occurrences of illness, with Mozambique and Honduras experiencing the greatest occurrences of illness.

Discretion must be used when observing the correlation between disease and dirty water. There are many illness-causing vectors that are also contracted from drinking dirty water. Illness such as diarrhea, vomiting, and intestinal worms can be contracted from eating undercooked food as well as not washing hands after defecation. It can be seen when comparing the *E. coli* removal efficiencies of each of the countries with the prevalence of illness that there is not a direct correlation with wellness. This leads to the interpretation that there are other factors that work with clean drinking water to affect health.

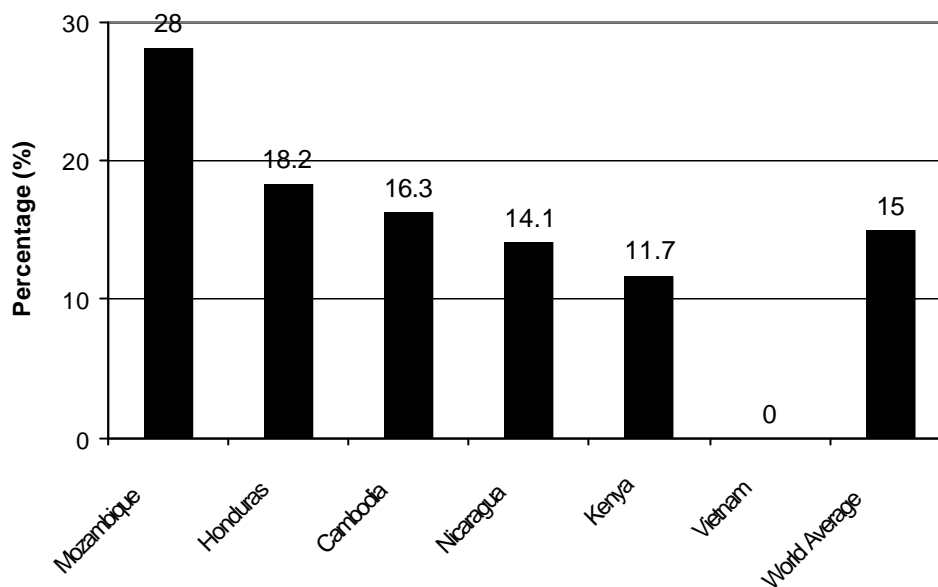
**Figure 19: The Percentage of BioSand Filter Beneficiaries with Diarrhea in the Past Month**



**Figure 20: The Percentage of BioSand Filter Beneficiaries Who Have Experienced Vomiting in the Past Month**

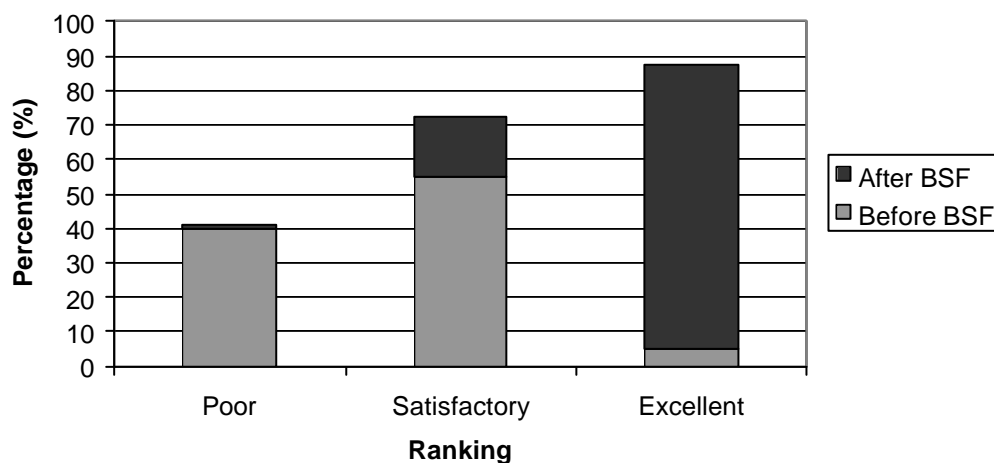


**Figure 21: The Percentage of BioSand Filter Beneficiaries Experiencing Intestinal Worms in the Past Month**



In addition to determining the water-borne illnesses that were present before and after receiving the BSF, the households were asked to rank their household health before and after receiving a BSF. The beneficiaries were asked whether their health was poor, satisfactory, or excellent and Figure 22 illustrates their responses. From Figure 22, before owning a BSF, only 5.0% of the households surveyed described their household health as being excellent, but then after receiving a BSF, 82.4% described their household health as being excellent.

**Figure 22: Perceived Household Health Before and After Receiving the BioSand Filter**



## 6.0 INTERPRETATION OF RESULTS

The results of the Performance Evaluation and the Questionnaire must be interpreted carefully. The interpretation of the results will address the first three objectives outlined in Section 2.0 and provide a basis for determining recommendations.

### 6.1 Interpreting Fecal Coliform Removal Rates

In order to meet the objective of ascertaining the **effectiveness** of the BSF, a Performance Evaluation of the BSF was conducted by taking water quality tests of the source water, the resting pause water, and the filter's outflow. The most important component of determining **effectiveness** is through evaluating the wellness of the beneficiaries. Due to the reasons explained fully in Section 3.2.1, fecal coliform was used as an indicator of the sanitary conditions of the water being tested. In order to determine the overall fecal coliform removal rate for the BSF across six countries, linear regression was used.

The purpose of the Performance Evaluation was to determine the effectiveness of the BSFs regardless of the various factors that can affect filter performance. In order to calculate the fecal coliform removal rate for the BSF, an average calculation to determine removal rate does not account for the deviations in the results. Statistical analysis using a linear regression was used to accurately determine a removal rate efficiency based on the results for the entire pool of data.

#### 6.1.1 Known Scientific Research

The purpose of the Samaritan's Purse Evaluation was to determine the performance of the BSF within the context of the projects. The fecal coliform indicator *E. coli* was used in the water quality analysis in order to determine the probability that illness would result from consumption of the sampled sources. The presence of *E. coli* is generally accepted as an indication that there are disease-causing pathogens such as bacteria, protozoa, or viruses present in the water. This is due to the fact that *E. coli* undergoes the same removal mechanisms in water treatment as most known pathogens. However, there are diseases in water that exhibit different removal mechanisms in water than *E. coli* does. It is valuable to compare the results of the BSF survey against previously published results.

Under laboratory conditions where all factors influencing filter function can be controlled, the accepted removal rate for *E. coli* is 97%. The BSF Household Filter Evaluation of Samaritan's Purse projects discovered that the average removal rate is 93%. This is significant considering the severely underdeveloped conditions that the filters are being used. Further, the results from the MIT study show an 83% removal efficiency for *E. coli* in BSF filters in Nepal, which is very similar to the results found in this Evaluation in both Cambodia and Vietnam.

The BSF Household Filter Evaluation has determined an average fecal coliform removal rate for the BSF of 93%, which is lower than the removal rate of 97% proven in scientific

literature. But the average removal rate is very close to reported values when considering the results of individual countries. For example Honduras, Nicaragua, and Mozambique have average removal rates of 100%, 99%, and 98% respectively. The lower removal efficiencies of BSF filters in Cambodia and Vietnam of 83% and 81% are lower than the documented claims, however, they are similar to the BSF Evaluation conducted in Nepal by MIT. In Cambodia and Vietnam, a high percentage of filters are located outside of the home and consequently can be accessed by other vectors of contamination. Filters located inside the home have been proven by statistical analysis from this Evaluation to increase the removal efficiency of the BSF by up to two times, as compared to the removal efficiencies of filters located outside the home.

Improvements can be made to raise the removal efficiencies of the BSF. These include ensuring all filters are placed inside shelters, as well as improving education to beneficiaries. Unless the connection between routes of contamination and transmission of disease are made, fundamental improvements in compliance will not occur. In addition to the contaminants that are removed from the source water, the BSF is also an effective method of decreasing turbidity, improving smell and improving taste. These are characteristics that make drinking the filtered water more appealing because, if the water does not appear clean, people are less likely to drink it. These issues will be addressed in the Recommendations section.

### ***6.1.2 Recognized Water Standards***

The World Health Organization Guidelines for Drinking Water Quality (GDWQ) reports that there must not be any *E. coli* present in drinking water (WHO, 1993). However, in the GDWQ the WHO states, with respect to isolated communities in developing countries, “the guideline values recommended here should be regarded as a goal for the future” (WHO, 1997). The WHO recommends that the respective nation should set “medium-term guidelines” (WHO, 1997) until this level of water quality can be achieved. However, the results of all water quality testing in developing countries must be evaluated relative to the WHO guidelines, as most countries that were subject to this Evaluation do not have interim guidelines.

The results of the BSF Performance Evaluation indicate a 93% fecal coliform removal rate. This means that some BSFs are not removing 100% of *E. coli* from the filtered water and are not meeting the WHO GDWQ of 0 fecal coliform/100 mL. In *Engineering in Emergencies* it is stated, “although it may be a desirable target to reach eventually, this guideline is not practical in many untreated, or partially treated, supplies in developing countries. An acceptable and attainable microbiological water quality will depend on individual circumstances.” It is impossible to determine the effectiveness of the BSF based on water quality testing results from developing communities without considering wellness of individuals.

There is no documented literature that states that the BSF is expected to remove all *E. coli* present in water. There are a large percentage of BSF filters which do achieve this standard. However, there are some BSF filters that do not meet the WHO GDWQ

standard for *E. coli* presence in drinking water. It must not be forgotten that a result of the BSF Evaluation is that 85% of beneficiaries were drinking water directly from contaminated sources before receiving the BSF. There are very few, if any, treatment options available for these people, and the BSF is an option that can improve their health. In Section 6.5, the health of individuals consuming water filtered by the BSF will be discussed.

### **6.1.3 Results Scenarios**

The BSF Evaluation determined an average fecal coliform removal rate of 93%. The raw data contains trends in coliform removal efficiencies. Listed below are the four different scenarios that occurred in the tests, and a brief description of the factors that affect these results.

1. The first scenario occurs when source water containing *E. coli* is poured into the BSF and water with little or no presence of *E. coli* flows out. This scenario is representative of a properly functioning BSF as supported by laboratory results. A typical BSF filter in this scenario would have 100 cfu/100 mL going in and five cfu/100 mL in the effluent to exhibit a 95% removal rate.
2. The second scenario occurs when source water containing *E. coli* is poured into the BSF and *E. coli* remains in the outflow water. Obviously this scenario is not representative of proper intermittent slow sand filtration and requires further investigation into the various factors producing this result. A typical BSF filter in this scenario would have 100 cfu/100 mL entering the filter and 40 cfu/100mL in the effluent to exhibit a 60% removal rate.
3. The third scenario occurs when source water containing no *E. coli* is poured into the BSF and there is no indication of *E. coli* present in the outflow water. As this result would indicate a removal rate of 0%, this scenario must be taken into account when calculating removal rates. A typical BSF filter in this scenario has 0 cfu/100 mL being poured into the filter and 0 cfu/100 mL in the effluent to exhibit a 0% removal rate.
4. The fourth scenario occurs when source water containing no *E. coli* is poured into the BSF but *E. coli* is detected in the outflow. This result is obviously not indicative of proper intermittent slow sand filtration and requires further investigation into the various factors producing this result. The primary cause is a contamination in the pause water of the filter. A BSF filter that fits into this scenario would have 0 cfu/100 mL entering the filter and 100 cfu/100 mL in the effluent, exhibiting a - 100% removal rate.

The following discussion is meant to address the results scenario in two and four. There are essentially four factors that could influence these results, which are not representative of a properly functioning BSF. These factors include a contamination of the filter media,

gross contamination of collected source water, improper filter maintenance, or changing the water source.

The first factor, contamination of the filter media, is avoided by Samaritan's Purse through the extreme care that is taken in filter media selection. There could be extenuating circumstances where the filter media is contaminated biologically during installation. However, the environment inside the filter media column ensures that any biological contamination, other than the schmutzdecke, will not survive, essentially regenerating the filter media. This is why all filters analyzed in this survey were installed and used for at least three months; to ensure any regeneration processes would have previously occurred. As a result of this, it is not possible for *E. coli* to grow inside a BSF, as *E. coli* is suited to living in the digestive tracts of mammals. The presence of *E. coli* in any sample means the water has been in direct contact with feces.

The gross contamination of the source water is a factor that is difficult to control. What this means is that, during the collection of water to be filtered, a spike of contamination comes into contact with the water the result of an irregular usage. This could include the collection bucket scraping the side of a well or the bottom of a river that is contaminated. This spike of contamination is then poured into the filter where it can overload the schmutzdecke. Another example of gross contamination of the source water is through not using a lid on the BSF. When the lid is not kept on the BSF, it is possible for airborne or other contaminants to enter the filter reservoir.

A spike contamination of *E. coli* will affect BSF fecal coliform removal rates in the following ways. If there are extremely high concentrations of *E. coli* bacteria present in the source water, it is possible to overload the filter and have some *E. coli* escape treatment. In this case, the removal rate and, thus, overall effectiveness of the filter remains high when considering the contamination of the source water. Immediately after irregularly using the filter, or overloading the filter with highly contaminated water, the pause water or resting water in the filter can still contain *E. coli*. At this time, if lower contaminated water is run through the filter, it is possible that some *E. coli* that had escaped treatment previously might still be present in the outflow. Results of the pause water quality testing indicate that gross contamination of the pause water occurs occasionally. This scenario would indicate low filter effectiveness, but can be explained as gross contamination of the pause water due to irregular usage.

The third factor affecting removal rates is the hygiene of the beneficiary family, or simply how the beneficiary looks after their filter. Improper maintenance could lead to contamination. For example, if the spout of the filter is never cleaned with soap and water. Dust, insects, children, and animals come into contact with that spout leaving behind residues such as bacteria. In this case, even if the water filtered through the BSF contains little or no *E. coli*, after coming into contact with the spout it is possible for the water to become re-contaminated. This is called post filtration contamination, which can be reduced through improved education.

The fourth factor, which can negatively affect removal rates, is climate, or changes in weather, which alter the source water. The BSF must be used with a consistent source water, as is taught by the BSF technicians. However, in most developing countries there are wet and dry seasons, during which the water source for families changes out of necessity. This affects the function of the BSF by changing the microbiology in the schmutzdecke. When this occurs, the mat of microorganisms that is specialized in treating a specific set of biological components of the water is stressed and it cannot function optimally. This means that some *E. coli* could escape treatment, until the schmutzdecke recovers. This damage to the schmutzdecke reduces removal efficiency of the BSF until the schmutzdecke can regenerate, which takes between 3 to 14 days.

Each of these four factors and their affect on Scenario two and Scenario four has a significant impact on the Performance Evaluation of the BSF. SP has attempted to reduce the instances of these factors occurring through careful construction methods and the education of beneficiaries. Even in the instances where filters are not performing optimally, “a large quantity of reasonably safe water is preferable to a smaller amount of very pure water” (USAID, 1998). The results of the survey will help SP determine how to improve the BSF education program.

#### **6.1.4 Science and the BSF Performance Evaluation**

It is understood that large amounts of *E. coli* present in tests from the outflow of a properly working BSF are not indicative of proper intermittent slow sand filtration function. This could be the result of post-filtration contamination, improper usage, or from gross contamination in the pause water from a previous use. Research funded by Environment Canada and the International Development Research Center (IDRC) has found that properly functioning filters exhibit a fecal coliform removal rate of 97% (Palmateer et al, 1999). This is a result from laboratory testing, whereas the Samaritan's Purse Evaluation has a result of 93% fecal coliform removal rate in developing countries where the conditions are not controlled.

The literature documenting the BSF does not state that the BSF removes 100% of *E. coli*, however it does state that the BSF removes 100% of parasites, worms, and giardia, as well as 99.89% of cryptosporidia. This means that *E. coli* may be present in the outflow of a BSF but, through scientific literature, it is proven that other disease causing pathogens are removed or are significantly reduced. In this case *E. coli* only indicates the presence of *E. coli* and other pathogens. The use of the BSF positively impacts the health and wellness of beneficiaries by improving their water quality.

The statistical analysis conducted within the context of this survey points to the fact that 93% of *E. coli* and related disease-causing pathogens are removed from contaminated water through the use of the BSF. Although there is no single water treatment process that can transform water to its cleanest, purest state, the fact that the BSF is decreasing the presence of pathogens by 93% will make a dramatic improvement in the health of individuals. By reducing the level of pathogens in the water to levels lower than those that cause illness in individuals, the overall wellness of people is positively impacted.

The use of disinfection after filtration improves the water quality of the filtered water even further.

The nature of pathogens in water, and consumption levels required to cause disease in an individual, are directly related to an individual's level of immunity and health. If the immune system of an individual is suppressed continually from drinking dirty water, they will have a lower threshold with which to resist illness. By decreasing the number of pathogens in drinking water, the health of a person can be maintained at a higher level and therefore will produce a higher resistance to illness. Reducing the impact of one of the vectors for disease in individuals improves the picture of overall community health and wellness.

It is widely accepted and understood that there are a number of factors such as contaminated food, food preparation, environment, air-borne diseases, poor hygiene, and contaminated containers which can contribute to illness. The use of the BSF to improve drinking water quality reduces one of the factors that affect the health of individuals. If there was a negative correlation between the health of individuals and the use of the BSF, this would have appeared in the Performance Evaluation.

In order to evaluate **effectiveness** of the BSF, both the results of water quality testing from the Performance Evaluation and the wellness results from the Questionnaire must be considered together. In Section 6.4, these combined influences on effectiveness will be discussed.

## **6.2 Interpreting Indicators in Living Conditions**

In *Section 5.2*, the living conditions of the beneficiaries demonstrate a direct relationship with BSF effectiveness. In households where there is a solid roof made of durable materials, a clean cement floor, a structure to keep animals away from the house (Figure 23), and running water, the BSF was found to be the most effective. This is not really a novel concept in that houses that meet these criteria also boast the highest education and socio economic levels. It needs to be noted that BSF effectiveness and compliance are highest when these variables are met.

Water quality testing on the water sources for the BSF has found that, although wells draw ground water that tends to be less contaminated than that of surface water, the water is still susceptible to contamination. The water can be contaminated through using a dirty rope, dirty buckets, animals, and objects falling in and it needs to be treated or filtered before consumption. Shallow wells that are not constructed properly can be contaminated through overland run-off or seepage from nearby surfaces.



**Figure 23: Animal Contact with BSF in Central America.**

Table 3 illustrates numerically the percentage of households surveyed that demonstrate the various criteria that the Evaluation Team thought important in determining household health and wellness. In homes where these criteria are not met, health, wellness, nutrition, and education are all subject to lower rates. Only 16.3% of the houses surveyed have access to running water. As population growth increases more rapidly than infrastructure growth, this percentage will likely drop in the coming years. Thus, the low percentage of houses with access to running water shows the need for an appropriate technology such as the BSF.

The vast differences in source water locations can be evidenced in Figure 8, which graphs the primary water source for the beneficiaries surveyed. 55.4% of households obtain their drinking water from shallow and deep wells, but in Kenya, 37.8% of the households surveyed obtain their water from a stagnant water source. An example of a shallow well can be seen in Figure 24.



**Figure 24: Shallow Well Water for a Household in Cambodia.**

### **6.3 Interpreting Indicators of User Compliance**

In order to meet the objective of **sustainability**, the Evaluation Team, the ACCORD Research Group, and Dr. Hollaar created a comprehensive questionnaire. The questionnaire will also help establish the relationship between **BSF performance** and **user compliance**. A BSF that is providing drinking water is only as good as the habits and knowledge of the user. If the drinking water is being collected in a contaminated container, or if animals or children have access to the spout, the integrity of the filter and the fecal coliform removal rates will obviously be compromised. For this reason, Section 5.4 dealt with trends and indicators of user compliance in order to address the issues of ownership and demand.

The survey found that 98.4% of households are using their BSFs, and this is especially encouraging in that all the BSFs have been in use for a period of three months or greater. The use of the BSF by the beneficiaries three months after installation indicates the sustainability of the filter. Similarly, of those still using their filters, 88.5% use their BSF everyday for drinking, cooking, washing hands, washing dishes, and bathing. In addition, Table 4 shows the various criteria that the Evaluation Team put forward to measure user compliance. From this chart though, it can be seen that future BSF projects will need to emphasize the need for keeping the spout clean, placing the BSF inside the

home, maintaining 5cm of resting water above the sand, and assuring that animals cannot get near the filter. From Figure 11 it can be seen that one-third of all beneficiaries have either a vague, improper, or no understanding of BSF maintenance and this needs to be improved in the future.

Figure 12 and 13 are interesting in that they show that 85.3% of beneficiaries do not use any method of pre-filtration and 76.9% of beneficiaries do not use any method of post-filtration other than the BSF. Similarly, local health officials relate that the majority of households without a BSF do not use any method of filtration and drink their water directly from the source. In communities such as these, the importance and effectiveness of the BSF becomes even more pronounced. The **sustainability** of the projects is shown by 98.4% of users still using their filters at least three months after installation.

#### **6.4 Interpreting Indicators of Household Wellness**

In addition to fecal coliform removal rates, the second component of evaluating **effectiveness** is that of the household wellness. Household wellness is really the main issue that the BSF projects aim to address, and the following discussion will concentrate on that. From Figure 17, 98.1% of the beneficiaries surveyed believed that the health of their household had improved since receiving a BSF. Not only is this number significant in indicating overall wellness, but there is significance in that every country surveyed had the same responses.

Once the Evaluation Team had established a 98.1% satisfaction with the BSF, it was important to know the ways in which the household wellness had been improved. As the Team did not want to ask any leading questions or prompt certain responses, there were a number of different responses to the questions. From Figure 18 it is evident that most beneficiaries listed that the BSF had improved their health most dramatically through reducing illness, diarrhea, stomach problems, typhoid, cholera, coughing, headaches, and colds. In addition, the beneficiaries added that the filtered water tasted better, was cleaner, and was refreshingly cold.

Figure 19, 20, and 21 illustrate that 10.7% of BSF beneficiaries have experienced diarrhea, 8.7% vomiting, and 15.0% intestinal worms over the past month. There are many routes of contamination, which will cause these diseases in individuals. These illnesses can not be solely attributed to drinking water. The BSF water quality testing for this Evaluation was determined to be a 93% removal rate for *E. coli*. There is no direct correlation between these diseases and the removal efficiencies of the BSF. Routes of disease transmission include contaminated food, air-borne germs, and unwashed hands which would also contribute to these results. However, base-line survey data taken in El Jicaral, Nicaragua by local health officials over the past few years points to very similar results and reduction levels.

In El Jicaral, local health officials carefully recorded the monthly cases of cholera and diarrhea which were observed at the local health clinic. These records from the time

period between 1996 and 2000 are not published. In 1996 and 1997 there were many cases of these illnesses however, the BSF program was initiated in 1998 and, in the following years, there were no instances of cholera or dysentery reported at the local health clinic. Access to clean drinking water is one of many factors which affect the health of individuals.

Finally, and possibly the most important, is the question dealing with the beneficiaries' perceived health before and after receiving the BSF. This is somewhat of an all-encompassing question in that it does not merely deal with the impact of the BSF on household health, but also includes the impact of an increased level of health and hygiene education within the household. From Figure 22, before receiving the BSF, 39.9% responded that their health was poor with only 5.0% responding that their household health was excellent. After receiving the BSF however, only 0.3% responded that their health was still poor, while an 82.4% said that their health was now excellent. **These results are relative and rely on qualitative data, but what is more important than the actual numbers are the very significant differences in perceived health before and after receiving the BSF, proving that the beneficiaries have embraced the technology.**

## **6.5 Difficulties Encountered and Lessons Learned**

It is important to evaluate the approaches and methodology in order to learn from the difficulties experienced. In addition, in a task of this magnitude where technology needs to be used in rural communities within a developing country, there are bound to be a number of difficulties. As a result, the following sections deal with the difficulties encountered, how those problems were solved, and the lessons learned within the context of the specific countries.

### **6.5.1 Kenya**

In Kenya, the Evaluation encountered many realities of conducting a Survey in a developing country, including weather. Road quality for example, is directly affected by the amount of rain that falls. For this reason, it is very important that surveys are scheduled during times of relative dryness. In addition, due to poor infrastructure in most of rural Kenya, setting up a portable water laboratory can be difficult. As the laboratory depends on an available water source, and 110V electricity twenty-four hours per day, the laboratory might often have to be established at a distance from the surveyed community.

### **6.5.2 Mozambique**

As the people of Canicado, Mozambique are extremely poor, they view the BSF filter as a prized possession. In order to receive a BSF the people must pay 5 USD and in doing so they must make a sacrifice, thus drastically increasing ownership. However, education levels in Canicado are also quite low, and this obviously plays an important role in user

maintenance and compliance. Thus, it was interesting to note a strong correlation between recipient education and filter efficiency.

### **6.5.3 Cambodia**

Upon set-up in Kampong Thom, the fuse blew on the incubator due to traveling conditions, and only one of the extra fuses was available. It is important to always have extra fuses on hand because it was difficult to locate the correct size fuse for the Millipore Incubator in Kampong Thom. In Kratie it is possible to locate a wider variety of fuses. In Kratie, there were several different amperage batteries used as power sources. Due to the logistics of recharging batteries, it was easiest to use an automotive battery. The use of mosquito tenting was invaluable in Kratie for keeping bugs off of laboratory equipment and field laboratory areas.

A vehicle is essential for future surveying in Kampong Thom. Due to the distance that must be traveled to the villages and the temperature, it is important that a cooler with ice be available. It is very difficult to carry a large enough cooler to hold the samples on the back of a motorcycle. The cooler could be kept in the back of the vehicle, and surveyors could be transported to the different villages. In Kratie, the samples were stored in small hand-held coolers until they were transported to the laboratory where the larger cooler with ice was located. A vehicle would have been helpful in Kratie, however many of the roads would have been impassable due to mud roads or flooding.

### **6.5.4 Vietnam**

Samaritan's Purse Staff determine which villages will receive a BSF project, and then works together with the local Security Team from each village. The local Security Team is trained to respond to problems that arise with the filters in their community. The quality of filter function then lies in the level of understanding between these men. As there tends to be general misunderstanding with regard to water hygiene practices, an education program focusing on teaching beneficiaries about germs and bacteria, and how these are transferred through water, is extremely important. Unfortunately, the political structure of Vietnam limits community meetings where possible teaching could occur.

Additionally, in northern Vietnam the months of September and October (when the survey was carried out) are a time when a high percentage of the population is working in the rice fields. This means that 80% of households do not have adults using the filters at these times and, in many homes, children are using them instead. Thus, educating young children must be a priority in future BSF projects.

### **6.5.5 Honduras**

In the Honduras survey, the only real difficulties faced resulted from the weather. The day after the Evaluation Team arrived in San Pedro Sula, a tropical storm swept through Northern Honduras causing flooding in many areas. The airport and some surrounding

towns were briefly cut off from the city and the main highway between San Pedro Sula, where Samaritan's Purse headquarters is located, and La Ceiba, the region where several project sites are located, was closed, Figure 25. As a result, the Evaluation Team made a list of towns that were within a two hour drive from San Pedro Sula and were known to have reliable road access. From this list, a random selection of villages to be surveyed was made.



**Figure 25: Flooded streets in Honduras in the aftermath of the tropical storm.**

### ***6.5.6 Nicaragua***

Apart from basic language barriers and poor infrastructure, there were no major difficulties encountered in Nicaragua, and the local BSF team helped to make the Evaluation run smoothly and efficiently.

## 7.0 RECOMMENDATIONS FOR ENHANCING PROJECT EFFECTIVENESS

The **recommendations** are an objective of the BSF Evaluation, based on the interpretation of the **effectiveness** and **sustainability** objectives.

### 7.1 Overall Recommendations

When the BSF was first introduced into developing communities it was thought that, due to its appropriateness and the low-maintenance required for operation, it would have a positive impact immediately. However, after implementing a few projects, Samaritan's Purse staff members quickly realized that the BSF must be complemented with an intensive and extensive education program. The Evaluation Team recognized the importance of listening and learning from current BSF beneficiaries and BSF technicians as to how Samaritan's Purse could enhance future project effectiveness. **Thus, the following recommendations come in response to the objective of listening and learning from the BSF recipients, and come in the form of recommendations for future BSF projects:**

- **Assisting** BSF recipients with a clean water bucket and a dirty water bucket that are properly labeled in order to help them distinguish between dirty water and clean filtered water.
- **Educating** beneficiaries, using appropriate teaching resources, on the relationship between water quality and the transmission of water-borne diseases.
- **Producing** appropriate education materials (for illiterate populations) on BSF usage, maintenance, and water-hygiene.
- **Building** on and enhancing the capacity of local BSF technicians, as well as assuring that there is a properly trained individual within each village to attend to minor problems, project monitoring, and basic trouble-shooting.
- **Working** within existing health education frameworks (local health workers and dissemination channels) in order to improve overall community health.

Samaritan's Purse has historically supported disinfection as a means to meet WHO water quality standards and will continue to do so. At the same time, Samaritan's Purse understands that many communities lack access to sustainable, affordable, and safe methods of disinfection.

### 7.2 Country Specific

Although BSF construction and project design is rather similar throughout the world, different cultures, geographies, climates, socio-economic levels, and education levels do present new and unique challenges. As a result, local BSF staff and technicians have suggested the following country specific recommendations.

### **7.2.1 Kenya**

In Kenya, it has been recommended by both the project supervisor and the BSF technicians that building a central production center might be a wise solution to improving the quality of the filters. Similarly, if all the sand is processed in this central location, it will reduce cost and ensure a high quality. Although transportation costs to various locations could obviously be exorbitant, it is thought that this production center would service communities within a 100km radius and then, when demand drops, could be moved to another central location.

### **7.2.2 Mozambique**

Due to the incredibly low level of education within rural Mozambique, the project managers realize the need for an increase in water-hygiene education for the filter recipients. Not only would this enhance the effectiveness of the filters, it would also help alleviate other communicable diseases and illnesses.

### **7.2.3 Cambodia**

The most important recommendation for the projects in Cambodia is to ensure that the owners place the filters under shelter. Also, in Kampong Thom, there is a high concentration of iron present in the water which, over time, builds up within the bio-film layer, slowing the flow rate of the filter to the point where the flow actually stops, Figure 26. Local staff must be able to approach this problem with effective suggestions in order to improve the function of the filter. As there is not a standard concentration of iron in shallow wells, it is important that the staff have the ability to solve these problems on a case-by-case basis.



**Figure 26: Iron residue resulting from high concentration of dissolved iron in source water.**

**7.2.4 Vietnam**

The main recommendation for Vietnam is to convince the beneficiaries that it is necessary to place their BSF under a shelter. In Vietnam, the surveyed beneficiaries have an excellent grasp of flow-rate maintenance, but often lose a few centimeters of sand off the top because their source water tends to be extremely turbid. As a result, it is suggested that extra sand be accessible at each village (under the authority of the local BSF team) so that the beneficiaries can “top up” their sand level when necessary.

**7.2.5 Honduras and Nicaragua**

It is extremely important that more time and effort be spent on training the beneficiaries in the proper use and maintenance of the BSF. Local BSF technicians and educators believe that at least 80% of the total effort should be spent on training and follow-up, which could end up covering 50 – 70% of the total expense.

Since the collection of water, filtration of water, cooking, cleaning, and just about every other domestic task is performed by women, the filter training should be done by female instructors and focus on the women within the community. Men should also be involved, especially for the more labour intensive aspect of the project, but it is essential that women are involved in all aspects of the project.

In addition, there also needs to be regular follow-up visits after the filter is installed. These should follow a defined follow-up schedule. Similarly, it is recommended that each project have a local BSF technician within the village who works alongside a local health representative. These assistants could serve as the main contact person in the village to deal with trouble-shooting and enhancing user education. In Nicaragua, there is one region where the local health director is a strong proponent of the BSF, and this has led to greater acceptance, greater compliance and, consequently, greater removal rates.

**7.3 The Importance of User Education**

As has been noted throughout the Evaluation there is a direct relationship between user education and BSF performance. Beneficiaries with a higher level of general education also maintain the BSF to a better degree and, thus, experience a more effective removal rate from the source water. For this reason, members of the Evaluation Team, along with local BSF technicians, recommend a greater emphasis on user education through appropriate materials. As education methods are so dependent on variables such as culture, geography, and socio-economic level, the following section has been aggregated according to continent.

### ***7.3.1 Kenya & Mozambique***

In both African countries, the Evaluation Teams noticed that the final quality of the drinking water is directly related to the user's education. In houses where the recipients had obtained a high level of education, and had been properly instructed in filter use and maintenance, the vast majority of the filters performed at levels of greater than 95% removal rates. However, in households where beneficiary education was lower, the filter did not perform as well. Similarly, in households where animals are present or the filter is outside of the house, removal rates are again less effective. Even if a filter removes 100% of the contaminants, if the recipient is drinking the water with dirty hands, using a contaminated bucket to catch the water, or allowing animals to lick the spout, the final output water will not be as clean as documented.

For this reason, Samaritan's Purse realizes the high importance of quality user education and desires to design and implement a water hygiene education program for illiterate populations. Building on some of SP's current programs, this program would work within pre-established and existing health education frameworks in order to enhance local capacity. It would attempt to utilize the knowledge of local community members, and empower them to teach water and sanitation education amongst their peers and within their culture.

### ***7.3.2 Cambodia and Vietnam***

In both Cambodia and Vietnam, the Evaluation Team found that 98.8% and 100% respectively of households were using their BioSand Household Filter. In order to assess the education level, beneficiaries were asked for their responses to the various factors affecting their health. The Evaluation Team felt that the effort required to maintain the distinction between a dirty water bucket and a clean water bucket is a good indication of the effort directed towards maintaining their BSF. Whatever the reason, the extremely high compliance of the Southeast Asian population indicates their understanding of and need for the BSF in their water purification process.

In Vietnam, the vast majority of BSF beneficiaries believed that the main factor in making someone ill was the weather. These same families reported that the main reason they liked the filter was because the BSF provided clean water, Figure 27. It is seen that there is a connection missing regarding the transmission of disease in water, and this needs to be addressed in future projects. This fact is also apparent from the number of homes that lack two buckets, resulting in the consumption of water collected in a contaminated bucket. However, as most families boil their water to make tea before they consume the filtered water, this usually removes any cross-contamination after filtration.



**Figure 27: Filter recipient in Vietnam.**

Although there is a lower literacy rate in Cambodia, the Evaluation Team found the Khmer people to have a greater understanding of what makes them ill. Khmer households reported that they liked the BSF because it provided clean water, and frequently added to their answer that they enjoyed the clean water without disease, thus making the link between the two. Similarly, the Cambodian participants had a higher percentage of their households using the two-bucket system.

### ***7.3.3 Honduras and Nicaragua***

Similar to the previous two sections, local health officials in both Honduras and Nicaragua have reinforced the need for continuing SP efforts with regard to user education. It has been well established that the BSF is not a “parachute” technology that can be dropped into a community with the expectation that health will improve. Through using local health structures and dissemination channels, local health officials believe that user education can be improved. It is well understood that even if a BSF is performing optimally and the beneficiary is collecting filtered water in a contaminated bucket or stored in a dirty container, their health will not improve to the degree to which it could. Thus, the following section will deal with various examples and possibilities for improving user education and knowledge.

## **7.4 Education Program**

Appropriate and culturally relevant educational materials are vitally important in the implementation of a basic health and hygiene education program. To ensure consistency and provide cultural sensitivity it is important that, where possible, the education program include the local Community Health Educator (CHE). In an ideal situation there should

be two people from each village who are educated and trained to maintain the filter program within the village. In order to work within the cultural context, it is essential that at least one of these educators be a female. In an idealized education program, the CHE team is responsible for **preliminary assessment, education, and follow-up education** seminars.

The **preliminary assessment** provides a base from which to implement an effective education program. Each source should be tested to determine the turbidity and whether the water source requires aeration in order to reduce dissolved iron, or a preliminary settling tank to reduce suspended materials. In addition, the CHE team should ensure that each filter is provided with two buckets, one for clean, and one for dirty water, and that lids are used. The preliminary assessment is essential in order to determine the issues that need to be addressed in the education program.

The **education program** stage includes community meetings as well as smaller training seminars at households before and after BSF installation. This education will be most effective if participatory learning is integrated with visual aids. The initial community meeting may include local government officials, as well as community members. Further community education seminars may be useful, however smaller group meetings should be encouraged to accommodate participatory learning. At each installation in each home, the BSF staff and CHE team should make the most of the opportunity, and use the time to properly and effectively educate the household on proper usage of the filter.

**Follow-up education** should be on a regular schedule after installation. Ideally this should occur in the beneficiaries' homes, as well as through small group learning environments within the community. Again, it is imperative that the principles of participatory learning are utilized.

#### **7.4.1 Education Materials**

The participatory learning method should be followed in order to ensure that the principles are properly understood. The visual aids should be developed 'in country' with the aid of a community member so that cultural and ethnic sensitivities can be accommodated. There are several topics that should be pictorially represented for illiterate village members.

- 1) Fecal/Oral routes of water contamination – including air pollution, groundwater movement, surface water movement, animal and human defecation near streams, wells, etc.
- 2) BSF Filter – cross-section and components
- 3) BSF Filter Biofilm – concept of good bacteria
- 4) BSF good practices – including proper usage of diffuser plate, clean bucket, dirty bucket
- 5) BSF bad practices – including animals accessing filter, dirty spout, extensions off of spout

The greatest emphasis within the education program should be placed on the information related to fecal/oral routes of transmission and contamination of source water. Unless the concepts of transmission of disease in water are understood, the concept of using two buckets will not be effective. For illiterate populations, these topics can also be addressed though other participatory learning activities such as dramas, role-playing, puppet shows, and small group education.

## **7.5 Future Evaluation System**

The sixth and final objective of this Evaluation was to develop recommendations for **creating an evaluation system** for future Evaluations, while creating baseline data. In any future performance Evaluation of this nature, it is imperative that appropriate water quality testing methodologies are adhered to. As well, it is essential that a survey be used to compliment the water quality testing. The procedures and methodologies used in this Evaluation are thoroughly documented and provide a baseline for future Evaluations. The analysis and interpretation of results must consider both the qualitative and quantitative responses. The implementation of future Evaluations must take into consideration the cultural sensitivities and working conditions in the different countries. It is paramount that the Evaluators collaborate on every level with the Partner.

## 8.0 CONCLUSIONS

After a thorough discussion on the aforementioned results, it is finally possible to draw interesting and thought provoking conclusions. First and foremost, through the literature review, consultation with professionals, and observing the BSF in both the laboratory and the field, it is proven that intermittently operated slow-sand filtration is an appropriate and effective water filtration application in developing countries. Government agencies such as the Canadian International Development Agency (CIDA) and the United States Agency for International Development (USAID) acknowledge the effectiveness of the BSF, and have actively funded BSF projects throughout the world. CIDA has sponsored BSF projects through Samaritan's Purse in Ethiopia, Nicaragua and Cambodia. As well, USAID has sponsored a BSF project through Samaritan's Purse in Honduras as an emergency response to Hurricane Mitch. The BSF design has received awards from the Pan American Health Organization (PAHO), the Association of Professional Engineers, Geologists, and Geophysicists of Alberta, (APEGGA), and has received financial support from the World Bank.

In accordance with these organizations, the Evaluation of almost 600 BioSand Filters across six countries found the BSF to be effective in removing fecal coliform at an average rate of 93%. And, as some source water contamination rates neared levels of 10,000 cfu/100 mL, it is obvious that the BSF is an extremely appropriate and effective means of dramatically improving the water supply for developing communities. In order to evaluate the **effectiveness** of the BSF there are two criteria, the Performance Evaluation and the wellness of the beneficiaries as seen through the results of the Questionnaire. The use of the BSF positively affects the health of individuals, as indicated by the fact that 98.1% of all beneficiaries told the Evaluation Team that their health had improved after using the BSF.

The World Health Organization Guidelines for Drinking Water Quality states that there can be no *E. coli* present in a 100 mL sample of drinking water. Several of the BSF filters' fecal coliform removal rates do not meet this standard. In *Engineering in Emergencies* it is stated that "although it may be a desirable target to reach eventually, this guideline is not practical in many untreated, or partially treated, supplies in developing countries. An acceptable and attainable microbiological water quality will depend on individual circumstances" (Davis and Lambert, 2000). It is impossible to determine the effectiveness of the BSF based on water quality testing results from developing communities, without considering wellness of individuals.

A system that would purify water to its purest state would include water treatment comprising several components or steps. Although disinfection is an important part of a water quality treatment program, raw water cannot be disinfected without primary treatment. In many countries, it is difficult to apply a sustainable disinfection option. The USAID Field Operating Guide states that "a large quantity of reasonably safe water is preferable to a smaller amount of very pure water." The BioSand Household Water filter is an essential, sustainable component in meeting the WHO drinking water guidelines.

Research funded by Environment Canada and the International Development Research Center (IDRC) has found that properly functioning filters exhibit a fecal coliform removal rate of 97% (Palmateer et al., 1999). This is a result from laboratory testing, whereas the Samaritan's Purse Evaluation has a result of 93% removal in developing countries where the conditions are not controlled. According to the expectations of BSF performance, the BSF can remove over 97% of fecal coliform from water. In the same research it states that 100% of giardia, 99.89% of cryptosporidia, 100% of worms, and 100% of parasites are removed from water by the BSF. This means that *E. coli* may be present in the outflow of a BSF, but it is proven that other disease causing pathogens are removed or are significantly reduced. Consequently, even though the WHO GDWQ may not be met by some BSFs, the pathogens, which this guideline are trying to prevent in water supplies, are being filtered by the BSF.

From this Evaluation it is possible to conclude that over 98.4% of all BSF recipients use their filter on a regular basis, and over 88.5% of all households use their BSF every single day. These high rates of acceptance point to the **sustainability** of the technology and are evidence of the BSF's **appropriateness**. If communities did not believe in the benefits of the BSF, these percentages would be much lower.

Local health officials relate that before receiving the BSF, very few of the beneficiaries conducted any sort of water treatment such as boiling or purification of the source water before drinking it. It is questionable whether expecting people to boil and disinfect their water is sustainable in developing countries, especially when considering environmental concerns. People who previously did not own a BSF would be drinking water straight from a contaminated source and not using any water treatment method at all. Thus, it may be concluded that the presence of the BSF in households improves access to water quality treatment that would otherwise be unavailable. High user compliance indicates beneficiary recognition of the improved household wellness and community health from using the BSF.

It also must be noted that the Evaluation found a direct relationship between the **user's compliance and knowledge** of the BSF and the filter's performance. Through **listening and learning** from the beneficiaries, it is possible to conclude that in houses where the user maintained the filter properly, kept children and animals away from the outflow spout, and made sure that the walls and lid were always clean, the BSF had a more effective removal rate. In houses where this was not the case and animals could drink directly from the spout, or flow-rate maintenance was not performed correctly, the removal rates were significantly lower. Thus, it is clear that this relationship points to the associated **recommendations** for needing increased and more appropriate water-hygiene education for all BSF beneficiaries. This is especially the case amongst women and children as they are the ones who use the BSF most directly.

Yet arguably even more important than rates of removal, or issues of user compliance, are the conclusions that can be drawn from the beneficiaries' perception of their household health before and after receiving a BSF. 5% of beneficiaries surveyed

reported that their health before receiving a BSF was “excellent”, whereas 82.4% of beneficiaries surveyed reported their current health after receiving the BSF was “excellent.” This dramatic increase not only points to the effectiveness of the BSF within these communities, but is also a reflection on the degree to which **local education, follow-up, and monitoring programs** have impacted household health and wellness.

The driving force behind Samaritan’s Purse water projects is to positively influence community health and wellness. Wellness is a combination of observed physical conditions and mental perception of health in individuals. The World Health Organization defines health as “a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity”. There are many vectors that affect health, such as contaminated food, food preparation, environment, hygiene and water. It is not accurate to define health in individuals from developing countries solely by *E. coli* results from a water quality test. The BSF is an effective method for improving water quality, which is an essential component of wellness in individuals.

Over 1.1 billion people worldwide do not have access to an improved water supply or sanitation. Many water treatment options for the disadvantaged of the world further burden these people through a lack of sustainability and effectiveness. However, 98.4% of the BSF filters across Central America, Africa, and Southeast Asia are currently being used and 98.1% of these same beneficiaries claim that their health has been improved from using the BSF. Through this comprehensive and exhaustive Evaluation, as spoken by the beneficiaries themselves, it is proven that the BioSand Filter is helping to make a significant difference in the lives of many of the world’s poor. **The impact of the BSF, as designed by Dr. Manz, documented in scientific research, implemented by Samaritan’s Purse, and accepted by users worldwide is evidence that peoples’ lives are dramatically improved through this sustainable and effective technology.**

“... whoever drinks of the water that I shall give him will never thirst.”

-- *John 4:14*

## 9.0 LITERATURE CITED

- American Public Health Association. 1976. *Standard Methods for the Examination of Water and Wastewater*. APHA: New York.
- Davis, J and R. Lambert. 2000. *Engineering in Emergencies*. IT Publications: United Kingdom.
- Davnor. *Technology*. [Online: Accessed November 29, 2001]  
<http://www.davnor.com/welcome/technology.htm>
- EPA. 2001. *E. coli in Drinking Water*. [Online: Accessed December 5, 2001]  
<http://www.epa.gov/safewater/ecoli.html>
- Huisman, L., and W. Wood. 1974. *Slow Sand Filtration*. WHO: Geneva.
- Hurd, J, Tse, L., Paynter, N., and M. Smith. 2001. *Nepal Water Project*. MIT: Massachusetts.
- Manz, D. and B. Buzunis. 1995. *Nicaragua Community Scale Household Filter Project*. University of Calgary, Dept. of Civil Engineering: Calgary.
- Metcalf and Eddy. 1991. *Wastewater Engineering Treatment, Disposal and Reuse*. Irwin McGraw Hill: Massachusetts.
- Palmateer, G., Manz, D., Jurkovic, A., McInnis, R., Unger, S., Kwan, K. and B. Dutka. 1999. *Toxicant and Parasite Challenge of Manz Intermittent Slow Sand Filter*. *Environmental Toxicology* 14:217-225.
- Samaritan's Purse. 1998. *BioSand Household Water Filter, 3<sup>d</sup> Edition*. Samaritan's Purse: Calgary.
- Shulz, C., and D. Okun. 1992. *Surface water Treatment for Communities in Developing Countries*. Intermediate Technology Publications: Great Britain.
- Tchobanoglous, G. and E. Schroeder. 1987. *Water Quality*. Addison-Wesley: Massachusetts.
- USAID. 1998. *Field Operations Guide for Disaster Assessment and Response*. USAID: Washington.

- WHO. 1993. *WHO Guidelines for Drinking Water Quality 2<sup>nd</sup> ed. Vol 1 – Recommendations*. [Online: Accessed November 27, 2001]  
[http://www.who.int/water\\_sanitation\\_health/GWDO](http://www.who.int/water_sanitation_health/GWDO)
- WHO. 1996. *Escherichia Coli O157:H7 Fact Sheet #125*. [Online: Accessed November 30, 2001]. <http://www.who.int/inf-fs/en/fact125.html>
- WHO. 2001. *Global Water Supply and Sanitation Assessment 2000 Report*. [Online: Accessed: January 12, 2002]  
[http://www.who.int/water\\_sanitation\\_health/Globassessment/GlasspdfTOC.htm](http://www.who.int/water_sanitation_health/Globassessment/GlasspdfTOC.htm)
- WHO. 1996. *Water and Sanitation Fact Sheet #112*. [Online: Accessed November 30, 2001]. <http://www.who.int/inf-fs/en/fact112.html>
- WHO. 1997. *WHO Guidelines for Drinking Water Quality 2<sup>nd</sup> ed. Vol 3 – Surveillance and Control of Community Supplies*. WHO: Geneva.
- WHO. 2001. *Sustainability and optimization of water supply and sanitation services*. [Online: Accessed November 30, 2001].  
[http://www.who.int/water\\_sanitation\\_health/wss/wuwtoptim.html](http://www.who.int/water_sanitation_health/wss/wuwtoptim.html)